Agriculture

for Advanced Secondary Schools

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Student's Book

Form Five

Tanzania Institute of Education

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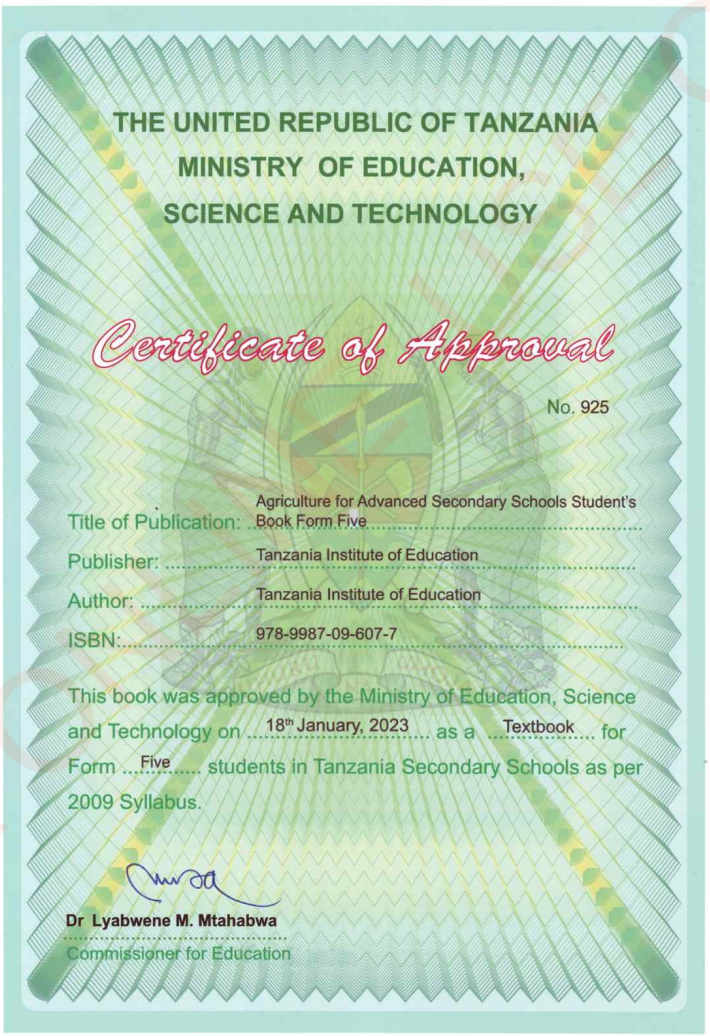

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Abbreviations and acronyms

AC	Average Cost
AD	Annual Depreciation
APP	Average Physical Property
ATP	Adenosine Triphosphate
AEC	Anion Exchange Capacity
AP	Average Product
BC	Before Christ
BDC	Bottom Dead Centre
BCA	Biological Control Agent
CEC	Cation Exchange Capacity
CF	Crude Fibre
COVID-19	Corona Virus Disease – 19
CR	Compression Ratio
CP	Crude Protein
CV	Cylinder Volume
DB	Damage Boundary
DCP	Di-Calcium Phosphate
DE	Digestible Energy
DM	Dry Matter
EE	Ether Extract
EIL	Economic Injury Level
EFC	Effective Field Capacity
EMC	Expected Moisture Content
ETL	Economic Threshold Level
FC	Fixed Cost
GSM	Global Soil Map
gm	Gram
GM	Gross Margin
GMO	Genetically Modified Organism
HCN	Hydrogen Cyanide
hp	Horse power
IDM	Integrated Disease Management
Kg	Kilogramme

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MC	Marginal Cost
ME	Metabolisable Energy
MLF	Ministry of Livestock and Fisheries
MP	Marginal Product
MR	Marginal Revenue
PD	Piston Displacement
pH	(‘pondus Hydrogenii’) negative logarithm of hydrogen ion concentration
rpm	Revolutions per minute
TC	Total Cost
TDC	Top Dead Centre
TDN	Total Digestible Nutrient
TFC	Total Fixed Cost
TIRA	Tanzania Insurance Regulatory Authority
TP	Total Product
TR	Total Revenue
TVC	Total Variable Cost
TZS	Tanzanian Shillings
UAV	Unmanned Aerial Vehicle
ULV	Ultra-Low Volume
UV	Ultra-Violet

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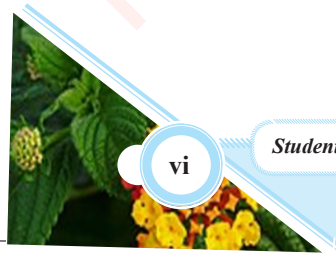

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Preface

This textbook, *Agriculture for Advanced Secondary Schools* is written specifically for Form Five students in the United Republic of Tanzania. It is written in accordance with the *2009 Agriculture Syllabus for Advanced Level Secondary Education Form V – VI* issued by then, Ministry of Education and Vocational Training (MoEVT).

The book consists of eleven chapters, namely farm power, workshop technology, soil science, crop pests, weed science and plant diseases. Others are animal nutrition, pasture agronomy, agricultural production economics, farm planning, and information and communication technology (ICT) in agriculture. In addition to the contents, each chapter contains illustrations, activities and exercises. You are encouraged to do all the activities and exercises as well as other assignments provided by your teacher. Doing so, will enable you to develop the intended competencies.

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Chapter One

Farm power

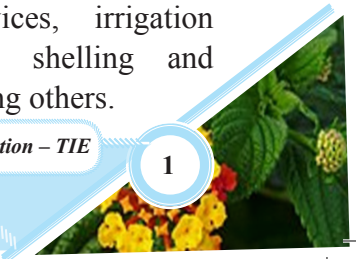
Introduction

In accomplishing various activities such as lifting heavy objects, the weight of the object to be lifted depends on the body weight which is proportional to the power needed for lifting the object. This means that the power needed to perform a certain task is proportional to the resultant work done. In agriculture, power is needed to undertake farm activities such as tillage, transportation, processing, and other field operations. In this chapter, you will learn about the concept of farm power, sources of farm power, and criteria to consider when selecting appropriate farm power. You will also learn about the concept of heat engines and their systems. The competencies developed from this chapter will enable you to choose and use appropriate farm power that will improve agricultural production.

Concept of farm power

Farm power is the amount of energy provided by various sources such as humans, animals, or machines required to perform a certain farm operation. Farm power is used to operate tools such as hand-hoe, implements such as ploughs and machines such as planters and combine harvesters. The decision on the type of farm power to employ depends on its capacity, functions, and economic factors. These factors have led to a shift of farm power from human to animal; to water and wind power; from steam engines to internal combustion engines, and electric motors. Depending on the economic levels and nature of the farm operation, all sources of power are still in use to date.

Farm power is generally categorized into animated and inanimate. Animated farm power is derived from human beings and draught animals such as oxen and donkey. Inanimate farm power is the energy expended from natural physical objects that do not have life. Inanimate farm power can be further categorized as mechanical (e.g., tractors, power tillers, and other fuel engines operated machines), electrical-driven machines for example milling machines, weeders and sprayers, and renewable energy sources for example biogas, solar, and wind operated machines. These power sources can be stationary or mobile during operation. Stationary power sources include diesel/petrol engines, electric-powered motors, and renewable energy. These are used in running stationary operating implements such as water-lifting devices, irrigation equipment, threshers, shelling and grading machines among others.



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Mobile power sources are required to perform different field operations using implements such as ploughs, planters, cultivators and harvesters. Mobile power sources include human beings, draught animals, tractors, power tillers, and self-propelled machines (combine harvesters and bulldozers). Sprayer implements can be attached to tractors. Aerial spraying can also be performed by dusting process using aircraft and low-altitude unmanned aerial vehicles (drones) depending on the level of mechanization and farm size. Different sources of farm power are described here under:

Human power

A human being can directly conduct farm operations using either hand tools such as hand hoe, machete, spade and slasher; or indirectly using animal power or inanimate powered operated tools, implements, and machines. The application of other power sources is very essential as human beings generate low power. For instance, a healthy adult person can generate an average power of 48 to 60 watts which is very low, compared to other sources. Alternative power sources such as draught animals and power-operated machines are preferred.

Animal power

Animals that produce power for farm operations such as cattle (oxen), camel, horse and donkey are called draught animals. They have been used since ancient times and are still in use to date Figure 1.1 (a) and (b). In Tanzania, the leading regions in the use of draught animals are Mwanza, Geita, Singida, Mara, Shinyanga, Simiyu, Manyara, and Tabora. This is due to the presence of a high number of livestock keepers. Wild animals such as buffaloes and elephants have been rarely used in the history of human kind. These animals produce a workforce that is dependent on their body weight. However, the produced work is only one-tenth of the animal's body weight. Thus, to be more efficient animals with large body weights are preferred in agriculture. Other factors for high power production are feed ration, animal breed, and yoke used for hitching.

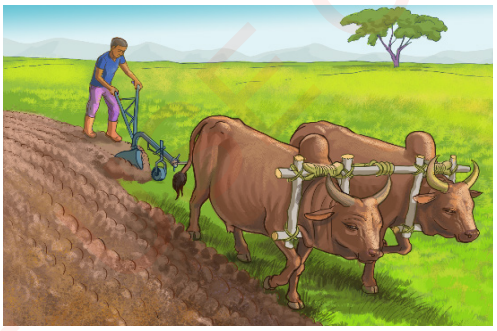

Figure 1.1 (a): Oxen tilling the land

Figure 1.1 (b): Donkey pulling a cart

Management of draught animals

Factors to be considered to obtain maximum power output from animals include:

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(a) Maintenance of their health through the provision of nutritious and adequate feeds as well as provision of vaccines, control parasites, and treatment when they become sick;

(b) Do not overload the animal. Study their ability to perform different tasks;

(c) Protect animals from injuries caused by a yoke, harnessing, and long hooves. Make sure that hooves are of appropriate length, they should also be protected from bad weather conditions like too hot, rain and strong wind conditions;

(d) Animals should work during the cool time of the day

(e) After work, give the animals some time to rest before grazing;

(f) Do not harass the animals during work. Train them so they can learn verbal instructions or visible gestures and thus adhere to the given instructions; and

(g) Animals forming a pair should be of equal size to equally distribute the load. The working yoke should be smooth to avoid neck injury.

Advantages of draught animals

The advantages of using draught animals over others include:

(a) They are a versatile and dependable source of power (muddy and irregular fields);

(b) Their investment costs are low;

(c) They do not require complex skills to operate;

(d) They are used for transport in areas with poor roads;

(e) They are a green source of power, unlike mechanical sources which use petroleum products;

(f) Their fresh manure and urine are used for biogas production; and

(g) Their well-decomposed manure is a source of organic fertiliser.

Challenges of draught animals

The following are the challenges of draught animals:

(a) They demand a large quantity of feed thus they are appropriate for rural areas with plenty of edible plants;

(b) Animals are characterized by low efficiency as compared to inanimated power sources;

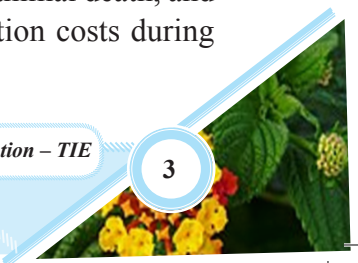
(c) They have to be well fed and cared for, even when are not producing power for farm work;

(d) If animal wastes are not properly managed, they may cause an unpleasant smell;

(e) They may cause injury to an operator when becoming angry;

(f) Draught animals require training which needs skills in animal behaviour;

(g) Animals are susceptible to diseases. This may result in a decrease in work efficiency, animal death, and increased production costs during treatment and



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(h) Grazing animals reduce daily working hours.

Mechanical and electrical power

Unlike animal power, mechanical and electrical powered machines (Figure 1.2 (a – d)) completes tasks within a short time, with high working efficiency and uniformity. Mechanical power includes stationary engines and mobile tractors. Examples of these machines are power tillers, tractors, drones, and self-propelled combines. Selection of the machine size/capacity depends on the type and size of the implement to be attached and the load size. For example, the cultivation performance of a tractor varies with implement design, soil type, speed of operation, and depth of operation.

Electricity facilitates farm operations such as running electrical motors which are used for running water pumps, processing farm products, and lighting. Electricity is also used for refrigeration and cattle feed grinding in the dairy industry among others.

Advantages of mechanical and electrical powers

The following are the advantages of using mechanical and electrical power sources in farm operations:

(a) Electricity is high efficiency generated and operated at low costs;

(b) Both mechanical and electrical machines can work continuously for longer periods; and

(c) Machines driven by electricity can work in all weather conditions.

Challenges of electrical and mechanical powers

The following are some challenges relating to electrical and mechanical power:

(a) Require high investment costs and complex skills to operate;

(b) It is dangerous if not handled properly; and

(c) A constant electrical power supply is required for electrical farm operations (i.e., power outages hinder farm operations).

Figure 1.2 (a): Land cultivation by using power tiller

Figure 1.2 (b): Land cultivation by using a tractor

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Figure 1.2 (c): Spraying using a tractor

Figure 1.2 (d): Spraying using Unmanned Aerial Vehicle (UAV)

Renewable energy sources

Renewable energy is obtained from renewable sources such as sun, wind, and biomass. Biogas energy, wind energy, and solar energy are potential sources of energy for agriculture and domestic purpose. Renewable energy is used for cooking, heating, water distillation, food processing, water pumping, electric generation, and light generation.

Wind energy

The wind is simply moving air. This moving air has kinetic energy which can be converted into mechanical energy or electrical energy using rotating windmills (Figure 1.3 (a) blades or turbines. The mechanical power produced can either be used directly in such operations as pumping water and processing animal feeds. Wind power can also be directly used for winnowing crops such as maize and beans before packing them into storage containers. To produce useful energy, a certain minimum wind speed is required. For instance, to operate a 0.5 horse power (hp) wind mill, a minimum of 32 km/h wind speed is required. The variation in wind speed is the major limiting factor. In Tanzania, the Singida region is one of the potential areas for wind power generation.

Figure 1.3 (a): Windmill

Figure 1.3 (b): Solar pannel

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Solar energy

Solar energy is produced by the sun and may be converted to thermal or electrical energy. Solar produces energy that is used for solar dryers, solar stills, solar lighting, lantern, cooker, and pumping water as shown in Figure 1.3 (b).

Biomass energy (Biofuels)

This is the energy generated from living materials such as wood and wood residues, agricultural residues, energy crops, and waste from industry, farms and households. Common examples of biofuels include ethanol, biodiesel and biogas.

Geothermal energy

Geothermal energy is generated from steam produced by hot water several metres/kilometres below the earth's surface. It is used for heating and producing electricity. The earth's temperature is a result of heat energy naturally formed in the earth's core during the earth's creation and the radioactive decay of the earth's materials.

Generally, one of the advantages of energy generated from renewable sources is that they exert less strain on a limited supply of fossil fuel.

Activity 1.1

1. Visit a nearby farming community and study the types of agricultural activities conducted by farmers then, prepare a report based on:
   (a) Main type and scale of agricultural production activities carried in the area;
   (b) Sources of farm power used by farmers for farming activities; and
   (c) Potential power sources which are the least or not utilised at all (explain reasons behind) in the area.
2. Use different sources including library and internet sources to find and discuss:
   (a) the advantages and challenges of renewable energy sources in agriculture; and
   (b) comparative advantages and challenges of renewable energy sources over non-renewable energy sources applied in agriculture.
3. Summarize your responses in your portfolio and share it in class.

Selection of tractor as a source of farm power

In medium to large-scale farms, tractors form an important source of power for various farm operations. A tractor can be attached with various implements to perform different activities such as tilling, harvesting, processing and transporting farm produce. Tractors as farm machines come in various sizes and with varied capabilities. Some tractors are designed to perform specific operations (for example inter-row

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weeding) while others are designed to perform heavy-duty works such as land clearing. To decide on which size, type and capability of a tractor are needed, one should consider the following factors:

(a) **Land size:** It is more economical to use tractors with higher horsepower in larger plantations than to use them in small-scale farms;

(b) **Cropping pattern:** The arrangement and types of crops to be grown will determine the type of tractor to be used;

(c) **Soil conditions:** In lighter soils, a tractor with low overall weight may work but it will not be able to work in deep soils;

(d) **Climatic conditions:** In very hot zones and desert areas, a tractor with air-cooled engines is preferred over that with a water-cooled engine. An air-cooled engine can also work well at higher altitudes where water freezing is common;

(e) **Repairing facilities:** The tractor model should have a nearby dealer with technical skills and spare parts available for repair and maintenance;

(f) **Running cost:** The tractor should be of relatively low fuel consumption and low-cost spare parts; and

(g) **Initial cost and resale value:** The initial cost of buying the tractor should be relatively low to minimize the interest rate. The resale value of the tractor should also be kept in mind (re-sale value).

In addition, the tractor test report from an authorized testing station should also be critically analyzed as it provides a guide in decision-making on whether to buy or not.

Tractor management

Tractor management has three phases which are: selection of matching equipment/ implements, training on best techniques for operating the equipment, and maintaining its efficiency. If a tractor is wrongly selected may lead to the poor matching of equipment thus increasing maintenance costs, shortening tractor life, and loss of functional output. To ensure the proper selection of a tractor, personnel with technical skills and experience should be involved during the acquisition process. In large-scale farming, it is advisable to employ knowledgeable farm managers in the fields of agricultural engineering and mechanization.

The field capacity of farm machinery

The field capacity of farm machinery also referred to as the performance of the machine or simply machine capacity is the rate at which a machine performs its primary function. It is expressed in hectares or acres covered per hour of operation. For example, in ploughing, the field capacity is the number of acres that can be ploughed per hour. Crop harvesting is expressed as tons of crops harvested per hour.

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Estimation of machine capacity helps in scheduling field operations; estimation of labour and power/fuel requirements; and the estimation of machine operating costs. The machine capacity can be best expressed in terms of field efficiency. This is the relationship between the effective field capacity and the theoretical field capacity. The two concepts are further described hereunder.

The theoretical field capacity of a machine

This is the rate of field coverage that would be obtained if the machine were performing its function by utilizing fully its rated time while the forward speed covers 100% of its rated width. It is expressed in ha/h and is calculated using the following equation:

$$\text{Theoretical machine field capacity (ha/h)} = \frac{\text{width (cm)} \times \text{speed (m/s)}}{\text{time (h)}}$$

The effective field capacity of the machine

It is the actual coverage of the work that the machine has performed in relation to total field time. For instance, in ploughing, it is the actual area completed divided by the total time (hours) spent in the field. The effective field capacity of the machine is estimated by recording the total area (ha) covered and hours spent for several fields over the whole season.

$$\text{Actual machine field capacity (ha/h)} = \frac{\text{Area covered (ha)}}{\text{Time taken (h)}}$$

Or

$$\text{Actual machine field capacity (ha/h)} = \frac{\text{S (km/h)} \times \text{W (m)}}{\text{time (h)}}$$

Where: S = speed (km/h), W = theoretical width of cut (m).

Field efficiency

This is the ratio of an actual machine field capacity and theoretical field capacity. It is expressed in percent as:

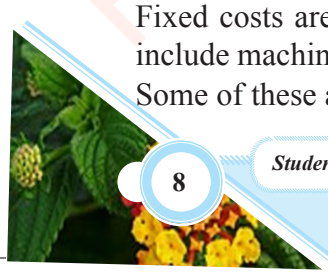
$$\text{Field efficiency} = \frac{\text{Actual machine field capacity}}{\text{Theoretical machine field capacity}}$$

Estimating the costs of farm machinery

The cost of farm machinery is expressed as fixed and operating costs. These two categories are described in the following sub-sections.

Fixed costs

Fixed costs are costs incurred without considering the level of production. These include machines depreciation, interest on the capital, housing, insurance and taxes. Some of these are described hereunder:



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(a) Depreciation

Depreciation refers to the loss of value of a machine over time. There are three methods of calculating depreciation, namely:

(i) Straight line method;

(ii) The sum of the year digit method; and

(iii) The diminishing balance or declining balance method.

Just for the sake of this section, the straight-line method will be considered, and details of the other methods will be discussed in chapter Ten (Agricultural production economics).

Using the straight-line method, depreciation is usually calculated annually, hence called annual depreciation; it is calculated by using the following formula:

$$AD = \frac{C - S}{N}$$

Where by AD = Annual depreciation,

C = Original cost or capital invested,

S = Salvage value,

N = Number of years (Expected life span)

Worked example 1

A farmer bought a tractor for TZS 350 000 with the life span of 15 years. At the end of its life the value of the tractor will be TZS 50 000. Using the straight-line method, calculate:

(i) Annual depreciation of the tractor.

(ii) Depreciation per each working hour.

Solution

(i) The annual depreciation of a tractor:

$$AD = \frac{C - S}{N}$$

Data given; C = TZS 350 000, S = TZS 50 000, N = 15 years.

$$AD = \frac{350\ 00 - 50\ 000}{15}$$

$$= \text{TZS } 20\ 000$$

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(ii) Depreciation per each working hour.

$$D = \frac{C - S}{L \times H}$$

Where D = depreciation per year, C = capital invested, S = the salvage value (10% of capital) L = the age of the machine in years, H = the number of working hours per year

Worked example 2

A planter bought in 1980 for TZS 200 000 was involved in a serious accident in 1983 after working for 500 hrs., the wreckage of the planter was sold at an auction for TZS 20 000 Calculate the depreciation per an hour.

$$D = \frac{C - S}{L \times H} =$$

Data given; C = TZS 200 000, S = TZS 20 000, 3 years (from 1980 to 1983),

H = 500 hrs.

$$D = \frac{200\,000 - 20\,000}{3 \times 500} = \frac{180\,000}{1500} = \text{TZS 120 per hour.}$$

(b) Interest

It is calculated on the average investment of the machine taking into consideration its value in the first and last year. It is calculated using the following formula:

$$I = \frac{(C + S) \times i}{2 \times H}$$

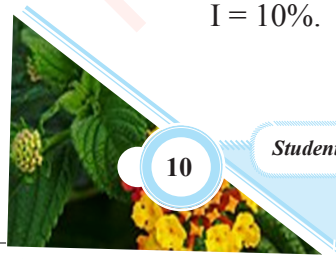
Where: i = the interest per hour, I = is the % rate of interest per year

Worked example 3

A harrow was bought at TZS 120 000 with an expectation that it will last for 17 years before writing it off with a total of 1 000 working hours. At this time the value will be TZS 10 000, the buying interest cost is 10%. Calculate its interest cost per an hour.

$$I = \frac{(C + S) \times i}{2 \times H}$$

Data given: C = TZS 120 000, S = TZS 10 000, L = 17 years, H = 1 000 hours, I = 10%.



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$$I = \frac{120\,000 + 10\,000 \times 10\%}{2 \times 1\,000} = 6.5$$

I= TZS 6.50 per hour.

(c) Housing: Housing cost is based on actual existing rates in the locality.

(d) Insurance: Insurance charge is calculated and paid to the insurance company depending on the rate given by a government authority currently the Tanzania Insurance Regulatory Authority (TIRA)

(e) Taxes: Taxes is calculated based on the income generated each year.

Operating costs

These are costs which vary with the level of output. They include:

(a) Fuel cost: Cost calculation is dependent on actual fuel consumption by the machine;

(b) Lubricants and other consumables: These charges are calculated on basis of actual consumption;

(c) Repairs and maintenance: This cost varies with the management and age of the machine; and

(d) Wages: Calculated based on the actual wages of an operator.

Worked Example 4

A farmer bought a tractor with a capacity of 60 hp at TZS 90 000 000. The manufacturer's tractor life is 10 years under optimum operation. A farmer uses a tractor for 1 000 hours every year. The farmer also owns an 11-tined cultivator with tines spacing 25 cm apart. The buying price of the cultivator was TZS 2 000 000. The tractor uses 3 litres of diesel per hour when ploughing using the tined cultivator. The cultivator's lifespan according to the manufacturer, is 10 years. On average the cultivator is used for 450 hours per year. The operation speed of a cultivator is 5 km/h. Given the salvage value to be 10% of the buying cost, the interest rate = 14%, repair, and maintenance to be 10% of the initial cost of the machine per year. Taxes, insurance and housing take 3% per year of the initial cost of the machine. The diesel costs TZS 2 200 / litres, Lubrication cost is assumed to be 30% of fuel costs. The daily operator charges (8 working hours) is TZS 15 000. Calculate the cost of ploughing 2 ha of land with the cultivator.

Solution

Cost of operation for a tractor

(a) Fixed costs

(i) Depreciation

$$D = \frac{(C - S)}{L \times H}$$

Where: D = depreciation, C = TZS 90 000 000, S = 10% of TZS 90 000 000, L = 10 years, H = 1 000 hours

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$$D = \frac{(90\,000\,000 - 9\,000\,000)}{10 \times 1\,000} = 8\,100$$

Depreciation cost = TZS 8 100 /hr.

(ii) Interest (I)

$$I = \frac{(C + S) \times i}{2 \times H} = \frac{(90\,000\,000 + 9\,000\,000) \times \left(\frac{14}{100}\right)}{2 \times 1\,000} = 6\,930$$

Interest costs (I) = TZS 6 930

(iii) Taxes, Insurance and housing (TIH) = 3% of $\frac{(C + S)}{2 \times H}$

$$TIH = (3/100) \times \frac{(90\,000\,000 + 9\,000\,000)}{2 \times 1\,000} = 1\,485$$ (TIH) costs = TZS 1485

Total fixed operation costs (TZS/h) = 8.100 + 6 930 + 1 485 = TZS 16 515/hr.

(b) Variable costs

(i) Repair and maintenance (R & M)

$$R \& M = 10\% \text{ of } \frac{C}{H} (10/100) \times \frac{90\,000\,000}{1\,000} = 9\,000$$

R & M cost = TZS 9 000/h

(ii) Fuel cost (FC)

FC = Consumption rate × Fuel price/litre

= 3 × 2 200

Fuel cost = TZS 6 600

(iii) Lubricating oil cost (LC)

LC = 30% of fuel cost = (30/100) x 6 600

Lubricating oil cost = TZS 1 980 /h

(iv) Operator cost/h = 15 000/8 = TZH 1 875/h

Total variable cost = 9 000 + 6 600 + 1 980 + 1 875

= TZH 19 455 / h

Therefore, Total cost of operation for tractor = Total fixed cost + Total variable cost

=TZS. 16 515/h + TZS. 19 455

= TZS 35 970 /h

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Cost of operating a cultivator:

(a) Fixed costs:

(i) Depreciation

$$D = \frac{C - S}{L \times H}$$

Where: D = depreciation, C = TZS 2 000 000, S = 10% = 10% of TZS 2 000 000, L = 10 years, H = 450 hours

$$\text{Depreciation cost (D)} = \frac{(2\,000\,000 - 200\,000)}{10 \times 450} = \text{TZS } 400 \text{ /hr.}$$

(ii) Interest (I)

$$I = \frac{(C + S) \times i}{2 \times H} = I = \frac{(2\,000\,000 + 20\,000) \times \left(\frac{14}{100}\right)}{10 \times 450}$$

Interest cost = TZS 342.2

(iii) Taxes, Insurance and Housing T I H = 3% of $\frac{(C + S)}{2 \times H}$

$$= (3/100) \times \frac{(2\,000\,000 + 200\,000)}{2 \times 450}$$

TIH costs = TZS 73.3

Therefore, the total fixed operation costs (TZS/h) = 400 + 342.2 + 73.3 = 815.5 TZS /h

(b) Variable costs

(i) Repair and maintenance (R & M)

$$R\&M = 10\% \text{ of } \frac{C}{H} = (10/100) \times \frac{2\,000\,000}{450} = 444.4$$

R & M costs = TZS 444.4 /h

(ii) Lubricating oil cost = No cost

(iii) Operator cost/h = No cost

Therefore, the total variable cost = TZS 444.4 /h.

Total cost of operation for implement = Fixed cost + variable cost

= 815.5 + 444.4 = TZS 1 259.9 /h

Therefore, total cost of operating a tractor with its implement = 35 970 + 16 515

= TZS 52 485 /h

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The field capacity of an implement/machine

Worked example 5

Given a cultivator with 11 tines spaced at 25 cm, worked for 10 hours with the speed of 5 km per hour. Calculate the actual machine field capacity.

$$\text{Actual machine field capacity (ha/h)} = \frac{\text{S (km/h)} \times \text{W(m)}}{10}$$

Data given: S= Speed 5 km/ hour, Time =10 hours, W = 11 x 25 cm = 2.75 m = 0.0275 km

$$\text{Machine field capacity} = \frac{5 \text{ km} \times 0.027}{10} = 1.375 \text{ km per hectare.}$$

$$\text{Time required to plough 1 hectare} = \frac{1 \text{ ha}}{\text{fied capacity}} = \frac{1 \text{ ha}}{1.375 \text{ hrs}}$$

$$= 0.727 \text{ hrs. per ha.}$$

Therefore, the time required to plough 1 hectare (ha)= 1/ field capacity = 1/ 1.375

= 0.727 h/ha

The ploughing cost (tractor and implement costs) for 1 ha

= time (h)/ha x cost of ploughing

= 0.727 h/ha x TZS 52 485/h = TZS 38 156.6 /h

For a 2ha field = TZS 38 156.6 /h x 2 = TZS 76 313

Activity 1.2

Conduct a field visit to a school farm and nearby farms to:

(a) Observe and identify various sources of farm power used in the farm;

(b) Observe farm operations related to different sources of farm power; available in each farm;

(c) Write a field visit report and present in class for discussion. The report should discuss the various sources of farm power observed during the visit. The recommendation of the most appropriate source based on suitability, efficiency, investment, and running costs should be made.

Note: Video clips may be used to supplement the field visit information.

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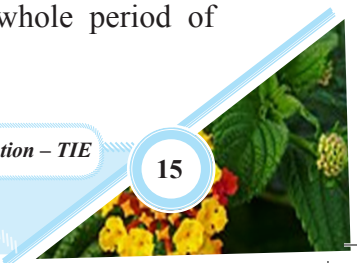
Exercise 1.1

1. Using your own words explain the concept of farm power.
2. Describe various sources of farm power. In your description explain how they are used in the farm operations.
3. Identify any four categories of renewable energy and explain five advantage and disadvantage of each.
4. Explain the factors to be considered by a farmer to obtain maximum output from draught animals.
5. Which source of farm power provides high crop intensity and uniformity? Explain.
6. What should be done to assure that a tractor is operating at its field capacity?
7. Describe how to maintain a machine during the idle time at the end of the season.
8. Explain the use of electricity as the source of farm power in rural areas.
9. Using your own words explain the concept of farm power.

Heat engines

A heat engine is a device working through a cyclic process, absorbing heat energy from a heated reservoir, converting some of its energy to mechanical energy, and the remaining energy is dissipated through low-temperature reservoirs. The process of mechanical energy production is continuous using a continuous supply of heat input resulting in mechanical work. Heat engine operations follow Carnot's theorem (adopted from the thermodynamic principle) in four stages namely: isothermal expansion, adiabatic expansion, isothermal compression, and adiabatic compression (Figure 1.4). From figure 1.4 (a), lines A to B represents isothermal expansion. At this stage the gas absorbs the heat energy (q_{in}) from the high-temperature reservoir, causing a rise in gas entropy (Figure 1.4 (a) and (b). This causes the expansion of gas within the cylinder and a decrease in pressure resulting in upwards piston motion. At the end of the isothermal, the adiabatic expansion process represented by lines B to C (Figure 1.4(a)) begins where gas expansion proceeds to increase in volume (Figure 1.4(b)). The temperature also decreases due to the conversion of some heat to work used in pushing the piston upwards. Isothermal compression is represented by line CD where the internal energy of the gas raises increasing temperature from T_l to T_h. Line D to A (Figure 1.4 (a)) represents to adiabatic reversible compression process where gas pushes the piston downward. In each stage, the movement of a piston in the cylinder is indicated in Figure 1.4 (b). The process continues during the whole period of engine operation.



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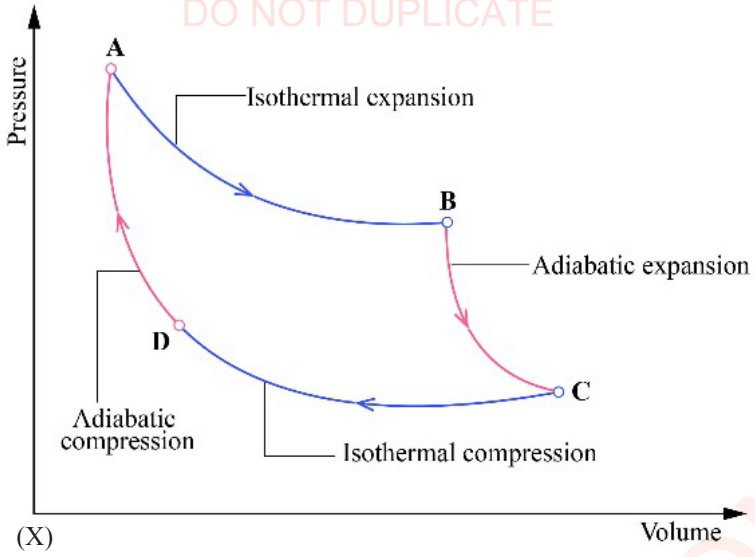

Figure 1.4 (a): Illustrate Carnot's theorem

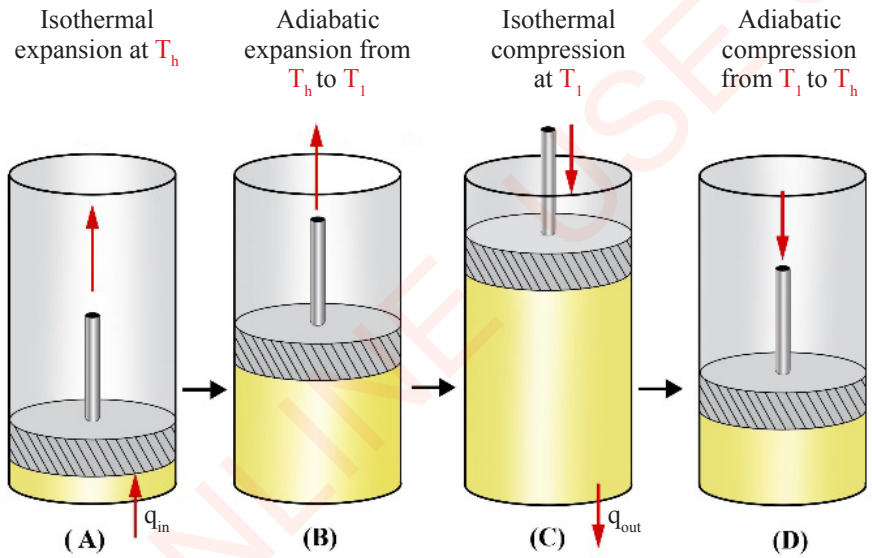

Figure 1.4 (b): shows what happens inside the engine cylinders during the four stages

Classes of heat engines

Heat engines can be categorised into two major categories namely external combustion engines and internal combustion heat engines as described hereunder:

External combustion engines

An external combustion engine (Figure 1.5) is an engine where the fuel is burnt outside the engine cylinder where the boiler produces hot gas or steam from boiling water. The steam power is

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subjected to the engine cylinder to develop the mechanical work. External combustion engines include steam engines (used to run locomotives and marine vessels), steam turbines (power generation and large marine), and closed-cycle gas turbines (used in power generation and marine). Some of the advantages and challenges of the external combustion engine are described in the following subsections:

Advantages of external combustion engine

(a) It is flexible to various sources of thermal energy sources such as firewood, coal and charcoal;
(b) The combustion of fuel (firewood, coal, charcoal) is completed and hence less air pollution;
(c) Heat energy sources are used more efficiently;
(d) Less noise is generated during operation; and
(e) It is more economical for huge power generation.

Challenges of external combustion engine

(a) It is not suitable for low load requirements;
(b) It is characterized by leakage of working fluid;
(c) The lubricant consumption is high;
(d) The engine is relatively big;
(e) The working temperature is high requiring special building materials and great care in the operation; and
(f) It is characterized by lower thermal efficiency (15 – 20%)

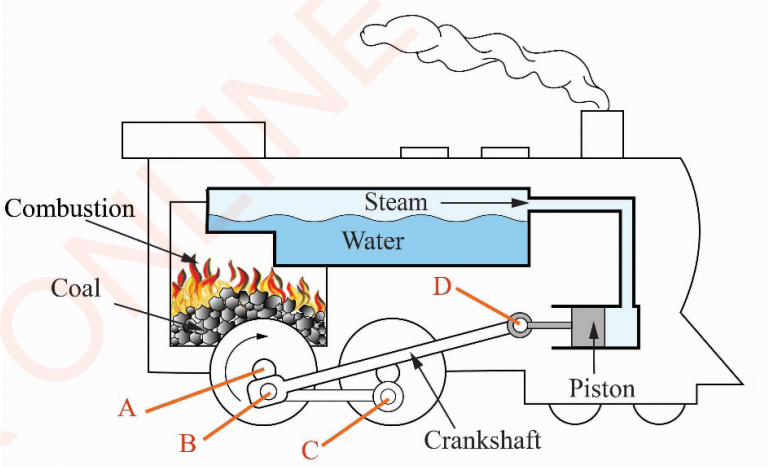

Figure 1.5: The external combustion engine

Internal combustion engines

In the internal combustion engine (Figure1.6), the fuel is burnt inside the engine (engine cylinder). This is the form of the engine which is widely used. Internal combustion engines have

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been widely adopted due to their many advantages over external combustion engines.

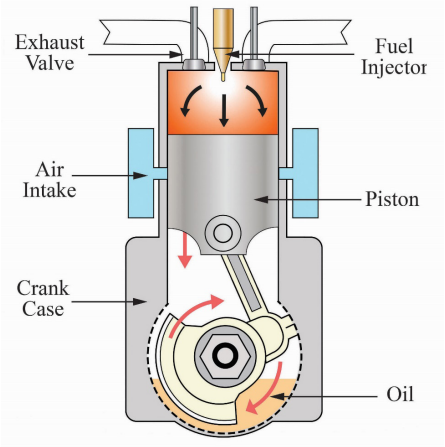

Figure 1.6 Internal combustion engine

Internal combustion engines are classified according to the number of strokes, thermodynamic working cycle, type of fuel used, number of cylinders, cylinder arrangement, engine speed, and cooling system used.

(a) Number of strokes

With this classification, there are two types of engines namely four-stroke and two-stroke cycle engines. In a four-stroke engine, a complete combustion cycle is accomplished in four strokes of the piston or two revolutions of the crankshaft. Four events take place inside the engine cylinder. These are the suction of air (air-fuel mixture into the cylinder), compression of the gases, combustion of compressed air/fuel-air mixture for power production, and exhaust of burnt gases. Examples of farm machines using four-stroke engines include tractors and cars. The two-stroke cycle engine completes all four events (suction, compression, power or expansion, and exhaust) in two strokes of a piston or one revolution of a crankshaft. Examples of machines with the two-stroke engine are chain saws and mowers. In each stroke of the piston, two events take place.

Activity 1.3

1. In a group, make a field visit to a nearby garage or mechanical workshop then inquire and observe the following types of engines:
   (a) Four-stroke engine; and
   (b) Two-stroke engine;
2. Through internet and YouTube searches, observe videos on how four and two-stroke engines work.
3. In a tabular form, summarize in your portfolio the differences between four-stroke and two-stroke engine.
4. Present your summary in class for discussion.

(b) Type of cooling system

Internal combustion may be classified based on the cooling system used. There are generally two types of cooling systems these are liquid-cooled and air-cooled engines. In air-cooled engines, heat is carried away by air flowing around the fins on the engine block. Air-cooled engines are normally small and suited for small and mobile machinery such as lawnmowers and chainsaws.

On the other hand, liquid-cooled engines, use coolant which may be water, glycol and dielectric fluids circulating through air jackets in the engine block picking up heat. The heat exchange takes place in the radiator through the radiation process. Liquid-cooled engines are usually big and fitted for bigger farm machine such as tractors and self-propelled machines

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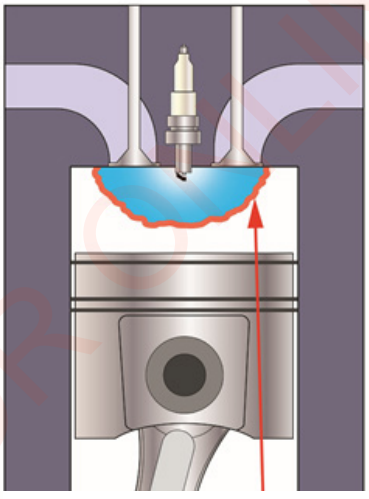
such as combine harvesters.

(c) Type of fuel used

For this classification of the engine, there are three major categories. These are petrol, diesel, and gas (propane, butane or methane gases) engines. For petrol engines, petrol is used as a fuel. A mixture of petrol and air enters the cylinder in a proper ratio during the suction stroke. The fuel mixture in vapour form is ignited through the spark ignition process with the help of an electric spark produced by a spark plug (Figure 1.7 (a)). The energy in a diesel engine is produced by the combustion of diesel. Under this, the air is compressed in the cylinder and atomized diesel is sprayed for ignition (Figure 1.7 (b)).

The method of ignition is called compression ignition. This is common in all heavy vehicles. Gas engines use gas as a source of energy and their mode of operation is similar to petrol engines.

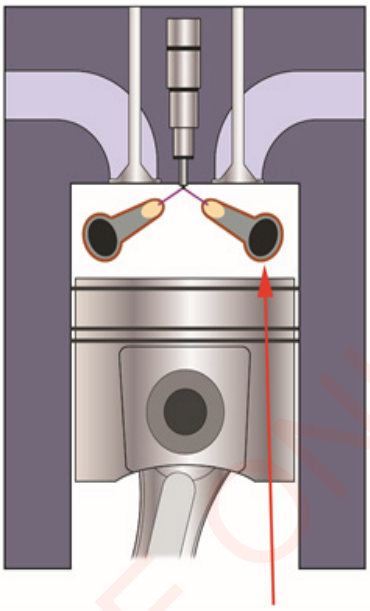
Petrol engine
(Spark ignition)



Hot-flame region

Figure 1.7 (a): Petrol engine

Diesel engine
(Compression ignition)



Hot-flame region

Figure 1.7 (b): Diesel engine

(d) Number of cylinders

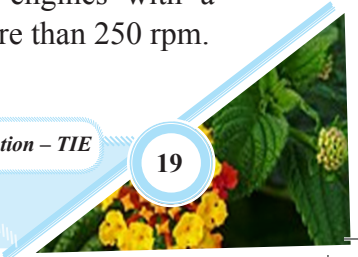
Under this classification, there are single-cylinder engines for example motorcycles and multi-cylinder engines for example tractors and cars.

(e) Cylinder arrangement

Under this category, we have a horizontal cylinder (most the single-cylinder engines) and vertical cylinder engines (most the multiple cylinder engines).

(f) Engine speed

Here there are low-speed engines (crankshaft speed of the engine is less than 100 rpm), medium-speed engines (crankshaft speed between 100 and 250 rpm), and high-speed engines with a crankshaft speed of more than 250 rpm.



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Main parts of the internal engine

The main parts of the internal combustion engine include the cylinder, engine block, cylinder head, piston, connecting rod, crankshaft, flywheel, crank-case, camshaft, timing gear, inlet and exhaust manifolds, inlet and exhaust valves.

Engine block

An engine block is the solid casting comprising cylinders and water jackets for the water-cooled engines (Fig 1.8 (a)). Air-cooled engines comprise cooling fans.

Engine cylinders

These are parts of the engine where the combustion of the air-gas mixture is formed (Figure 1.8 (a)). It includes space for the piston to draw the air or air-fuel mixture ready for combustion. In cylinders, the piston compresses the gas or fuel-air mixture, and the gas is allowed to expand and then transmits power resulting in useful work. To withstand high temperatures formed, cylinders are made of high-grade cast iron.

Figure 1.8 (a): A six cylinders' engine block

Figure 1.8 (b): Engine cylinder head

Cylinder head

Is part of the engine which can be detached (Figure 1.8 (b)). It covers cylinders and includes the combustion chamber, spark plug/atomizer, and valves.

Piston

Is a cylindrical part closed at one end and open at the other end, it maintains a close sliding fit in the engine cylinder (Figure 1.9 (a)). The piston is connected to the connecting rod by a piston pin. Within the cylinder, the expanding gases produce a force that pushes the piston down. The piston will be moved up by the inertial force of the flywheel during compression and exhaust strokes, making the up-and-down movement of the piston to be continuous.

Figure 1.9 (a): A piston and connecting rod

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Figure 1.9 (b): A crank shaft

Figure 1.9 (c): Piston and a piston rod connected to a crankshaft

Figure 1.9 (d): Flywheel

Connecting rod

Connecting rod is attached to the piston with its larger end connected to the crankshaft (Figure 1.9 (a)). The connecting rod is made of cast iron due to its high compressive strength, low coefficient of expansion, and resistance to high temperatures. It is used to transmit power in form of upward and downward movement to the crankshaft. The movement of both the piston and connecting rod is called reciprocating motion.

Crankshaft

This is the main shaft of an engine which converts the reciprocating motion of the piston into the rotary motion (Figure 1.9 (b) and (c)). The crankshaft is made of drop-forged steel or cast steel. It is provided with counterweights throughout its length to ensure a counterbalance of the unit.

Flywheel

The flywheel is attached at one end of the crankshaft. It is responsible for storing energy during the power stroke (Figure 1.9 (d)). It provides a uniform rotary motion utilizing the stored energy during idle strokes. The engine timing marks are usually stamped on the flywheel helping in adjusting the engine timing.

Crankcase

This is the part of the engine which supports and encloses the crankshaft and camshaft (Figure 1.10 (a)). It provides a reservoir for the lubricating oil of the engine. Its upper portion is integrated with the cylinder block while the lower part of the crankcase contains the oil pan made of cast iron or cast aluminium.

Figure 1.10 (a): Crank case

Figure 1.10 (b): Camshaft

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Camshaft

This is a shaft that operates the inlet and exhaust valves at the proper time (Figure 1.10 (b)). It is driven by a crankshaft using gears, chains, or sprockets. In a four-stroke engine, the speed of the camshaft is half the speed of the crankshaft. Camshaft also operates the ignition timing mechanism, oil pump, and fuel pump. It is mounted in the crankcase, parallel to the crankshaft.

Timing gear

A timing gear is provided to control the timing of the ignition, opening and closing of valves, and fuel injection (Figure 1.11 (a)). Timing gear contains two gears mounted on one end of the camshaft and the other on the end of the crankshaft. Camshaft gear is bigger than that of the crankshaft and has twice as many teeth as that of the crankshaft gear. For this reason, this gear is commonly called half-time gear.

Figure 1.11 (a): Timing gear

Figure 1.11 (b): Inlet manifold

Figure 1.11 (c): Exhaust manifold

Inlet manifold

This is the part of the engine through which air or air-fuel mixture enters the engine cylinder (Figure 1.11 (b)). It is fitted by the side of the cylinder head.

Exhaust manifold

This is the part of the engine through which exhaust gases are expelled outside the engine cylinder (Figure 1.11 (c)). It can withstand high temperatures of burnt gases and is fitted by the side of the cylinder head.

Inlet and exhaust valves

Inlet valves allow petrol and air mixture in petrol engine or air alone in diesel to enter in the combustion chamber. An inlet valve opens only during suction/ induction stroke and remains closed in all other strokes. Exhaust valves releases burnt gases from the cylinders. They open only during exhaust stroke and remains closed in all other stokes.

Operating principles of internal combustion engines

An engine cycle is said to be completed when power is produced and the cylinder is ready for next event that will lead to power production. A stroke is the piston

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movement in either direction between a Top Dead Centre (TDC) and a Bottom Dead Centre (BDC). It should be noted that, in a four-stroke cycle engine, a piston makes four movements/cycles (suction, compression, power and exhaust) to complete one cycle. Each cycle in a four-stroke engine, is completed by two crankshaft revolutions. In a two-stroke cycle engine, a piston makes two piston movements to complete one cycle. Power cycle is completed in one revolution of the crankshaft. The first stroke combines suction and compression, whereas, a second stroke combines power and exhaust. Operational event taking place in a four and two stroke engines is described hereunder. Compression ratio, is the total swept volume of the cylinder with the piston at Bottom Dead Center (BDC), divided by the total compressed volume with the piston at Top Dead Center (TDC).

Events taking place in a four-stroke cycle engine

In a four-stroke cycle engine, four strokes involve four events which are suction, compression, power and exhaust, utilizing two revolutions of a crankshaft. Each event is equivalent to one full stroke. These events are further describe:

(a) **Suction/induction/intake stroke:** In the suction stroke, the piston moves from TDC to BDC creating a suction force. The exhaust valve remains closed, the inlet valve opens allowing clean air (for diesel engines) or air-fuel mixture (for petrol engines) to be sucked in as the piston moves to BDC.

(b) **Compression stroke:** In compression stroke, the inlet and exhaust are closed and the piston moves to TDC. As the piston moves, it compresses air in the cylinder and raises air temperature to about 650-800^{o}C. This temperature instantly ignites any fuel that is injected into the cylinder.

(c) **Power stroke:** This is a power generation stroke of an engine. Towards the end of the compression stroke, an ignition/ combustion occurs leading to power generation. Diesel fuel is injected into the cylinder (combustion chamber) at a pressure of about 140-160kg/ cm^3 which is higher than that in the cylinder at the end of the compression. The injected fuel is ignited by compressed air. The expansion of gases as a result of combustion forces the piston to move rapidly to BDC, producing power hence, the power stroke.

(d) **The exhaust stroke:** At the end of the power stroke, the exhaust valve opens. As the piston moves from BDC to TDC it pushes burnt/exhaust gases out through the exhaust valve remains and exhaust manifold.

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Events taking place in a two-stroke cycle engine

In a two-stroke engine, one stroke involves two events either suction and compression if the piston moves from BDC to TDC or power and exhaust if the piston moves from TDC to BDC. Each event happens halfway for each stroke as described herein:

(a) **Stroke one - suction and compression:** The piston moves from BDC to TDC. As it moves, it creates a vacuum which sucks in the air (for the diesel engine) or air-fuel mixture (for the petrol engine) through the inlet port. Suction is completed almost half the stroke. As the piston continues to finish, the other half of the stroke compresses the air or air-fuel mixture.

(b) **Stroke two - power and exhaust:** At the TDC the compressed air or air-fuel mixture is ignited by injected fuel or sparks from sparking plugs for diesel and petrol engines respectively. Then the power stroke begins. The resulting combustion produces high-pressure gases which exert force on the piston forcing it to move to BDC. The power production phase ends with half ways as the piston moves. The remaining half of the piston movement is the exhaust phase of stroke two. Exhaust gases escape via the exhaust port. Stroke two is completed when the piston reaches BDC, hence completing an engine cycle.

Advantages of the internal combustion engine

(a) It is compact and lighter as compared to external heat engines;

(b) It has low heat loss because the combustion is done inside the cylinder;

(c) It has lower fuel consumption as compared to external combustion engines; and

(d) It has higher thermal efficiency (about 40%).

Challenges of the internal combustion engine

(a) It uses processed fuel (liquid petroleum) which sometimes has higher costs;

(b) It has higher emissions when compared to the external combustion engine;

(c) It is not used for large-scale power generation; and

(d) It generates noise due to the detonation of fuel.

Activity 1.4

1. Search, through YouTube application download and observe videos or animations describing working principles of two-stroke cycle and four-stroke cycle engines:

2. Visit a school or nearby farm/ mechanical workshop, then:
   (a) Identify machines utilizing two-stroke and four stroke engines

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(b) Identify main parts of two-stroke and four-stroke engines

(c) Observe how a two-stroke and four-stroke engines operate.

3. Write a report and present in class for discussion. A report should include:

(a) Working stroke of a two-stroke engine as compared to a four-stroke engine

(b) Examples of farm machines that utilizes two-stroke and four-stroke cycle engines.

(c) Advantages of two stroke over four-stroke cycle engines.

Exercise 1.2

Answer the following questions

1. What do you understand about heat engines?
2. With the aid of a labelled diagram discuss Carnot's theorem as applied in a heat engine.
3. Outline the main classes of heat engines. Describe their advantages and disadvantages. Recommend the best class to adopt.
4. The internal engine may be classified in many ways. Briefly describe them.
5. Outline the main parts of a four-stroke engine.
6. What is the function of the camshaft?
7. Which part of the engine supports the crankshaft and provides a reservoir for the lubricating oil of the engine?
8. Describe two ways in which the combustion takes place in the internal combustion engine.
9. Distinguish between a four-stroke and a two-stroke engine.
10. Cranking is very important in running the engine. Briefly describe how cranking initiates the motion.

Worked example 6

An engine has a size of 100 mm × 124 mm, meaning that it has a bore of 100 mm and a 124 mm stroke. Compute:

(i) The piston displacement;

(ii) The total cylinder volume; and

(iii) The compression ratio.

Solution

(i) Piston displacement (PD)

$$PD = \frac{\pi}{4} D^2 \times L$$

Where D = Diameter of the cylinder or bore, L= Stroke (maximum length of travel from one extreme position to the other in one direction), and PD = the volume covered by a piston when moves from the top dead centre (TDC) to bottom dead centre (BDC).

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$$PD = \frac{\pi}{4} (100\ mm)^2 \times 124\ mm$$

$$= \frac{3.14 \times 100\ mm \times 100\ mm \times 124\ mm}{4} = 973\ 400\ mm^3$$

(ii) Total cylinder volume (TCV);

$$TCV = PD + CV, \text{ where } CV = \frac{PD}{6}$$

$$CV = \frac{973\ 000}{6} = 162\ 233.3\ mm^2$$

So, the space or volume between the top of the piston and the engine cylinder head when the piston is at the TDC is 162 233.3mm^3

$$TCV = 973\ 400\ mm^3 + 162\ 233.3\ mm^3 = 1\ 135\ 633.3\ mm^3$$

(iii) Compression ratio

$$CR = \frac{TCV}{CV} = \frac{1\ 135\ 633.3\ mm^3}{162\ 233.3\ mm^3}$$

$$= 7.0$$

Activity 1.5

In a group, visit your school workshop or any nearby garage then, perform the following tasks:

(a) Using a ruler, measure and record the diameter of the tractor engine cylinder;

(b) Use the length of the piston from bottom to the top part of the cylinder to calculate the compression ratio; then

(c) Share your computation in class.

Exercise 1.3

1. In a tabular form, compare internal and external combustion engine.

2. Calculate the compression ratio of an engine with a cylinder diameter of 100 mm and a stroke of 100 mm.

Engine systems

The main engine systems are fuel supply, cooling, electricity, ignition, and lubrication. They all function to ensure the efficient working of a machine as described in the following sub-sections.

Fuel and fuel supply system

The diesel engine fuel system is composed of a fuel tank, primary fuel filter, fuel pump, secondary fuel filter, fuel injection pump, high-pressure pipes, fuel injection nozzles, and overflow pipe (Figure 1.12).

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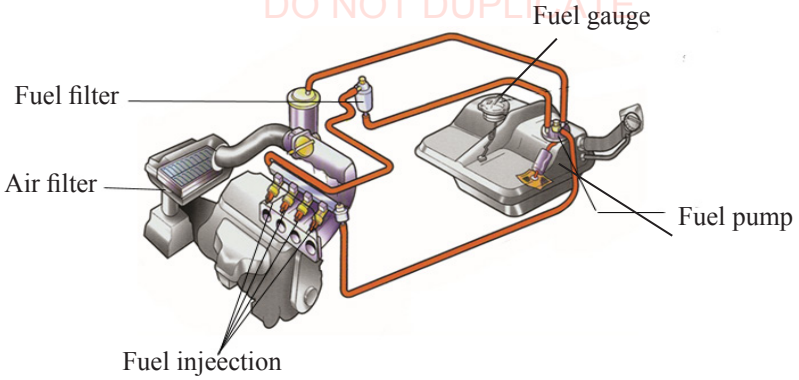

Figure 1.12: Engine fuel system

The primary filter is used to remove coarse impurities from the fuel. Fuel is then drawn by a fuel transfer pump (fuel lift pump) activated by a cam on the engine camshaft. The drawn fuel is forced under low pressure (2.5 kg/cm^2) through the secondary fuel filter to the injection pump which is driven by a camshaft. The injection pump carries a metered quantity of fuel at a predetermined time to the injection nozzles through the high-pressure pipes. During this process, some fuel leaks out from the injection nozzles and returns to the fuel tank through the overflow pipe.

In a petrol fuel system, petrol from the tank passes to a carburettor through a pipe which is fitted with a filter or an on-off tap, then the fuel is mixed with air in a correct ratio by a carburettor then, is atomised into fine droplets into a combustion chamber.

Table 1.1: Differences between diesel fuel system (engine) and petrol fuel system (engine).

Petrol engines	Diesel engines
(i) It has a carburettor for mixing air and petrol at the correct ratio.	(i) It has an injector pump and nozzles for metering and atomizing fuel incorrect amounts.
(ii) Fuel and air are mixed in the carburettor before it gets into the engine.	(ii) Fuel and air are mixed within the cylinder.
(iii) Fuel is ignited by an electric spark.	(iii) Fuel is ignited by the compression of air in the combustion chamber.
(iv) It produces little smoke because petrol is completely burnt.	(iv) It produces a lot of smoke since the diesel is not completely burnt.
(v) The petrol engine is light in weight and suited for light duties.	(v) It is relatively heavy and suited to heavy duties.

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(vi)	Specific fuel consumption is high.	(vi) Specific fuel consumption is low.
(vii)	It uses petrol as a fuel.	(vii) It uses diesel as a fuel.
(viii)	It has a lower air compression ratio of between 4.5:1 to 8:1 thus less efficient	(viii) It has a higher air compression ratio of between 14: 1 to 20: 1 thus more efficient.
(ix)	No extra addition of air/fuel thus the ratio is constant at 15:1.	(ix) Air is taken in during induction stroke, thus the ratio of air/ fuel is not constant.
(x)	It lacks sediment bowel.	(x) It has a sediment bowel.

The governor

The governor is a mechanical device that automatically regulates and maintains engine speed within a specified limit in accordance with the load. This device is normally used in stationary machines such as milling machines and water pumps. In mobile machinery, the engine speed is controlled by the accelerator pedal which controls the amount of fuel in the engine. The governor works by controlling the fuel supply when the engine is subjected to various loads. Generally, there are two main reasons for employing a governor. Firstly, it maintains a constant engine speed under different load conditions. Secondly, it protects the engine and the attached equipment against the impact of a rapid increase in the engine speed which occurs when the load is reduced or removed.

Cooling System

Burning fuels in an internal combustion engine produce a high amount of heat up to (1600ºC) which not all of it is converted into useful work. This extra heat if not checked, can damage many parts of the engine. The cooling system is responsible for maintaining the optimum temperature of the engine by dissipating excessive heat. There are two main types of cooling systems in internal combustion engines, namely air cooling and liquid cooling system (Figure 1.13).

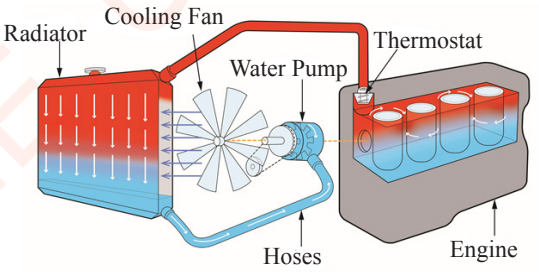

Figure 1.13: The engine cooling system (water-cooled engine system)

Liquid cooling system

In a liquid cooling system, cooling is accomplished by constantly passing coolant through water jackets in the engine block. The liquid coolant is pushed through the cylinder block by means of a water pump. As it passes through the water jackets, heat exchange occurs, where a coolant gains heat while the engine loses heat. Then, hot coolant

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enters the radiator through the upper horse, where it is cooled by cool air flowing through it by means of a cooling fan. The cooled liquid coolant then returns to the engine for further heat exchange and the process is cyclic as long as the engine is running at it. Important parts of a liquid cooling system are a radiator, a cooling fan, a water pump, a pressure cap, hoses and a thermostat. A pressure cap works to maintain pressure in the cooling system. Hoses provide means for coolants to enter and leave the engine block and radiator. A thermostat works to control the optimum engine working temperature. When the engine is cool, the thermostat closes the water flow out of the engine until the engine attains a working temperature. After an engine has attained an optimal working temperature (92^{o}C) within the cylinder block, the thermostat opens and closes water to allow circulation to maintain the operating temperature.

Maintaining a liquid cooling system

A liquid cooling system utilizes liquid coolant to effect cooling. Therefore, it requires an efficient coolant. Coolant is considered efficient if its thermal capacity is high and its viscosity is low. The thermal capacity of a coolant relates to the quantity of heat needed to effect a unit change in temperature. The most efficient coolant is, therefore, the one with the highest boiling point and lowest freezing point. Apart from using efficient coolant as recommended by the manufacturer, the following should be done to maintain a liquid cooling system:

(a) The radiator condition should be observed because it is the major engine cooling component. If improperly managed can cause overheating;

(b) The radiator should be cleaned regularly during operation to keep out contamination (trash and leaves) which may block fins thus compromising cooling efficiency;

(c) The radiator should always be full of water. Avoid using hard water to avoid salt deposits thus affecting the working efficiency;

(d) The radiator fan belt tension should be maintained properly. Too tight of the belt leads to tear and wear of the bearing. Too loose reduces cooling efficiency;

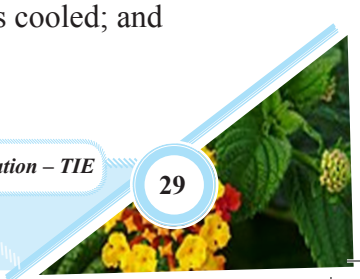
(e) Before starting the work check the level of cooling liquid in the radiator. Add the liquid to the recommended level when the level is below the recommended mark;

(f) After the engine is switched off do not refill it with cold water. Refill while the engine is running to protect from sudden contraction which can crack the cylinder head;

(g) The thermostats should work perfectly. Replace them in case they are not working well;

(h) Hose pipes should be checked to ensure they are not defective or clogged. Replace them in case they are defective;

(i) After every 300 hours of operation, the radiator should be drained. Draining should be conducted when hot to remove suspensions. Refilling should be conducted after the engine is cooled; and



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(j) Apply rust inhibitors based on manufacturers' recommendations to protect engine parts.

Air cooling systems

Air cooling systems use fins located on the surfaces of the engine block. The fins serve to increase the surface area exposed to the cooling air, thus increasing the rate of heat exchange. Airflow is enhanced by a fan driven (direct or indirect) by the crankshaft. Air cooling systems are less complex and hence easy to maintain. This cooling system is commonly used in light farm machines such as mowers, chainsaws and low-horsepower tractors.

Table 1.2: Differences between water cooling system and air-cooling system.

Liquid cooling system	Air cooling system
(i) Uses liquid coolant	(i) Uses air as a coolant.
(ii) It is commonly used in heavy-weight farm machines such as tractors.	(ii) It is commonly used in light farm machines such as mowers, chainsaws and mini-tillers.
(iii) Water-cooled engines swap out cooling fins for passageways through the engine block, cylinders and cylinder head through which coolant flows.	(iii)Air-cooled engines can struggle to maintain consistent temperatures as they rely on the vehicle moving to enhance cooling.

Generally, inefficient cooling of the engine may result into:

(i) Expansion of cylinder and piston to the extent of seizing a piston in the cylinder thus stopping the engine;

(ii) May also result in engine knock and loss of power due to pre-ignition of the fuel mixture.

Activity: 1.6

Aim: To determine the most efficient coolant sample.

Apparatus: Heat source (e.g. Bunsen burner), a measuring cylinder (of 100 cm^3), Pyrex beaker (250 cm^3), tripod stand and wire gauze.

Materials: Samples of three different coolants (preferably one sample of plain water and the other two samples of commercial coolants of different brands).

Procedure:

(a) Measure 100 cm^3 of sample one and pour it into a beaker.

(b) Heat the sample until when it starts boiling. Immediately, measure and record the temperature.

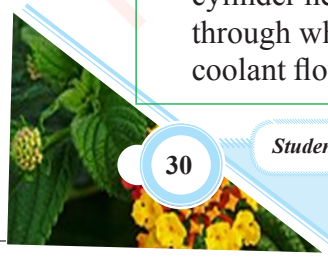
(c) Repeat procedures (a) and (b) for samples two and three.

(d) Write the results of the three samples in a table, making it easy to compare.

Questions:

(i) Which of the three samples will make an efficient coolant? Why?

(ii) What are the other qualities of an efficient liquid coolant?



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Electric system

This system comprises different components and circuits that perform various functions (Figure 1.14). These components include a generator, engine starting circuit, engine operation indicators (oil levels, water, and fuel) and ignition circuit.

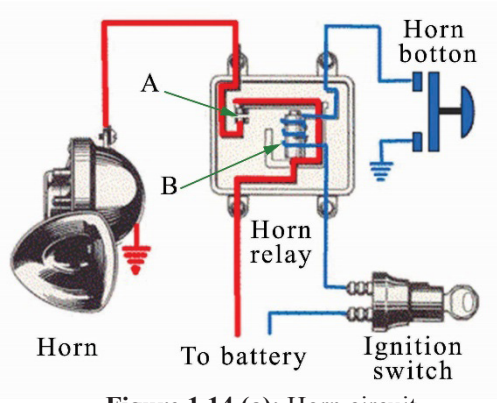


Figure 1.14 (a): Horn circuit

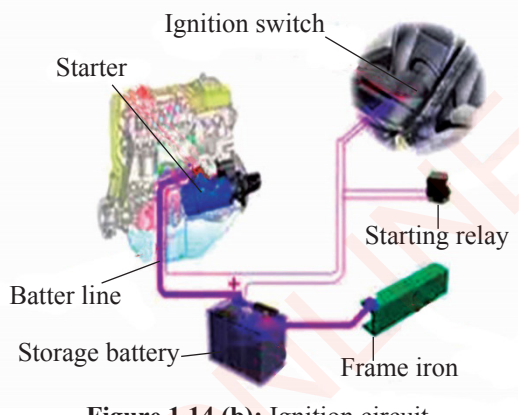


Figure 1.14 (b): Ignition circuit

Generator/olternator

The generator circuit converts mechanical energy produced when the engine is operating into a direct electric current (Figure1.15). As the generator (alternator) revolves, produces current passing through the rectifiers to the battery. This recharges the battery. The output power from the generator depends on the engine speed. Excessive engine speed may result over power supply which may damage other components. To prevent excessive power generation and associated damages, the system is fitted with the following:

(a) Cut-out relay: Protects the generator damage from a reverse flow of currently produced in the battery;

(b) Voltage regulator: Controls overcharging of the battery which is necessary for prolonging battery life. It also protects the electric system from high voltage. High voltage is detrimental to lights and ignition coil or condenser; and

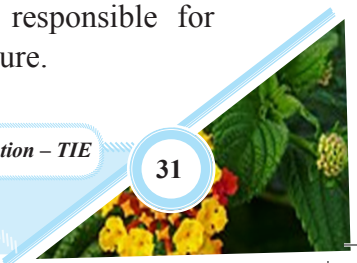
(c) Current regulator: Control the amount of output from a generator thus preventing the generator from overheating when the battery is low.

Other components of the electrical system include:

(d) Distributor and distributor cap: Distributes the voltage current to the spark plugs depending on the firing order of the engine. The distributor cap covers the distributor and protects the sparks from being exposed.

(e) Rotor: It is inside the distributor it contacts each distributor terminal connected to the spark plug.

(f) Spark plug: Provides a gap which using high voltage current, produces sparks responsible for igniting fuel mixture.



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(g) Battery: Provides current for starting of the motor to crank the engine.

Ignition system

Ignition system is responsible to provide source of igniting material into a combustion chamber in a timely manner for combustion to occur. Depending on whether the engine is powered by petrol or diesel, there are two types of ignition systems used in farm machinery, the spark ignition and compression ignition. Spark ignition is common in petrol engines and functions to create electric sparks in the combustion chamber so that air-fuel mixture can ignite. Sparks are timed to occur towards the end of the compression stroke. Diesel engines utilizes compression ignition. In compression ignition, raised temperature of compressed air ignites fuel injected into combustion at the end of compression stroke.

Lubrication system

Moving parts of a running engine are subjected to wear due to friction. Debris of the worn out engine components may further prevent smooth running of the engine. Heat is also generated due to friction of moving parts. The primary function of lubrication system is to form a film of oil between moving parts in order to reduce wear due to friction. Supply of lubricating oil to the various moving parts of an engine is achieved by means of a lubricating system. Generally, the lubrication system serves the purposes:

(a) reduce wear through reduced frictional effect;

(b) reduces heat from the piston and other parts (cooling effect);

(c) sealing off compression forces in the combustion chamber (sealing effect); and

(d) cleaning debris from worn out parts (cleaning effect).

The parts which require lubrication include cylinder walls and piston, piston pin, crankshaft, and connecting rod bearings, camshaft bearings, valves, and valve operating mechanism, cooling fan, water pump, and ignition mechanism. Components of the engine lubrication system are oil sump, oil pump, oil filter, crankcase breather, and relief valve.

Types of lubrication system

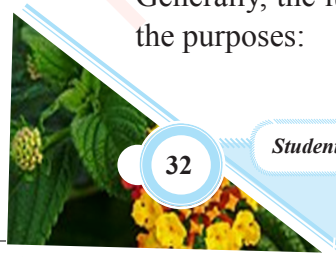
There are three types of lubrication systems used in farm machinery. These are splash feed, force feed and the oil mist type.

(a) Splash feed type

This is a type of lubrication where by a dipper or oil scoop or the cranks of the crankshaft are dipped in the oil and splashes it up to lubricate different parts of the engine as they move. This system is common for engines of light farm machines.

(b) Force feed type

This is the most common method in four stroke cycle engines. The components of this type are the oil sump, pump, filters and oil galleries (ways) around the cylinder block, pistons, connecting



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rods, camshaft, crankshaft and valves. The oil in this case circulates above the engines and drips back to the oil sump.

(c) Oil mist type

This is common with two stroke cycle engines. The oil is mixed with fuel mainly petrol in the tank at the rate of 0.25 L of oil to 6 L of petrol.

Lubrication process

When the engine is not running, oil is stored at the bottom of the crankcase called oil reservour or oil sump. When engine is started, oil is pumped to various components by means of an oil pump. Oil reaches principal components through oil galleries, the distributing channel drilled in the cylinder block, crankshaft, camshaft, rocker arms, gears and connecting rods. The pump produces high pressure to help oil reach everywhere in the engine according to design. Oil from the sump to the rest of the lubricating system passes through oil filter so that debris can be filtered.

Maintenance of the lubrication system

(a) Use the original brand and grade engine oil;

(b) The oil in the reservoir should be maintained to the required level;

(c) Engine oil should be changed timely depending on the instructions provided by the manufactures;

(d) Oil filters should be replaced as recommended by the producer. Usually is conducted during oil changing unless there is a malfunction; and

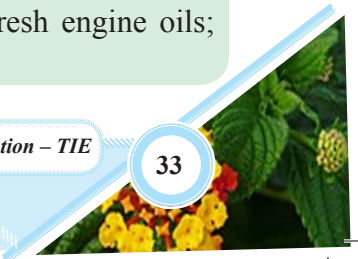
(e) Oil pump screen and oil pan should often be cleaned to ensure their working effectiveness.

Activity 1.7

Aim: To determine viscosities of engine oil samples by feel method.

Materials and apparatus: watch glass, samples of different fresh and used engine oils

1. Use the following procedure to determine viscosity of fresh and used engine oil samples of the same grade
   (a) Pour used oil and fresh oil on separate watch glasses;
   (b) Take sample of used oil from watch glass using your forefinger and rub against your thumb. Try to remember the feel;
   (c) Repeat procedure in (b) for fresh oil sample;
   (d) Record your observations in terms of easiness of fingers to skid against each other for the two samples.
   (e) Discuss with your fellow students which oil sample is less/or more viscous than the other, giving reasons.
2. Follow the procedure above to:
   (a) Determine viscosities of the three different samples and grades of fresh engine oils; and



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(b) Determine the most and least viscous engine oil samples among the three oil samples.

(c) Discuss with your fellow students on qualities of good engine oil.

The transmission system of farm machinery

Mobile farm machinery such as tractors, combine harvesters and power tillers uses transmission systems to transfer power from the engine to the driving wheels. Power transmission has to be smooth, without causing shocks to the machine and the operator. To achieve that, the system is designed to connect and disconnect the engine to/from the wheels when required, and to increase or decrease the engine wheel speed relative to engine speed by means of gears. Main components of the transmission system are clutch, gearbox, propeller or drive shaft, differential and wheels (Figure 1.16).

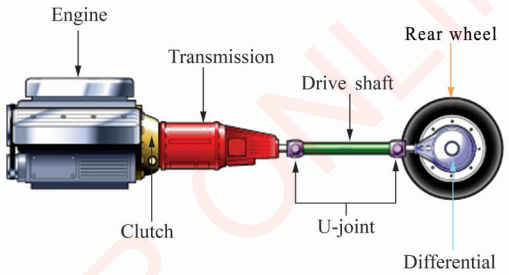

Figure 1.16: The engine transmission system

(a) **Clutch:** Also known as torque converter is used to connect and disconnect the engine from the rest of the transmission. Engine disconnection is required when gears are being engaged or when the machinery is in stationary mode while the engine is running.

(b) **Gearbox:** This unit houses gears which function to increase or reduce drive speed, hence reducing or increasing torque. Torque output is always inversely related to engine speed the inverse of the speed function. In relation to the engine and gears, which have a reduced speed than that of the engine increase torque, whereas gears which have an increased speed than that of the engine reduce torque. About the final drive gears that increase output speed reduce the torque while gears that reduces output speed increases torque. Gear transmission offers a series of advantages when compared to other types of transmission. For resistance it offer a high performance when transmitting forces and motions. But what make them stand out, is their excellence and accuracy of their gear ratios.

Gear ratio is calculated by dividing the number of teeth of the driving gear by the number of teeth of the driven gear that is:

$$GR = \frac{Ze}{Zs}$$ where:

GR = Gear ratio

Ze = Number of teeth in driving gear

Zs = Number of teeth in driven gear

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(c) **Propeller shaft:** The propeller shaft, also known as the drive shaft, is responsible for transferring engine rotational power or torque from transmission to the differential, which then transmits the torque to the wheels.

(d) **Differential:** The differential unit comprises of gear system that enables wheels of the same axle to rotate at different speeds. This is especially important when the machine is making a turn. When turning, the inside wheel will have a lower speed than that of the outside. The differential is also responsible for changing the direction of rotation of the propeller shaft at 90^0 and transmits the final drive to the wheels.

Worked example 7

A simple farm machine has 2 gears; gear A is the input and has 50 teeth; gear C is the output and has 150 teeth. Gear A rotates at 1500 rev/min anticlockwise. Calculate the gear ratio and the output speed of gear C.

Solution

Gear ratio (GR) = TC/TA

Where TC =number of teeth of gear C, TA = number of teeth of gear A.

Data given TC =150, TA = 50

GR = 150/50 =3

From the formula GR = NA/NC,

Where, NA is the input speed of A and NC is output speed of C.

But NA = 1500rev / 3 min

making NC a subject = 500 rev / min anticlockwise.

Therefore, the output speed is 500 rev/ min. anticlockwise.

Maintenance of transmission system

(a) Ensure the free play of the clutch pedal;

(b) Ensure appropriate levels of oil in the gear box, rear axle, and transmission housing; and

(c) Change the gearbox oil according to the manufactures recommendations.

Activity 1.8

1. Visit a school or any nearby farm workshop, to observe the routine maintenance service of a farm tractor. Where possible participate in some or all service operations.
2. Write a report based on the observed/performed maintenance services.
3. Share your report in class for discussion.
4. Write a summary of what you have learned from this chapter in your portfolio.

Exercise 1.4

1. Write short notes on engine systems. Explain the importance of each.

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2. With the aid of a well-labelled diagram, briefly describe the engine's electrical system.
3. Differentiate between spark ignition and compression ignition as applied in internal combustion engines.
4. Describe the function of the clutch as applied in the engine power transmission system
5. How is the transmission system of farm machinery maintained?
6. What are the reasons for engine overheating during the operation?
7. How can you ensure the maximum efficiency of the lubrication system? Describe briefly.
8. Describe the thermal siphon as applied in the engine cooling system

Revision Exercise 1

1. Outline five factors which are considered when deciding on the source of farm power to be adopted.
2. Scientists and engineers have worked hard to minimize the direct involvement of human beings in field operations. Explain how.
3. Describe six advantages and challenges of renewable energy in power generation for farm operations.
4. Power sources can be stationary or mobile during operation. Describe it by giving examples in each case.
5. Describe five advantages of animal over human power generation in farm operations.
6. Give a brief description of how a two-stroke engine works to produce power.
7. When buying farm machinery, the model selection should consider the availability of spare parts and technical skills. Explain why.
8. Discuss the three phases of tractor management.
9. One farmer is owning 60 hectares of land for farming. Due to a shortage of labour and the unavailability of farm machinery, the cultivated land per season is very low. The farmer's ambition is to own a tractor with cultivating, harrowing, and weeding implements. Apart from that, he would wish to install an irrigation system in his field to ensure a good harvest each season. To meet his ambition, the farmer prepares to apply for a loan from a bank through the government programme formulated to help farmers access loans. The farmer plans to increase the size of cultivated land from the current 3 hectares to 25 hectares for different types of crops in rotation based on

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the market demand. Suppose you are an expert on farm machinery, how will you advise the farmer to arrive at a rational decision?

10. The initial cost of a 40 hp Massy Ferguson Tractor is TZS 35 000 000. The manufacturer's lifetime of a tractor is 10 years. The farmer operates a tractor for 1 200 hours each year. The farmer also owns an 8-tined cultivator with tines spaced at 25 cm. The cost of the cultivator is TZS 1 200 000. The tractor uses 2 litres per hour of diesel while ploughing with the cultivator. The manufacturer´s life of the cultivator is 10 years. Each year a farmer uses the cultivator for about 300 hours. The recommended operation speed of the cultivator is 3 km/h. Calculate the cost of ploughing 3.5 ha of land with the cultivator. Assume: salvage value is 10% of the buying cost, the interest rate = 14%, repair and maintenance is 10% of the initial cost per year, taxes, insurance, and housing take 3% per year of the initial cost of the machine, diesel costs = TZS 2 200 /litre, lubrication cost is assumed to be 30% of fuel costs, and the daily operator charges is 10 000 TZS (in 8 working hours).

11. A tractor was hired to plough a 5-hectare farm. After about one hour of working, the engine temperature started rising. Because the operator wanted to finish the farm on that day, he ignored the temperature rise. A few minutes later, the water return hose pipe from the engine to the radiator busted and hot water got out with high pressure. Seeing that, the operator switched off the engine, brought some cold water immediately and added it to the radiator:
    (a) comment on the operator's decisions
    (b) what do you think were the reasons for engine overheating?
    (c) what should be done to stop overheating?
    (d) what might have happened to the engine as a result of working while overheating?
    (e) assume you are the owner of the tractor; what measures could you take against the operator?

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Chapter Two

Workshop technology

Introduction

A farm workshop is a focal point where maintenance of tools, implements, machinery and structures are carried out. In some large-scale farms, it is also a point at which new tools, implements and machinery are manufactured. A workshop needs to be organized and well managed for effective and efficient farm works, as well as for the safety of personnel and the working tools, equipment, implements, machinery and structures. In this chapter, the following aspects will be discussed in detail: Workshop management and organisation, workshop safety measures and types of farm workshops. The competencies developed from this chapter will enable you to manage and use effectively different farm workshop technologies for efficient farm production alongside taking precautions on workshop safety measures.

Workshop management and organisation

Management of a relatively large manufacturing farm workshop will consist of planning, organizing, activating, and controlling human and other resources to meet the objectives of a workshop. Workshops of small sized farms are usually managed by one or a few technicians, since they are organized around workbenches rather than independent sections and departments. For large farm workshops, the management team is involved in short- and long-term decision-making by following a well-structured organisation's strategic plan. The management team should be efficient to optimize workshop performance. The size of the management team depends on the size of the workshop and the level of production. Generally, efficient workshops consist of the general manager and various departments including production, technical (engineering), quality control, marketing, and security as described hereunder:

(a) **The general manager:** Is the head of the workshop and thus responsible for the management of the whole workshop. This is more applicable for multi-functional and large workshops.

(b) **Production department:** It is headed by the production manager who is responsible to oversee the functions and all forms of production in the department for optimizing workshop production.

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(c) **Engineering department:** Headed by the chief engineer. The department is responsible for the design production, repair and maintenance of tools, implements and machines.

(d) **Quality control department:** The department is led by the chief inspector and is responsible for ensuring the quality of the finished product.

(e) **Security department:** This department is responsible for the security of the workshop's properties and workers.

(f) **Marketing department:** The department is headed by a marketing manager who is responsible for increasing brand awareness and promoting business.

Workshop organisation

When working in the workshop, tools and equipment must be easily reached when needed. This is only possible if a workshop is well organized. This can be achieved through a good layout of the workshop. Workshop layout refers to how tools, equipment, machines and workbenches are arranged relative to each other. Good workshop layouts enhance work efficiency and reduce the risk of injury to the person working in the workshop. Generally, there are four major types of workshop layouts. These include:

(a) **Product layout**: In this type, machines are installed sequentially along the production line.

(b) **Process layout:** In this type, similar machines are grouped according to their functions.

(c) **Fixed-position layout:** In this type of layout the major part of an assembly remains at a fixed position. All accessories, materials, machinery, equipment, and tools required, are brought to the working site.

(d) **Combination layout:** In this layout, the advantages of the above types of layouts are combined. This is the most appropriate type of layout whereby a set of machinery or equipment is grouped. Each set or group of machines or equipment is used to perform similar operations.

Activity 2.1

In a group, visit at least three nearby workshops, observe the layout of each workshop, and inquire about how each workshop is managed, and the existing departments/sections. Then, write a report based on:

(a) Departments/section units of each visited workshop;

(b) The layout of each workshop; and

(c) Strengths and weaknesses of each observed workshop layout (propose measures for improvement where applicable).

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Workshop safety measures

The improper working in the workshop can cause injuries, permanent disabilities, machine damage, and even death. To avoid this, safety is the top factor to consider when performing different operations in a workshop. Generally, there are four key safety elements in developing a safe working environment in a workshop. These include:

(a) employee's involvement in developing safety rules;

(b) worksite analysis of potential hazard spots;

(c) hazard prevention and control; and

(d) Organise frequent safety and health training programmes.

Workshop hazardous situations

Workshop hazards can have a negative impact (harm, injury, death) on the safety and health of the worker, property or the environment. The major sources of hazards in a workshop include human inefficiency, machine malfunction, or accidents. Workshop points with a high probability of causing hazards are called hazard points. These include points where heavy objects are lifted, areas with moving parts of machinery, working at heights, excessively noisy areas, slippery surfaces, and areas stored with toxic substances. Workshop hazards are classified into two categories as safety hazards and health hazards.

(a) **Safety hazards**: These result from circumstances that can cause immediate injury to a worker. Examples include electric shocks and exposure to contact with moving parts of the machine such as a circular saw machine.

(b) **Health hazards**: These are caused by long-term exposure to certain substances. For example, exposure to a noisy environment affects hearing while exposure to chemicals may lead to diseases such as lung and skin cancer.

To work safely while using hand tools and power-operated machinery, different specific guidelines should be observed. Also, hazard points should be identified and provided with safety signs to help operators take precautions while working. Workers should also wear appropriate protective gears according to the working environment and type of exposure to hazards. In addition, workshop rules while working with hand tools, equipment and power-operated machines should be observed.

Common safety signs in a workshop

Some of the commonly used workshop signs which should be observed in hazardous areas include the following signs: slippery surfaces, high voltage zones, moving machinery areas, and areas associated with toxic chemicals. The signs are shown in Figure 2.1.

Danger
Slippery surface

Danger
High voltage

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Warning
Fork lift trucks

Danger
Trip hazards

Deadly
Hazard warning

Harmful chemicals

Figure 2.1: Examples of workshop signs to ensure a safe working environment

Workshop protective gears

The workshop environment involves different activities. To protect the worker from hazards and injuries, a workshop should have protective gears to be worn during operations. The common workshop gears include safety shoes, safety helmet, eye protection, gas masks, and safety clothing among others. Examples of workshop safety/ protective gears are indicated in Figure 2.2.

Hearing protection

Safety goggles

Fire extinguisher

Figure 2.2: Examples of workshop safety gears

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Safety rules while working with tools, equipment and hand-operated machines

The following safety rules should be observed while working with hand-operated tools, equipment and machines:

(a) Always use the appropriate tool to perform a specific task. Avoid using tools for jobs that are not designed for;

(b) Adhere to manufacturer's recommendations when using hand-operated tools;

(c) Consider using protective gear depending on the work requirement. For example, hand gloves, glasses, and goggles when welding;

(d) Avoid placing working tools or other items above shoulder height. This may cause injury to parts of the head including the eyes;

(e) Tools/equipment that are used often should be positioned closer to the working area;

(f) The working environment should provide for a change of working styles such as working while sitting, standing, and walking. This will avoid legs from swelling as a result of standing for a long time;

(g) Before using tools or equipment, inspect for defects and replace or repair if necessary;

(h) Cutting tools should always be sharp;

(i) Sharp edges should be covered with suitable covering materials to prevent injuries from unintended contact;

(j) Sharp tools lying on benches should point away from aisles and handles should not extend over the edge of the bench top; and

(k) Always make sure that, the working environment is clean and tidy to avoid cluttering which may cause accidents.

Safety guidelines/ rules while working with power-operated machines

The following safety rules should be observed while working with power-operated machines:

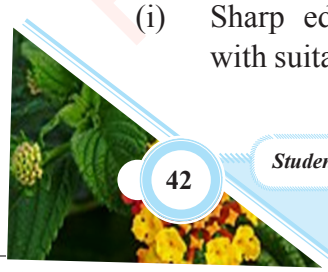
(a) Identification of all hazards associated with operations should be conducted at the early stages of workshop start-up and whenever new items are acquired;

(b) Assess the risks to the health and safety of all persons exposed to the hazards and hazardous environment e.g., make use of hearing protection when exposed to a high level of machine noise; the electrically operated machines should be properly installed;

(c) Eliminate or reduce the hazards and risks by full compliance with the use of design features;

(d) Safety guards should be installed in exposed places where parts of the machine rotate such as belts, to protect the worker from accidents;

(e) Avoid wearing loose clothes as they can be easily entangled with rotating belts and gears;



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(f) Avoid using your hand to push materials into the cutting area. Use a push stick instead to keep hands safe;

(g) All machines in the workshop must be installed with start and stop buttons at a point which can be reached by an operator without stretch. Start buttons should be protected to avoid starting the machine unintentionally;

(h) Avoid operating machines in a risky manner;

(i) While working consider the interaction between people and machines following ergonomic factors in hazard/risk assessment;

(j) In case of change, relocation, or provision of new machinery consult all involved parties;

(k) Make a routine assessment of the lighting, noise, temperature, and general tidiness in the work environment;

(l) Turn the power off and unplug the power cord (or lock out the power source) before inspecting, changing, cleaning, adjusting or repairing a blade or a machine. Also, turn the power off when discussing the work with a co-worker or supervisor; and

(m) When the work involves repetitive operation, the leader should provide a schedule that will allow workers to change the nature of work. Repetitive work for a long time may result in fatigue and hence cause injuries.

Activity 2.2

Conduct a visit to a nearby workshop with several power-operated machines. With the help of an expert, do the following:

(a) Observe workshop safety signs, protective gear, and its associated safety rules available in the workshop;

(b) Participate in carrying workshop activities using proper protective gear; then

(c) Write a brief report and share it in class.

Types of farm workshop

Small and some of the medium size farms will most likely have a multipurpose workshop for the repair, service and/or manufacturing of farm tools, equipment, machinery and structures. Some medium and most large-sized farms will most likely have more specialized workshops for repair, maintenance and manufacturing operations. This subsection discusses some specialized farm workshops namely woodworking, metalworking and machinery maintenance workshop. Some operations carried out in each of the workshop categories and associated tools, equipment and machinery are discussed. The types of farm workshops are summarized in Figure 2.3.

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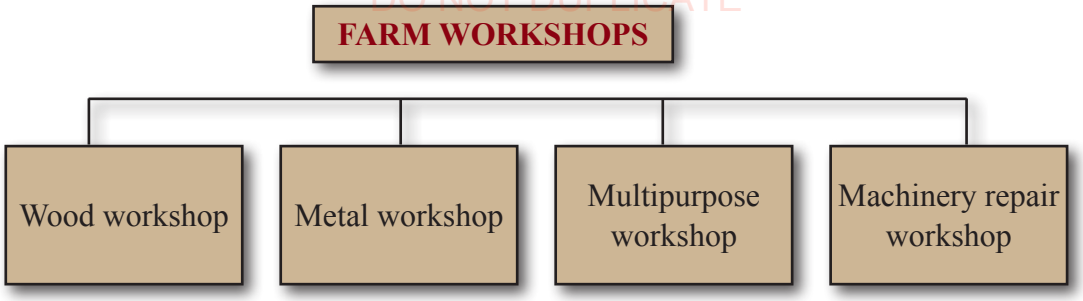

Figure 2.3: Types of farm workshop

Wood workshop

Woodworking processes such as sawing, planing, chipping, shaping, moulding, lathing and sanding are involved in the repair and manufacturing of wood products and structures. A product or structure can be made from wood alone, or in combination with other materials. Examples of wood structures in a farm include buildings, cages and wooden fences for various purposes in the farm. In Table 2.1 description of some machines used in woodwork is provided.

Table 2.1: Wood working machine and their uses.

Machine	Description
(a) Circular saw (i) Bench circular saw (ii) Hand-hold circular saw	These are power-operated machine for sawing timber into desirable size.
(b) Plane (i) Single side planer (ii) Double side planer	Used for planing wood surfaces to make them straight.

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(c) Drilling / boring machine

These are machines used to drill circular holes on wood surfaces for different function. It can also be used for drilling mortises and cutting circular or other shapes in the middle of a wood piece.

(d) Wood turning lathe machine

These are machines used to change the wood surfaces into circular shapes. The circular shape is attained through the high-speed rotation motion of a cutter installed.

(e) Spindle moulder

Used to prepare different types of wood moulds including circular decorations on wood for example, legs for tables, stools, sofas beds and curtain boxes.

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(f) Sanding machine

(i) Portable

(ii) Fixed

These machines may be portable or fixed. It is used for smoothing wood surfaces towards the finishing stage.

Activity 2.3

1. Visit a nearby carpentry workshop and do the following:
   (a) Find a piece of dry wood (2 × 2 inches);
   (b) Hold the piece of wood on the workbench using one hand;
   (c) Use another hand to hold a rip saw to cut along the grain of the wood and check for the smoothness and cutting speed of the rip saw;
   (d) Repeat cutting using a rip saw across the grain of the wood and check the smoothness and speed of cut; then
   (e) Repeat the 2nd and 3rd procedures using a cross-cut saw.
2. Which type of saw is better when cutting across and along the grain? Give a reason for your answer.

Activity 2.4

1. In a group or individually, visit a nearby carpentry workshop and do the following:
   (a) Count and record the number of teeth within 10 cm in both the rip saw and cross-cut saw; then
   (b) Observe and record the shape and size of each rip and cross-cut saw.
2. Briefly describe the structural set-up as observed in a rip and cross-cut saw that relate to their functions.

Metal workshop

A metal workshop houses a range of tools and machines used for working with metal sheets, pipes and bars (Figure 2.4). Metal works involves repairing and fabricating tools, equipment, machines and structures through various processes. These processes include forging, welding, soldering, brazing and riveting.

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Figure 2.4: A metal workshop with square steel pipes stacked on the floor

Forging

Forging is the moulding process involving the shaping of metal through hammering, pressing, or rolling. Some forging tools and equipment used in the forging process include a hand fan forge, anvil, sledge hammer and tongs. Before performing any other operation related to forging, it is essential to make marks on the metal according to the drawing. For this purpose, a brass ruler, tri-square and centre punch are used. Forging operations include: cutting, upsetting, drawing out, bending, flattening operation, punching or drifting, setting down operation and swaging.

(a) Drawing down: Is the process of increasing the length of any workpiece of metal while the cross-sectional area is reduced;

(b) Bending: This is a very common forging operation. It is an operation to give a turn to a metal rod or plate. This is required for those parts which have bends shapes; the process is done on the edge of the anvil;

(c) Cutting: This is a process where a metal rod or plate is cut out into two pieces, with the help of a chisel and hammer, when the metal is in red hot condition;

(d) Swaging: This is done to reduce and finish work for desired size and shape, usually in a round or hexagonal shape. For small tasks, a top and bottom swage pair is employed, whereas, for major tasks, a swage block can be used;

(e) Punching and drifting: It is a process of producing holes in a metal plate by pressing the punch over the plate.

(f) Jumping and upsetting: It is the operation whereby the thickness of the bar or cross-section is increased at the expense of its length. If the end of the bar is required to be upset, it is heated to bright red while holding the bar vertically on the anvil;

(g) Flattening: This is done on the anvil face; a hot work piece is placed on the anvil and flattened the work piece with the help of a flatter; and

(h) Forge welding: This is the process of joining two metal pieces by heating and hammering, the metal piece to be welded is cleaned and heated in the furnace to the welding temperature.

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Activity 2.5

In a group, visit a nearby metal workshop where forging operations are conducted. Under the supervision of the workshop manager, do the following:

(a) Wear safety glasses, respirator and protective clothes, earplugs and closed-toe shoes;

(b) Find a piece of metal and put it on the anvil block;

(c) Clamp the piece of metal using a clamping vice;

(d) Hold the sledgehammer and strike the piece of metal on the anvil, observe the response of the cold metal when striking it; then

(e) Repeat the 2nd and 3rd procedures using hot red metal; then answer the following questions:

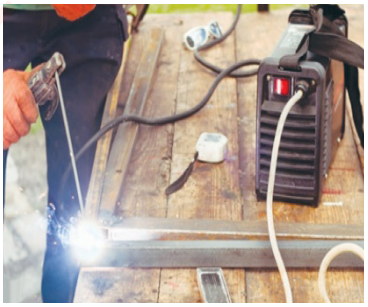
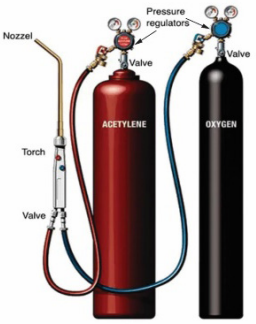
(i) Why is it important to wear safety glasses, a respirator, thick clothes and closed-toe shoes before conducting any forging operation?

(ii) What observations have you made regarding the workability of cold and hot pieces? Give a reason for your observations.

Welding

In metal works, welding is a fabrication for joining two or more parts of metal by using high heat usually using an electric arc or gas flame. In a process, base metal and filler metal melt to form molten materials. As the molten material cools, fusion occurs to form a joint. Examples of welded joints include butt, tee, corner, lap and edge. Important equipment used in welding includes an arc welding machine, gas welding equipment, electrode holder, lead cable and other metal work tools are also used. Some of these are presented in Table 2.2.

Table 2.2 Welding and related machines

Machine	Illustration
(a) A welding machine: Used for joining two or more metal parts using generated heat. The welding can be conducted by electrical arc welders (welding sticks) or gas welding (a mixture of acetylene and oxygen). These are indicated in Figures (i) and (ii)	 (i) Arc welding and  (ii) gas welding equipment

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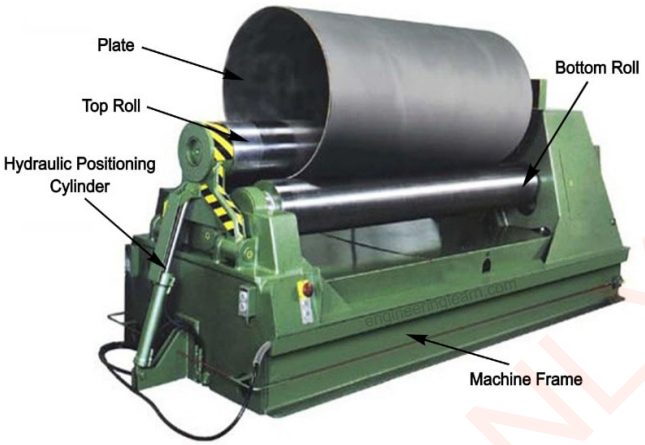
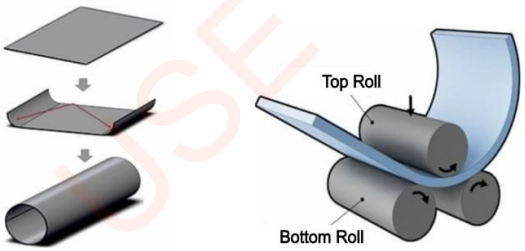
(b) Metal sheet bending machine: Used for bending sheet metals for different purposes. For example, the fabrication of cylindrical metallic equipment to be used in infiltration tests for agricultural water management.



(i) Metal sheet bending machine



(ii) Some worked sheets

(c) Angle grinder: This is a handled power tool with consumable stone discs or blades attached to them. The discs or blades, spin at high speed to grind, polish or cut metal.

Angle grinder

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Activity 2.6

In a group or individually, visit a nearby welding workshop and do the following: (consider appropriate use of safety gears)

(a) Under the supervision of the workshop manager, identify common tools, equipment and machine used in the workshop and give their respective uses;

(b) Observe and record the pattern of teeth in both single and double-cut metal files in relation to their functions;

(c) Find a piece of metal sheet and clamp it with a vice grip. Hold a single cut file with both hands and push the file forward, slide it from one end towards the other, and be careful to keep the file level during operation to avoid filling the surface unevenly. Observe the speed of cut and smoothness of the surface; then

(d) Repeat the 2nd and 3rd procedures using double-cut files.

  (i) What observations have you made regarding the speed of cut and smoothness of surface for both types of files?

  (ii) Which file was more appropriate for smoothing a metal sheet?

  (iii) What safety gears were appropriate to use in this activity?

(e) Write a report and present it in class.

Soldering

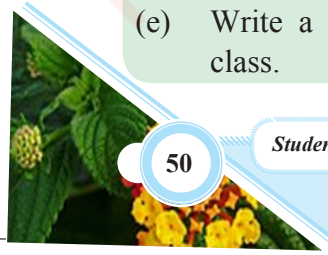
Soldering is a process used for joining metal parts to form a mechanical or electrical bond. It typically uses a low melting point metal alloy (solder) which is melted and applied to the metal parts to be joined. It is different from welding because the parts being joined are not melted and are usually not of the same material as the solder. Soldering is a common practice for assembling electrical components and wiring, although it can be used for plumbing, sheet metal fabrication or automotive radiator repair.

Brazing

Brazing refers to the process of joining two pieces of metal that involve the application of heat and the addition of filler metal. This filler metal, which has a lower melting point than the metals to be joined, is either pre-placed or fed into the joint as the parts are heated. In brazing parts with small clearance, the filler can flow into the joint by capillary action. The temperature of the molten filler used for brazing exceeds 800 F (430°C). In a related process called soldering, the filler metal remains below that temperature. Brazed joints are usually stronger than soldered joints. Tools used for brazing include a brazing handheld torch, filler metal (silver, copper and aluminium are common filler alloys) and fluxes.

Activity 2.7

Conduct a visit to a nearby place where brazing activities are taking place and do the following:



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(a) Under the supervision of the workshop manager, identify common tools, equipment and machine with their respective uses in brazing processes;

(b) Wear gloves, protective clothes and shaded goggles or glasses shield;

(c) Find two pieces of metal (work pieces) and put them close;

(d) Position the workpiece or parts to be joined using a support device such as vice grips;

(e) Clean the metal parts using a wire brush;

(f) Add flux coating to the joint;

(g) Hold the brazing handheld torch and heat the joint to the side opposite the filler metal, as the filler metal will flow towards the area with high temperature; and

(h) Clean the joint with clean warm/ hot water.

(i) Then, explain why:

(i) it was important to wear gloves, shaded goggles or a glass shield when working in performing brazing operations?

(ii) it is important to clean the metals joined with a wire brush?

(iii) is it necessary to clean the joint with hot water after brazing?

Riveting

Riveting is a metal joining process in which the two metallic parts are joined by the use of rivets. In this process, the metallic parts to be joined do not undergo any change in their physical structure. However, force is required for riveting. Riveting is used widely in automobile and metal bridge constructions and in many other applications where we require permanent/semi-permanent bonding and where bolting and welding are not an option. Riveting is mostly done for low-thickness sheet metals and Aluminium. Tools used for riveting are solid punch, riveting hammer, rivet set (die) and rivet. The most commonly used hammer is the ball peen hammer.

Activity 2.8

Conduct a visit to a nearby metal bridge construction site and do the following.

(a) Under the supervision of the workshop manager, identify common tools, equipment and machine with their respective uses in reverting processes;

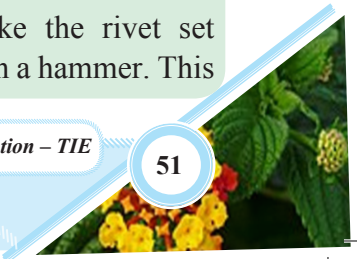
(b) Wear gloves, goggles or face shield, protective clothes ear plugs and safety footwear;

(c) Find two pieces of metal sheets to be joined and clamp the sheets using clamping vice;

(d) Determine the location of the rivets and select the suitable rivets;

(e) Hold the solid punch in a place where the hole is to be located. Strike the punch solidly with a rivet hammer to form a hole;

(f) Place the rivet with the head down. Then strike the rivet set once or twice with a hammer. This



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will flatten the sheet metal around the hole and draw the two sheets together;

(g) Use the flat face of the riveting hammer to strike the shank squarely with several blows. The shank will expand, filling the hole tightly while the top of the shank will flatten a little; and

(h) Place the cone-shaped depression of the rivet set over the shank and strike the set two or three times to round off the head.

Machinery repair and maintenance workshop

For proper functioning and extending the lifespan of farm machinery, machinery repair and maintenance is necessary. Repairing restores part of the machinery which is broken, damaged or simply stopped working. Normally, repair works are not scheduled; instead, they are carried out as the need arises. Maintenance works are routine tasks to prevent damage and prolong the life span of farm machinery. These are scheduled activities and depend on the manufacturer's recommendations. Both repair and maintenance works of farm machinery require specialized tools, equipment, machinery and consumable materials such as spare parts and lubricants to be accomplished. A machinery repair and maintenance workshop is organized to deliver repair and maintenance works of assemblies, sub-assemblies, components and individual parts of farm machinery. The following are some important equipment and machinery in a farm machinery repair and maintenance shop:

(a) **Vehicle lifting machines:** These are used to lift heavy objects such as vehicles/trucks/tractors for inspection and repair underneath the machine. They are made with varying capacities depending on the weight of the machine to be lifted. Most of them are operated by hydraulic-driven pistons.

(b) **Engine hoist (crane):** The engine hoist is used to facilitate removing or installing the engine from a machine (Figure 2.5 (i))

(c) **Strut compressor:** Strut compressors are used to compress the spring (coil spring) to reduce the spring size which facilitates removing or fixing it from/to its position (Figure 2.5 (ii)).

Figure 2.5 (i): Engine hoist with a lifted engine

Figure 2.5 (ii): A strut compressor

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(d) **Hydraulic press machine:** This is a device used for pressing out materials that require high pressure to remove or dismantle (Figure 2.6 (i)). They also facilitate fabrication, assembling, and maintenance. The power used is generated through the hydraulic system.

(e) **Hydraulic press for tire repair:** This is the machine used for removing wheel rubber in case of repair or changing the worn-out/ expired tire (Figure 2.6 (ii)).

Figure 2.6 (i): Hydraulic press machine

Figure 2.6 (ii): Tire repair

(f) **Air compressor:** This is a device that is used for inflating tractor/ vehicle tires (Figure 2.8). It is also used for cleaning, paint spraying, and pressurised washing among others.

Figure 2.7: The air compressor

(g) **Lifting jacks:** These are used for lifting and lowering heavy machines such as tractor /truck/ vehicle or their parts during such task as tire changing and any other repair on the underneath part of the machine. They include jack stand, hydraulic jack, tractor jack and transimission jack (Figure 2.8 (i) – (iv)).

Figure 2.8 (i): Jack stand

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Figure 2.8 (ii): Hydraulic jack

Figure 2.8 (iii): Tractor jack

Figure 2.8 (iv): Transmission jack

(h) **Battery charger:** It is used to charge a battery in case of losing its charge (Figure 2.10). Usually, a tractor/vehicle has its battery charging circuit. A malfunction of a charging system or long stay of a machine during the off-season or a long breakdown may lead to the battery drain requiring charging.

Figure 2.9: A battery charger

Maintenance works of farm machinery

Under this sub section, a tractor maintenance will be covered as representative of other farm machinery. This is because of its versatility and capability of accommodating attachments in the form of implements and machinery and thus, used for various farm operations. A farm tractor is subjected to various forces of tear, and its engine, as well as other systems and components, need to be serviced to keep it in operation and to enhance its lifespan. The routine maintenance services of specific systems, components and units of a farm tractor are based on the number of hours it has been working and as recommended by the manufacturer. The general service requirement for different units and systems are presented in Table 2.3.

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Table2.3: Farm engines servicing guide

Part of tractor	Service required
Linkages	Test the linkages if work properly.
Engine check-up	Check the oil engine level in the sump, and top-up if needed. Check air cleaner (change or clean).
Tires	Ensure the tightness of tyre rim nuts. Tyre pressure should be adjusted (if needed) by adding (in the case is low) or releasing (in the case is higher than recommended).
Brakes	Grease the shaft bearing. Master cylinders should be working properly. Check for brake oil leakages.
Electrical system	Check the battery's functioning. If the electrolyte is low, add distilled water. Dry cell batteries are not topped up with water or electrolyte. Clean terminals.
Fan belt	Check the condition and strength of the fan belt. Replace if is in improper condition.
Radiator	Check the water level in the radiator and any blockage. Add water if necessary. This should be done when the engine is already cool after stopping it. Otherwise, the hot water under pressure blows out and causes serious injury.
Front axle	Check the steering connections, and grease to easy motion
Bolt and nuts	Replace missing bolts, nuts and pins if any. Check the tightness of the bolts.
Greasing	Greasing is required to continuously lubricate the moving parts. These parts include ball joints, bearings, steering components and hitch pivots.
Fuel tank	Check for fuel tank leakages and repair if any.
Engine	Periodic check of engine oil level. Periodically change engine oil and filters. Most tractors require an oil change after 240 hours of operation. Refill when not on the required level.
Transmission	Check the condition and level of transmission oil. Change the oil as per the recommendations of the manufacturer.

Benefits of maintaining farm machinery

It is important to properly maintain farm machinery since it has many benefits for the farm. Some of them include the following:

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(a) It assures the machine's dependability, reliability, and functionality;

(b) It extends the useful life of the machine;

(c) It assures its availability whenever needed;

(d) It ensures efficient use of farm operation hours and provides high machinery use efficiency;

(e) It assures low operation cost by allowing increased output; hence, return on investments;

(f) It ensures the safety of the person operating the machine; and

(g) It provides room for increased cropping intensity and patterns.

Other farm technological processes that utilise a farm workshop

Repair and construction of farm structures are carried out onsite and not necessarily in a workshop. However, part of their processes may be done in a workshop. For example, a galvanized pipe may be cut and treaded at the workshop before installation on the site. Plumbing and masonry are some of the processes for the construction and repair of farm structures utilizing the services of farm workshops.

(a) Plumbing and pipe fitting

Plumbing is the process of installing, maintaining and repairing systems that convey fluids for different applications including domestic, irrigation, drainage and sewerage use. A plumber requires several tools and equipment to perform work. Fittings are important in accomplishing plumbing work. Both tools and fittings are usually stored in a workshop. Table 2.3 shows some common pipe fittings used for plumbing works.

Table.2.4: Pipe fittings and their uses

Name of fittings	Description
(i) Tee	It is threaded T-shaped components used for distributing the supply of water at a right angle to the direction of flow.
(ii) Elbow	It is the threaded fittings used for joining two pipes at the right angle while bend is used for any angle.

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(iii) Cross	It is used to connect four pipes at a right angle to each other.
(iv) Socket	It is used to connect two pipes of the same diameter.
(v) Nipple	It is a small length fitting having outside thread at ends, it is used to get an extra length of the pipe by screwing it with two pipes having an internal thread
(vi) Increaser or reducer	It is threaded pipe fittings having one of its ends larger than the other. Used for joining two pipes with different diameters.
(vii) Union	It is used to connect two pipes and can be disconnected easily when desired.
(viii) Cap	It has an internal thread and it is used to close the threaded end of pipes.

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(ix) Plug	It has an external thread and it is used with a Tee or cross to close the opening of pipes which is left for further use.
(x) Bushing	A pipe fitting is used to join two pipes of different sizes. A bushing is threaded inside and out.

Activity 2.9

In a group visit a nearby plumbing workshop or a plumber site and do the following:

1. (a) Find a piece of PVC pipe (Plastic pipe) having a diameter of 1/2" or 3/4";
   (b) Simply hold or clamp the pipe with a pipe vice over the edge of a workbench;
   (c) Use another hand to hold a pipe cutter to cut plastic pipe and observe the smoothness and speed of the cut; then
   (d) Repeat the 2nd and 3rd procedure using hack saw.
2. (a) Find a piece of metal pipe:
   (b) Simply hold or clamp the pipe with a pipe vice over the edge of a workbench;
   (c) Use another hand to hold a hacksaw to cut metal pipe and observe for ease or difficulty when cutting; then
   (d) Repeat the 2nd and 3rd procedure using pipe cutter.

   Then answer the following questions:
   (i) Which saw was more efficient when cutting PVC pipe? Give a reason(s) for your answer.
   (ii) Which tool was better when cutting metal pipe? Give a reason for your answer
3. Write a report and share it in class.

Masonry

Masonry is the process of building a structure using individual units, such as bricks, blocks, or stones, laid and bound together by mortar. A mason is a skilled person who uses several tools, equipment and structural member which are either stored or constructed and repaired in a workshop. Masonry tools, equipment and machines include a blocking chisel, mashing hammer, masonry line, masonry jointer, masonry

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brush, chalk line and concrete block-making machine.

Activity 2.10

1. Conduct a visit to a nearby masonry construction site and do the following:
   (a) Under the supervision of the visited in-charge technician, identify common tools and equipment available and their respective uses;
   (b) Find a concrete block of any size;
   (c) Simply hold a brick/block hammer and strike the block with the chisel end of the hammer to reduce its size and check for the smoothness of the block; then
   (d) Repeat the 2nd procedure using a claw hammer.
2. Which hammer is better for the reduction of concrete block size? Give reasons for your answer.
3. Write a report and share it in class.

Exercise 2.1

1. Explain:
   (a) the meaning of the term farm workshop; and
   (b) Importance of a farm workshop.
2. Outline different types of farm workshops.
3. How does a metal workshop relate to farm machinery?
4. Explain the four major types of workshop layouts. Which type is more appropriate for a well-established workshop? Give three reasons.
5. Distinguish between a tool and equipment.
6. List and give functions of hand tools and equipment used in the carpentry work, soldering, forging, brazing, riveting, plumbing and masonry.
7. Mention different types of power-operated machines that are found in the workshop and explain their functions.
8. Explain the functions of a workbench.

Revision exercise 2

1. Describe five safety rules when working with tools, equipment and hand-operated machines.
2. Outline six safety rules to be considered while working with power-operated machines.
3. Explain the functions of the jib crane and engine hoist as used in the farm workshop.
4. What are the functions of an air compressor?

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5. What are the functions of a wood-turning lathe machine? Describe how it operates.

6. What are the functions of vacuum cleaners as applied in carpentry workshops?

7. Explain the term safety as applied in farm workshops.

8. Why safety is considered the top factor in workplaces?

9. What are the major sources of hazards in the farm workshop environment?

10. Explain the classes of farm workshop hazards.

11. In any farm workshop, different safety equipment is provided for various functions. Based on your experience, list and describe at least four pieces of safety equipment used for:
    (a) Conducting arc welding;
    (b) Working with a surface planer; and
    (c) Conducting electrical installation.

12. Explain the importance of observing safety measures in any farm workshop?

13. Choose any workshop of your interest then explain the safety rules applied.

14. Suppose you have noted that, the workplace is not safe for you, would you continue working there? Justify your answers with reasons.

15. Assume you have been appointed as a workshop engineer of a certain organisation. Among your tasks is to take responsibility for safety of workers in the organisation. Explain what would you do to achieve this?

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Chapter Three

Soil science

Introduction

Soil science is a branch of science concerned with the formation, ecology, nature and classification of soil. The study of soil science includes soil formation, classification and mapping; physical, chemical and biological properties of soil; and relate these properties with the use and management of soils. In this chapter, you will learn soil science covering the general concept of soil and the three main branches of soil science namely; soil physics, soil chemistry, and soil biology. A detailed discussion of branches of soil science is covered in the respective sections of this chapter. The competencies developed will enable you to manage soils for improved crop production and environmental sustainability.

The concept of soil in agricultural production

Soil is a natural body comprised of solids (minerals and organic matter), liquid, and gases that occurs on the earth's surface occupies space and is characterized by horizons, or layers, that are distinguishable from the initial parent material.

As far as agriculture is concerned, soil is defined as the upper most unconsolidated layer of the earth's crust mixed with organic matter and has pores occupied by air and water upon which plants grow. Soil productivity is the degree to which the soil is capable to support plant growth and development to produce the desired products. For sustainable use of soil, it is important to manage and maintain its fertility. This can only be achieved through effective management of soil's physical chemical and biological properties which interact to influence soil fertility and productivity.

Composition of the soil

Soil is composed of minerals, organic matter, water and air. An ideal soil (Figure 3.1) consists of approximately 45% mineral, 5% organic matter, 25% water and 25% air. However, these percentages are only generalizations. In reality, the soil is very dynamic and its composition can fluctuate depending on numerous factors such as water supply, cultivation practices, and/or soil type. The relative amounts of water and air in the soil are constantly changing as the soil wets or dries because both soil air and soil water occupy soil pore spaces. Dry soil will have less water (soil moisture) thus more of its pore spaces will be occupied by air. Immediately

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after rainfall or irrigation, more water infiltrates the soil, driving the air out of pore spaces thus much more pores will be occupied by water. Therefore, in the real sense, the soil is roughly composed of 45% mineral, 5% organic matter, 20-30% water, and 20-30% air. The four components of soil fall into three phases namely; solid (Minerals and organic matter), liquid (soil water) and gaseous phase (soil air soil) hence the soil is usually referred to as a three-phase system.

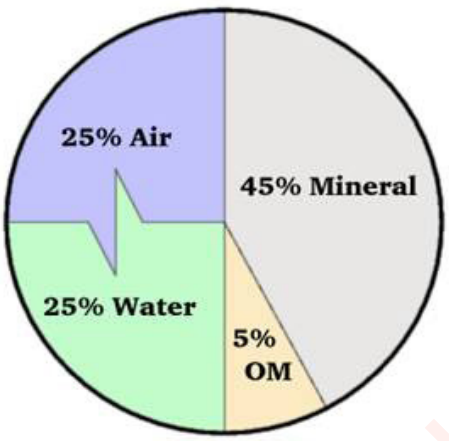

Figure 3.1 Approximate volumetric composition of the soil

Soil forming rocks and soil formation

Soil forming rocks

Rocks are aggregates of minerals. Usually, several minerals constitute a rock but sometimes only one or two minerals can constitute a rock. Minerals are naturally occurring rock constituents with fairly uniform chemical composition and regular well defined structure. Therefore, the type and properties of soils are a function of the properties of soil forming rocks and its constituent minerals. Based on the mode of formation, Soil forming rocks are classified into three major groups namely Igneous, Sedimentary and Metamorphic rocks.

(a) Igneous rocks

The rocks are formed when molten magma or lava cools on or near the earth's surface. The texture and grain size of igneous rocks depend on the depth and hence the rate at which the molten magma cools and undergoes crystallization. Examples of Igneous rocks include Granite, Scoria, pumice and Obsidian. Common minerals in igneous rocks include Quartz, Feldspars and Mica (Figure 3.2). Quartz is one of the most common minerals. It is transparent to translucent and forms hexagonal or pyramidal shapes.

Quartz occurs in a massive, granular or concretionary manner and in various colours ranging from white, grey, red, purple, pink, yellow, green, brown or black but can be colourless as well. It is resistant to weathering and thus can easily be seen in sand fractions of the soil. Feldspars are a group of rock-forming minerals which make up over 50% of the earth's crust. They contain silicon and aluminium ions bound together by oxygen ions to form a three-dimension framework of ions. In addition to silicon, aluminium and oxygen ions; Feldspars contain other cations such as sodium, calcium, potassium, or barium. Mica is a group of rock-forming layer silicate clay minerals also known as phyllosilicate minerals.

(b) Sedimentary rocks

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These rocks are formed from weathered materials or rocks when sediments are transported, deposited and compressed due to the weight of deposits and the action of various geological processes. The deposition may occur at the bottom of the sea, lakes or lower slopes of the landscape. Sedimentary rocks are always stratified and may contain fossils. Examples of sedimentary rocks include Conglomerate, Mud/sandstone, Lime stone, Shale and Gypsum (Figure 3.2). Common minerals constituting sedimentary rocks include Quartz, Feldspars, clay minerals and carbonates.

(c) Metamorphic rocks

Metamorphic rocks are formed as a result of chemical changes/alterations occurring on igneous or sedimentary rocks after being subjected to intense heat or pressure. Examples of metamorphic rocks include marble, qneiss, quartzite, and slate (Figure 3.2). Constituent minerals of metamorphic rocks include olivenes, pyroxines, hornblende, sillimanite, kyanite, andalusite, micas, feldspar and quartz.

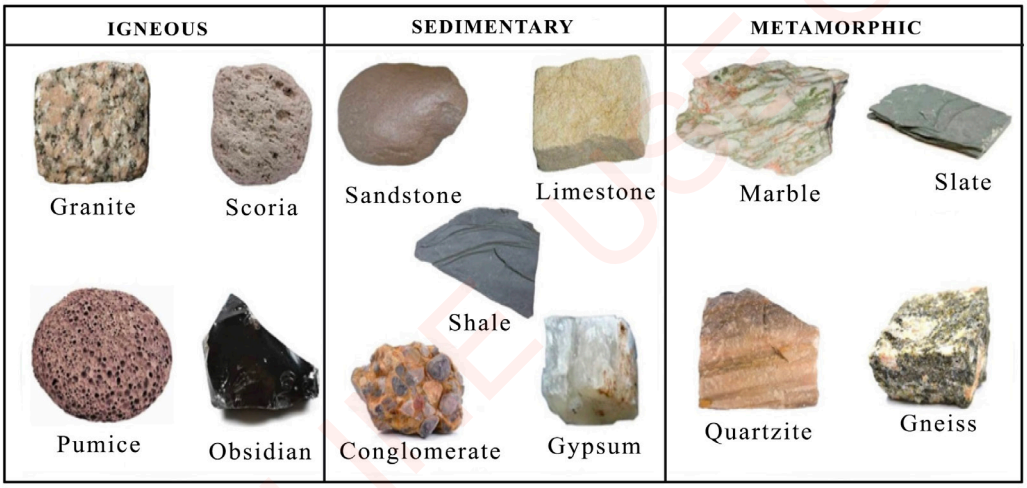

Figure 3.2: The major types of soil forming rocks

Weathering and soil formation

Weathering is the process whereby rocks are disintegrated or decomposed. Disintegration (physical weathering) and decomposition (chemical weathering) take place simultaneously and are interrelated. For example, an open broken rock due to hitting, friction, abrasion or grinding inrease more surface area exposed to weathering (physical weathering) thus speeding up the rate of chemical reactions (chemical weathering). Physical weathering does not give rise to any new substance, while chemical weathering results in to the formation of new chemical combinations such as minerals or acids which are important for plant growth. New substances formed as a result of chemical weathering have specific

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functions depending on their nature. For example, Silicon (Si) and Aluminium (Al) form the skeleton of secondary clay minerals. Iron and manganese are important for imparting red colour to soils and for oxidation and reduction reactions. Sodium and potassium are important dispersing agents for clay and humus colloids.

Weathering processes

Weathering involves physical, chemical and biological processes. All these processes are influenced by climatic factors and type of parent rocks.

(a) Physical weathering

Physical weathering or mechanical weathering, is a process by which rocks break down or change shape and texture by external physical forces. Processes such as exfoliation, abrasion, crushing, grinding, expansion and contraction are mainly responsible for physical weathering of rocks and minerals. These are facilitated by water, temperature fluctuations, freezing and thawing, erosion, and gravitational force. Because rocks are made up of different minerals, when exposed to high or low temperature, differential expansion and contraction occur. This results into cracking. Rain drops falling on exposed rocks or bare soil causes detachment of soil particles. When pieces of wood are carried by either water or wind, they cause abrasion on hard surfaces they encounter and cause erosion. Similarly, carried stones may be colliding on one another and results into physical weathering.

(b) Chemical weathering

Chemical weathering is the decomposition of rocks through a series of chemical reactions. Chemical processes that bring about chemical weathering include hydration, hydrolysis, solution, carbonation, oxidation, reduction and mixed reactions. The following are examples of chemical processes responsible for soil development (chemical weathering).

Chemical combination of water molecules with a particular substance or mineral (hydration):

(i) $2Fe_2O_3 + 3HOH \longrightarrow 2Fe_2O_3.3H_2O$

Haematite (red) → Limonite (yellow)

(ii) $2CaSO_4 + 2H_2O \longrightarrow CaSO_4.2H_2O$

(Anhydrite) → Gypsum

The dissociation of water into H^+ and OH^- ions combines with minerals and causes chemical changes (hydrolysis). In this case, water acts as a weak acid on silicate minerals:

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(iii) $KAlSi_3O_8 + 3H_2O \longrightarrow HAlSi_3O_8 + KOH$
(Orthoclase) Acid silt clay

(iv) Formation of solutions as a result of the reaction of water and the weathered or decomposed particles;

(v) Formation of carbonic acid as a result of mixing water and carbon dioxide absorbed from the atmosphere (carbonation). The weak carbonic acid formed helps to disintegrate aggregates;

(vi) Addition of oxygen to minerals to form oxides (oxidation); and

(vii) Removal of oxygen from minerals (reduction), formation of grey, blue or green colour in the soil as ferric iron is converted to ferrous iron compounds under water lodged conditions.

(c) Biological weathering

Biological weathering refers to the effect of living organisms on the breakdown of rocks. It includes the role of plants and the activities of soil organisms. It involves all processes that are facilitated by living organisms and decaying organic matter. Living organisms (plants, micro and macro fauna, and animals including man) contribute both to chemical and physical weathering. For example, plant roots widen rock joints and crevices during their growth and cause physical weathering. Likewise, they cause chemical weathering by releasing root exudates, and organic and inorganic acids. Also when burrowing animals move within the soil, they help to mix the soil components but also facilitate physical weathering.

Soil formation (Pedogenesis)

Soil is formed over a long period of time, where at first, several factors interact and convert consolidated rocks into unconsolidated soil parent materials. Over time, the soil parent materials produced are changed into small fragments which become one of the soil constituents under the influence of soil forming factors (parent rock, time, organisms, climate and relief).

Soil formation, or development involves a complex interaction of three processes; first is the formation of a parent material (the unconsolidated fragments) from weathered rocks, the second is the formation of new minerals from which the soil evolves, and the third is decaying of organic matter and incorporation of decomposed matter which results into the evolution of soil layers. All these processes are conditioned by the climate, topographical features, and natural vegetation of an area. Variation of these factors from one place to another result in the formation of different types of soils. Soil development may occur simultaneously with weathering. Figure 3.3 shows the diagrammatic presentation of the stages of soil formation. Note that, the soil depth increases with the time at which soil-forming rocks are exposed to weathering processes.

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Figure 3.3: Stages of soil formation

Factors of soil formation and development

Soil formation and the nature of formed soils is a function of parent material, climate, topography, living organisms and time. These are sometimes called factors of soil formation as described hereunder.

Parent material

Parent material is the starting point from which soil develops. Un-consolidated rocks or sediments and depositions carried by water, wind or gravity can be a good initial material for soil development. Weathered bedrock at one place can be a good source of parent material at another place, and most soils have been developed this way. Parent material contributes to characteristic features of a given soil. It influences both its physical and chemical properties. Course-textured soils are formed from weathered acidic igneous rocks and sandstones while fine-textured soils result from weathering of basic igneous rocks and sedimentary rocks. Soils that have been formed from sediments are classified based on the main force involved in their transportation. As a result, this gives rise to the following soil types:

(i) Colluvial: Formed when sediments are transported and deposited by gravity

(ii) Alluvial: Formed when sediments are transported and deposited by water

(iii) Glacial: Formed when sediments are transported and deposited by ice

(iv) Aeolian: Formed when sediments are transported and deposited by wind.

Climate

The type of soil and the rate at which it forms is largely influenced by climate. Temperature and rainfall are the key elements of climate. They determine

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the rate of physical and chemical weathering. Soil formation takes place more quickly in areas with frequent and large amounts of rainfall and vice versa. Temperature affects the rate of chemical reactions. For example, it is well established that, with every 10°C increase in temperature, the rate of a given chemical reaction is doubled. Thus, the rate of microbial activities responsible for the decomposition of organic residues and other chemical reactions is higher in warmer areas and low in colder areas. This is why you may find a lot of undecomposed leaves on the top soil surface in cold areas and fewer in warmer areas. Both temperature and rainfall are influenced by altitude. Generally, high-altitude areas receive higher amount of rainfall and are colder than low-altitude areas.

Topography/ relief

Relief features of an area are described by its slope, elevation and the way they are oriented or exposed. These features influence the temperature and rainfall regimes of that particular area. Thus, it also influences soil formation processes and hence the type of soil formed. Relief also influences the breaking down and transportation of eroded materials (Figure 3.4 (a)). It also influences air and water movement. Areas characterized by steep slopes usually have young and not well-developed soil profiles because weathered particles are constantly carried away and deposited elsewhere. Also, water percolation is limited as these places are associated with runoff (Figure 3.4 (b)).

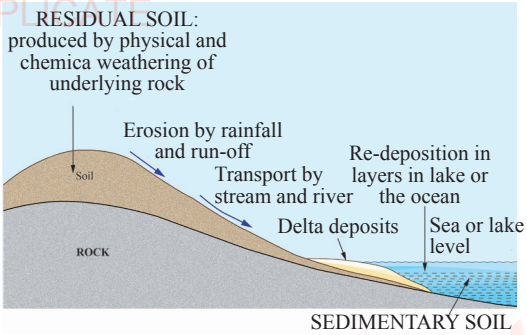

Figure 3.4 (a): Breakdown and transportation of eroded materials

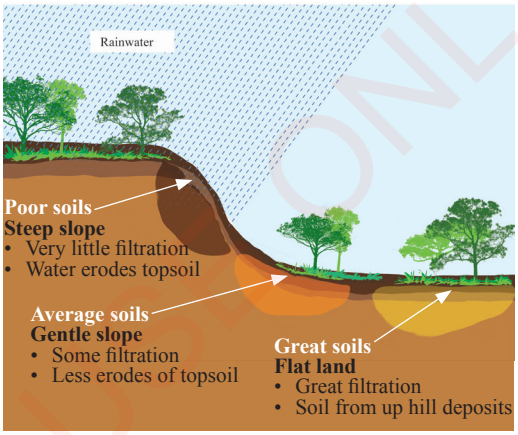

Figure 3.4 (b): Topographical features that influence soil formation

Living organisms

Living organisms are important facilitators of biological weathering. They contribute to soil formation either physically through their movement or chemically through the release of chemical substances in the soil. Dead organisms recycle back the nutrients held in their bodies to the soil. Plants, micro-organisms and animals contribute to soil formation. Humus, produced as a result of the decomposition of organic matter, imparts dark colour to the soil and increases its structural stability. Vegetation cover influences the amount and nature of organic matter added to the soil. It also influences water infiltration rate and erosion extent. The mixing of

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soil components is also influenced by the movement of relatively large soil organisms. Human activities such as cultivation mining, construction and the addition of organic matter or mineral fertilisers, also have an impact on soil formation. They may facilitate the breakdown of parent materials, mixing of soil constituents and addition or removal of some mineral matter. Plant roots from larger trees may facilitate weathering by causing cracking of rocks as they grow.

Time

Soil maturity is determined by time factor. The time taken for the soil to mature, is influenced by climate, nature of parent material, organisms and topographical features. In a situation where you find parent material with particles resistant to weathering exposed in area receiving little amount and/or less frequent rainfall, and located on hilly colder areas, this indicate that it takes long time for a soil to mature in such situation. A matured soil is physically and chemically stable. The composition of its soil layers does not change considerably with response to environmental changes. Soil development can take several thousand years in less favourable conditions but it can be less to several years under ideal conditions. A matured soil is the one with fully developed horizons.

Activity 3.1

Visit different places nearby the school compound and take note of weathering indicators/ activities and related factors of soil formation. What is your view about:

(a) Soils formed on the low land area compared to that on the hilly side;

(b) The rate of weathering in that place concerning the amount and frequencies of rainfall;

(c) The population and activities of soil organisms of that place about its average annual temperature;

(d) The soil type of an area in relation to the parent material in the area;

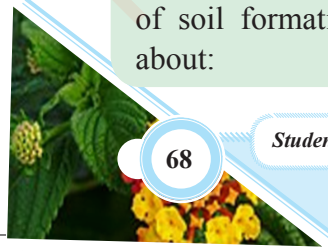
(e) The dominant soil colour and its implication to agricultural production;

(f) From an area where depositions occur after rainfall or where you can see exposed rocks collect and sort out the pieces as either biotite or muscovite. Propose possible mineralogical composition of the soil based on the type of fragments observed; then

(g) Make a summary of the lesson gained from this activity.

Identification of soil horizons

Horizons are simply layers of soils arranged together one on top of the other. The arrangement of soil horizons from the soil surface to the bedrock makes up a soil profile. Generally, soil horizons are grouped as organic horizons denoted by the letter O; and mineral horizons denoted by letters A, B, and C. Different soil profiles will have a different number of soil horizons depending on their age. Each horizon has its distinct physical, chemical and biological properties. 'O' horizon is the zone of organic matter accumulation. It



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is usually dark-coloured, with a diverse and large number of living organisms. 'A' horizon is a mineral zone just below the 'O' horizon and is characterized by intense leaching. It contains much less organic matter. In addition, 'B' horizon is the zone of accumulation or illuviation. Its contents may come from the washing of the surface layers or from within. Horizon 'A' and 'B' are collectively called solum. They are developed by soil formation processes. The 'C' horizon is the zone of unconsolidated materials under the entire profile. It is often less weathered than 'O' and 'A' horizons, and not yet subjected to horizon differentiation. Below these layers lies the bed rock, the consolidated earth component by which over time it provides the soil parent materials. Matured soils contain fully developed and stable horizons. For agricultural purposes, soil horizons of interest are those within the root zone (0 – 30 cm). Figure 3.5 (a) shows a hypothetical soil profile and Figure 3.5 (b) is an actual soil profile from the field.

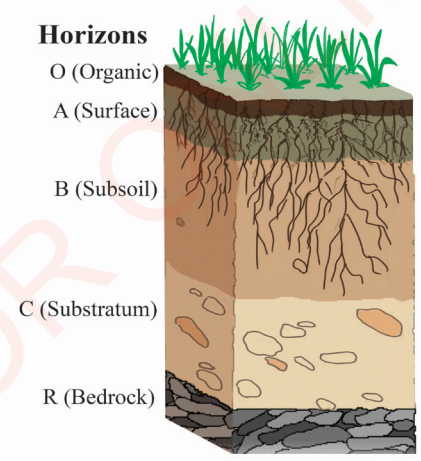

Figure 3.5 (a): Hypothetical soil profile

Figure 3.5 (b): Actual field soil profile

The relationship between soil profile and soil management practices

Soil properties are generally a reflection of soil profile. Physical properties of soil are reflected from physical, chemical and biological properties of the soil profile. Thus, knowing the properties of the soil profile helps to understand how to properly manage soil so as to maintain or improve its productivity. Soil management is an important practice to ensure that soil is sustainably used.

The important agricultural properties in a soil profile are; texture, structure, consistency, porosity, presence of living organisms, pH and mineralogical composition. Top soil (0-20 cm) of the profile represents an important layer for the growth of most field crops. Sub-soil layers, are also important as they reflect soil water movements and stability of the surface area. A highly compacted subsoil in the profile will result in water logging conditions and poor aeration as well as limited root penetration for deep-rooted crops. This can be improved by physical manipulation of the soil through deep tillage. The top layers of the soil profile

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should contain adequate organic matter as well as a sufficient number of active soil organisms. A limited amount of any of these will compromise its suitability for agricultural purposes. For example, soil with non-active soil organisms will take a long time to decompose organic matter. Soils with less amount of organic matter will have poor or limited microbial activities as they will have nothing to feed on.

Continuous application of organic matter in the soil is one of the management practices recommended for keeping the soil in good biological condition. Very loose top soil in a given profile increases leaching of important nutrients to the subsoils rendering it less fertile. Very loose top soil is also responsible for poor soil water holding capacity. Washing away of basic cations either by leaching or erosion can also occur, causing an acidic condition which is not a favourable condition for most agronomic crops. Management practices such as mulching, cover cropping, and application of organic matter are recommended to address such challenges.

Activity 3.2

In a group, visit any nearby pits, excavations, or road cuts and then, perform the following tasks:

(a) Observe soil profiles and identify important soil horizons within each of the profiles;

(b) Draw a typical soil profile;

(c) Relate the observed features of the soil profile vegetation or plant growth and soil management practices; and

(d) Write a report and present in class for discussion.

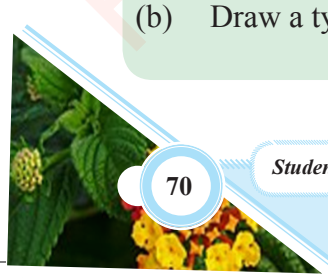
Exercise 3.1

1. Explain the concepts of soil as used in agriculture.
2. Describe the weathering process.
3. Describe roles of the soil forming factors.
4. Draw and label the parts of the soil profile, indicate all important soil horizons.
5. Explain the differences between ‘O’ and ‘C’ horizons.

Soil physics

Soil physics is a branch of soil science that deals with the physical properties of soil which have a direct influence on soil, which in turn influences crop production. Soil physical properties include soil texture, structure, colour, bulk density, porosity, and consistency. Some of these properties can be manipulated by various management practices to ensure improved productivity.

Physical properties of soil, are soil features which can be described in physical terms. These properties, are largely derived from parent material (weathered bed rock or sediments), and



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influence of soil forming factors. They determine the ability of the soil to retain moisture, allow water and air movement, retain and release plant nutrients and root penetration. These properties also determine population and activities of living organisms in the soil. Chemical reactions and transformations are also influenced by physical properties.

Soil texture

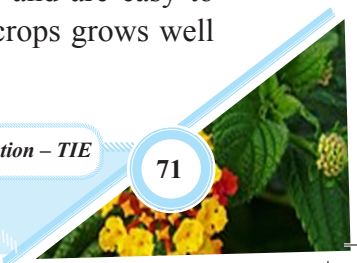
Soil texture refers to the relative proportions of sand, clay and silt particles presented as weight percentage in a given soil sample. Soil texture represents the feel of the soil, it is a very stable characteristic. Soil texture is interrelated with soil fertility in the long term. It is associated with soil porosity, aeration, drainage, permeability and cation exchange capacity. Therefore, soil texture influences soil biophysical properties.

Soil can either be sandy, loamy, or clay depending on which soil separates dominates. Sand particles are the largest (2.0 to 0.05 mm) in diameter; Silt particles are smaller, (0.05 to 0.002 mm); clay particles are the smallest less than 0.002 mm in size. Thus, clayey soils have the highest proportion of fine clay particles that gives a plastic feel. Sandy soils have a course feel and are dominated by sandy soil separates. Loam soils have equal proportions of sand and silt particles with a small percentage of sand particles. An ideal example of loam soil is one containing 40 % sand, 40 % silt, and 20 % clay particles.

Sandy soils are characterized by having bigger pore spaces which facilitate good aeration, root penetration and expansion and easy workability. However, they have poor water retention capacity and are characterized by low fertility status in terms of soil mineral nutrient composition. Nevertheless, root crops like potatoes, cassava and groundnuts can perform better in these soils if properly managed. The addition of organic matter, use of crop cover, green manuring and other related management practices can help to improve the nutritional composition and water-holding capacity of sandy soils.

Clayey soils are composed of fine textured particles which are tightly packed together. They are good nutrient retainers due to the colloidal nature of the particles. These soils encourage water lodging conditions due to poor drainage. Aeration and root penetration are also limited in clayey soils. Growing crops that require ample root or pod expansion in these soils might be challenging. Workability in this soil is also compromised as they are sticky when wet and very hard and forms cracks when dry. Besides, crops like lowland rice perform better in these soils.

Loamy soils are much better than sandy and clayey soils. They are loose and friable and have a good combination of sand, clay and silt particles. Also, they have a balanced nutritional composition, good water holding capacity, drainage and aeration properties and are easy to work on. A variety of crops grows well under loamy soils.



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Activity 3.3

In a group or individually perform the following tasks:

(a) Collect sandy, clayey and loamy soil samples from around your school environment;

(b) Put them in containers that are perforated at the bottom, and place them in a collecting dish or plate;

(c) Add equal amount of water in each slowly and take note of the speed with which water moves down the soil;

(d) Measure the amount of filtrate collected from the collecting dish for each soil type; then,

(e) Make a summary of what you learnt from this activity by considering soil textural properties for all samples in relation to water retention, and water movement. Give the managerial implication for each soil type in crop production.

Determination of soil texture and textural classes

Soil texture can be determined both in the field and in the laboratory. It can also be determined using modern computerised techniques which involve compiling sand, clay and silt map according to Global standards such as Global Soil Map (GSM) or Soil Grids. For this method, both soil separate data (map) and textural classes (map) are used as inputs for crop, meteorological or hydrological models. Therefore, to determine the soil textural class, first, we need to perform particle size. The procedure is called particle size analysis. This is the procedure of determining the percentage proportions of soil particles. This is done in two phases namely dispersion of the soil and separation of particles into size groups. In the dispersion phase, the soil is treated to remove organic matter and salts. Normally, a sample from the topsoil of a depth ranging from 0-30 is used for analysis. Samples can be taken at once or by considering three consecutive depths, that is 0–5 cm, 5–15 cm, and 15–30 cm, according to standard specifications. Then, the results obtained are used to determine the textural class of a given soil.

The determination of soil textural classes, is done by the use of a soil textural triangle (Figure 3.6). It has three sides representing the percentage of sand, silt and clay. Twelve different textural classes are placed inside with boundaries between them. Each textural class is comprised of various combinations of sand, clay, and silt. While reading, where the three lines intersect represent, the textural class of the soil. Separates that are found in large amounts than others will give its soil textural class name. For example, when soil is having more than 70 % or more sand separates will form sand, while those containing more than 35 % clay separates will form clays such as sandy clay, silty clay and clay.

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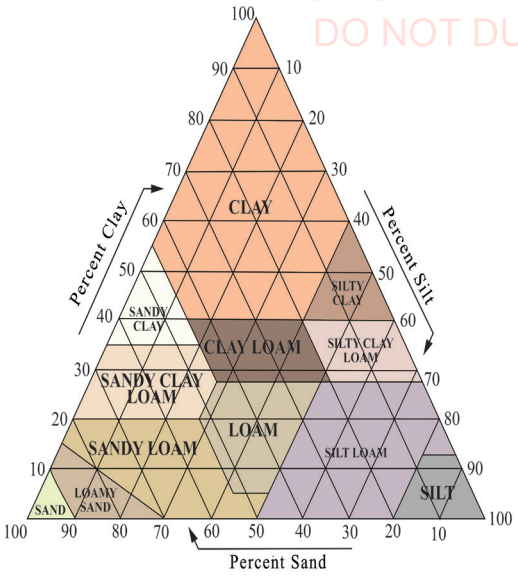

Figure 3.6: Soil textural triangle

Procedure on how to use the soil textural triangle

When using the soil textural triangle, the following steps should be considered:

Step 1: Point the value that represents the percentage of sand in the soil sample, at the base of a textural triangle. Whenever you read, follow its line upwards.

Step 2: Locate the number that represents the percentage of silt in the soil at the right side of the texture triangle. Follow the line downwards to the point where it meets the sand line. You can do it with assistance of a ruler or your finger to avoid confusion. Always remember the sand lines move upwards and the silt lines move downwards.

Step 3: Read the percentage of clay horizontally. Or follow the line emerging from the percentage sand horizontally until where it intersects the other two lines representing sand and silt. At the point where the three lines intersect will represent the textural class of that sample. For example, a soil sample that is 40 % sand, 40 % silt and 20 % clay is a loam, whereas a sample that is 10 % sand, 45 % silt and 45 % clay is a silty clay.

Activity 3.4 (a)

In a group under guidance of the teacher/laboratory expert performs the following:

1. Collect a representative soil sample around the school compound. Mix the soil thoroughly and divide it into-sub-portions to work with;
2. Sieve the working portion of soil through a 2 mm screen. Pour the sieved soil into a clear measuring cylinder. Add hydrogen peroxide to oxidise organic matter. Hydrogen peroxide is added drop wise until when the foams are no longer seen/forming;
3. Remove other cementing materials such as calcium carbonate and oxides of iron and aluminium by acid treatment. The amount of acid to be added will also depend on the completion of forms;
4. Add sodium oxalate or sodium hexametaphosphate and shake well;
5. Determine the proportion of various separates in the dispersed materials by either the Pipette method or Hydrometer method;

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6. Use the data obtained to determine the soil textural class using the soil textural triangle; then,

7. Suggest appropriate management practices for enhancing and sustaining the productivity of each unit from which the representative sample was collected.

Activity 3.4 (b)

In a group under guidance of the teacher/laboratory expert, perform the following:

Step 1: Collect soil sample, spread it evenly over clean paper or any other convenient material and let it dry.

Step 2: Pick out all gravel, rocks, pieces of wood or other debris and grind the remaining soil pieces so that no larger pieces remain and the soil resembles a fine, uniform powder.

Step 3: Add about one-fourth soil to a clear glass jar or measuring cylinder, add water to fill up the remaining portion and add one (1) teaspoon of table salt or non-foaming dishwasher detergent.

Step 4: Shake the jar/ cylinder well, with a tight-fitting lid on, for 10 to 15 minutes. Set the jar in a place where it can sit undisturbed and start a timer or stopwatch immediately.

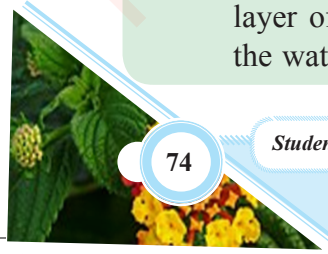
Step 5: Mark, on the side of the jar, the layer of sand that settles out of the water after a minute, the silt layer formed on top of sand after two to four hours and a clay layer formed after 48 hours (2 days) or more when water is clear.

Step 6: Calculate the percentage of each type of particle in the soil sample. Measure the thickness of each layer and the entire sample. Divide the thickness of each layer by the total thickness to determine the percentage of each. Use these percentages and the soil textural triangle to determine the textural class of each soil.

Soil structure

The aggregation of soil separates into definite shapes is termed as soil structure. Soil separates are bonded to one another by the assistance of cementing agents like humus, clay, root secretions microbial by-products and adsorbed cations. A cluster of soil separates is called aggregates. One small aggregate (a soil ped) can join with another ped or with other separates to form a bigger unit called structure. Shapes and arrangement of peds gives soil structural types. There are four types of soil structure namely plate-like, prism-like, block-like and sphere-like structure. Based on their degree of stability soil structure, can also be categorized into four structural grades namely structure less, weak, moderate and strong structure grades.

In many soils the process of aggregate formation is dominated by biological interactions. The roles of soil biota become increasingly important with successive increase in the size



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of aggregates, compared to early stage where particles are joined together by the charges of particles themselves. Very small aggregates are joined into secondary structural units (aggregates held together) by microbial products (polysaccharides) and larger aggregates are held together by fungal hyphae and plant roots and their exudates.

Soil porosity and soil density

Soil porosity is a physical property of soil which represents percentage of pore spaces in the soil. It is a measure of the soil volume not occupied by solid particles. Soil pores contain air and water at equal volumes under ideal soil conditions. More water than air, creates unfavourable environment for plant growth and performance of soil organisms. Soil porosity represents soil bulkiness. Bulky soils are compacted with small number of pore spaces and therefore, encourage runoff due to reduced infiltration and this makes their top layer be easily washed away. Larger soil fauna, earthworms, ants, cicadas, and many other macro-arthropods activities influence porosity by creating larger pores. Loose and porous soils have lower bulk densities than compact soils. Soils with sufficient organic matter also tends to have low bulk density.

Soil porosity

Soil porosity also known as percentage pore space of the soil, is the sum total of spaces not occupied by solid matter in the soil mass. It can simply be calculated from bulk density and particle density values by the following formula:

$$\% \text{ Pore space (Porosity)} = 100 - \left\{ \frac{\text{Bulk density}}{\text{Particle density}} \times 100 \right\}$$

Worked example 1

If the bulk density of the soil sample is 1.4 g/cm^3 and the weight of soil solid is 200g while the volume of soil solid is 90 cm^3. Calculate the soil porosity.

Solution

Bulk density = 1.4 g/cm^3
Weight of the soil solid =200 g
Volume of soil solid = 90 cm^3

$$\% \text{ Pore space (Porosity)} = 100 - \left\{ \frac{\text{Bulk density}}{\text{Particle density}} \times 100 \right\}$$

$$\text{Particle density} = \frac{\text{Weight of dry soil (soil solid)}}{\text{Volume of soil solid}}$$

$$= 200\text{g} / 90 \text{ cm}^3$$

$$= 2.2\text{g/ cm}^3$$

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$$\% \text{ Pore space (Porosity)} = 100 - \left\{\frac{1.4 \text{ g/cm}^3}{2.2 \text{ g/cm}^3} \times 100\right\}$$

Soil porosity = 100 – 63.64

% Pore space (Porosity) = 36.36%

Bulk density

This is the measure of the mass of a soil per given volume (i.e., g/cm^3), including solids and pore spaces. Bulk density is a commonly measured soil property by agriculturalists and engineers. High bulk density soils are soils with little pore space, so water infiltration is reduced, root penetration is inhibited, and aeration is restricted thus reducing agricultural productivity. Low bulk density soils are less compacted thus supporting good water movement, root penetration, soil aeration, microbial activities and general plant growth.

Bulk density is calculated by the formula:

$$\text{Bulk density} = \frac{\text{Weight of dry soil}}{\text{Total soil volume}}$$

Worked example 2

A soil sample was collected from the school garden. The weight of the soil sample was 250 g. Upon oven drying the weight dropped to 240 g. The volume of the soil was 200 cm^3. Calculate the bulk density.

Solution

Weight of the soil sample = 250 g

Weight of oven dry soil = 240 g

Volume of soil sample = 200 cm^3

Bulk density =?

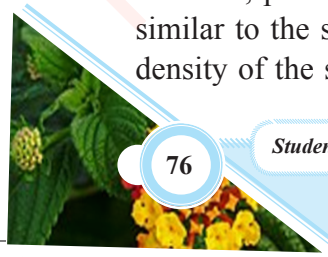
$$\text{Bulk density} = \frac{\text{Weight of dry soil}}{\text{Total soil volume}}$$

$$= \frac{240 \text{ g}}{200 \text{ cm}^3}$$

$$= 1.2 \text{ g/cm}^3$$

Particle density

Particle density is a measure of the mass of soil solids per given volume (g/cm^3); however, pore space is not included as it is with bulk density. Particle density is similar to the specific gravity of a solid and is not impacted by land use. Particle density of the soil is approximated as 2.65 g/cm^3, although this number may vary



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considerably if the soil sample has a high concentration of organic matter, which would lower particle density.

Particle density is calculated by the formula:

$$\text{Particle density (Pd)} = \frac{\text{Weigh of dry soil (Ms)}}{\text{Volume (V) of soil solid (volume of dry soil)}}$$

Where Ms = mass of dry soil, V = volume of soil solid (volume of dry soil)

Worked example 3

The weight of soil sample collected from school garden was 300 g. Upon oven drying the weight of the sample dropped to 250 g. If the volume of the soil sample was 180 cm^3 and the volume of the pore space was 30 cm^3, calculate particle density of the soil.

Solution

Weight of the soil sample = 300 g

Weight of oven dry soil = 250 g

Volume of soil sample = 180 cm^3

Volume of the pore space = 30 cm^3

Particle density =?

$$\text{Particle density} = \frac{\text{Weigh of dry soil}}{\text{Volume of soil solid}}$$

Volume of soil solid = Volume of soil sample – Volume of pore space

$$180\ cm^3 - 30\ cm^3 = 150\ cm^3$$

$$\text{Particle density} = \frac{250\ g}{150\ cm^3}$$

$$= 1.67\ g/cm^3$$

Activity 3.5

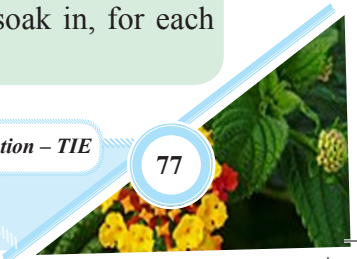
In a group or individually, under supervision of the teacher, perform the following tasks:

(a) Collect soil sample and fill them in two separate containers (that have holes underneath);

(b) Keep one of the soils in a container loose, while compact another one by pressing it several times using a heavy substance;

(c) Place the containers with soils on top of a collecting dish;

(d) Slowly pour in water. Record the time taken for water to soak in, for each container;



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(e) Collect the amount of water in the collecting dish and measure its volume; then,

(f) Make a summary of the lesson gained from this activity in relation to bulk density and water movement in the soil.

Soil consistence

Soil consistence is the degree to which a soil resists physical forces or pressure, like insertion of instruments or deformation when worked. It is a measure of how strongly soil particles are held to one another in making soil structure. Soil consistence is influenced by soil moisture status. Dry soils are more resistant to physical forces and may break into larger fragments or powder when subjected to pressure. Soil consistence of dry soil can either be loose, soft, slightly hard, very hard or extremely hard depending on its nature. Moist soil is not brittle and cannot produce powder when pressured. Fragments can be formed and united again when placed together. The consistency of moist soil is described as loose, very friable, firm, very firm or extremely firm.

When referring to wet soil, consistence is described as either non-sticky, slightly sticky, sticky or very sticky. Alternatively, can be described as non-plastic, slightly plastic, plastic and very plastic. Soil consistence influences farm operation, especially tillage.

Activity 3.6

Aim: To determine soil consistence

Requirement: Four different soil samples (labelled A, B C and D) two of them in dry and the other two in wet/ moist state

Procedure

(a) Using your thumb and fore finger, press dry samples and determine the soil consistence.

(b) Place the moist sample between your thumb and finger and apply pressure, then determine the consistence of the soil;

(c) Moisten the samples (each separately) and try to make some shapes and comment on whether are plastic, sticky or not. Give your opinion regarding the amount of clay and sand in the samples; finally,

(d) Summarise points of strength and weakness of each soil sample in relation to farming activities based on its consistence.

Soil colour

Soil colour is one of the soil physical properties that acts as an important diagnostic tool for soil description and classification. It is easily noticed and has an influence on soil temperature and can be a good indicator of soil productivity. White, red, brown, yellow, black and mottle (two or three colours in patches) are the common soil colours, however, brown, rust and grey are the most predominant. Organic matter content,

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mineralogical composition, aeration and weathering status influence soil colour. Organic matter (humus) makes the original soil colour dark. So, the soil can be dark brown or dark grey/ black. Mineralogical composition results in a range of soil colours. For example, red, brown, reddish-brown, brownish–yellow, or yellow colours are due to oxides of Iron II and Manganese III. Iron II oxide adds a greenish or bluish tingle. Some minerals may be dull grey in a reduced water-logged environment but become bright brown or yellow when they are oxidized. Under dry conditions, soils containing iron III oxide are red but turn yellow when hydrated.

Soil colour determination is done on moist samples to ensure correctness and uniformity. It is done with the aid of the Munsell colour chart. The chart is made of three components namely hue, value and chroma. Hue shows the dominant colour of an object, value shows the degree of lightness or darkness of a specific colour and chroma shows the purity of the observed colour.

Soil colour is important because it can help to tell the productive potential of the soil and the age of the soil profile. It can also influence soil temperature and hence its biological and chemical properties. A light-coloured soil implies that the leaching of Iron along with some other important minerals has occurred. It may also imply that it has been developed from parent materials like quartz, which is known to have no nutritional value or has little amount of organic component. Humus is black or dark brown therefore, when present in the soil, it imparts the soil with these colours. Mottled colours in soils indicate the occurrence of oxidation and reduction reactions which occurs at the time of water logging conditions and when the soil is re-aerated after the water has evaporated.

Activity 3.7

Aim: To determine soil colour by using Munsell colour chart.

Requirements: Soil samples and Munsell colour charts

Procedures

(a) Collect moist samples and break them to expose fresh surface. The pieces will look better if they fit into chips of a colour chart;

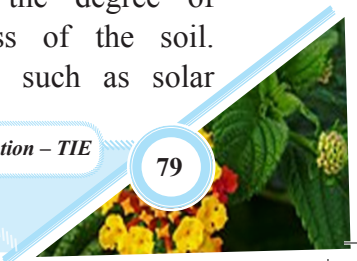
(b) Place a sliced soil sample into the chip with its respective colour of its resemblance or a visual match and assign its corresponding Munsell notation. Example a brown soil can be noted as 10YR 5/3 where 10YR represents its hue (the colour), 5 represent value (lightness or darkness of the colour) and 3 represents chroma (the intensity of the colour);

(c) Repeat several different samples and share your readings with others; then

(d) Summarise your observations and share it in class.

Soil temperature

Soil temperature is the degree of warmness or coldness of the soil. Environmental factors such as solar



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radiation, rainfall and evaporation as well as soil factors, influence soil temperature. Normally, moist soils have cooler temperatures than dry ones.

When evaporation occurs, soil heat is also lost with water vapour. Rain and irrigation water is important as it supplies the soil with water which helps in its temperature regulation. Soil temperature is very important as it influences both soil chemical and biological processes. Seed germination and general plant performance depend on soil temperature. Soil temperature can be measured by soil thermometers. Agronomic practices such as the use of mulches, irrigation and proper drainage system help to manage soil temperature.

Soil water

Soil water refers to the amount of moisture which is naturally contained in the soil. In soil, water is held in pore spaces (macro and micro spaces). Water that is held in large pores is easily drained down to the water table and is not readily available for plants. But water held in small pores is available for plant uptake although when held very tightly to soil particles is not available for plant uptake. When all pore spaces in the soil are occupied by water, the soil is said to be saturated. Under this condition soil air is limited and it impairs soil life.

Soil water is involved in physical, chemical and biological activities in the soil. It is a solvent and carrier for plant nutrients in the soil. Irrigation and rainfall water has to enter the soil mass for it to become soil water. The down ward movement of water in the soil is known as infiltration. Water permeability is the easiness with which water moves within the soil. The movement of water through a column of soil is termed percolation. Permeability, percolation and infiltration are highly influenced by soil porosity. Various methods ranging from electronic equipment to direct methods such as the gravimetric method are used in the determination of soil moisture. The gravimetric method is old but still applicable; it involves collecting a soil sample, weighing the sample before and after drying it and calculating its original moisture content.

Determination of soil moisture using gravimetric method

Results for gravimetric water content are usually represented as a percentage of soil water on a dry mass basis. The following procedure is followed:

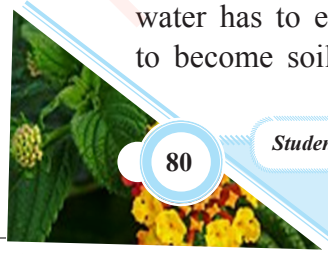
(a) Collect soil sample and mix it thoroughly to get a representative soil sample;

(b) Place empty soil moisture in a tin with its lid on a weighing balance and weigh it. Record its weight and tare it to zero. Place 40-50 g of soil into the tared soil moisture tin. Record the number of the tin and the weight of fresh moisture;

(c) Remove the lid, and place the tin with the fresh soil in the oven for 24 hours at 105 ºC.

(d) Remove the dried soil from the oven and cover the tin with a lid. Allow cooling for 15 minutes;

(e) Place the closed tin with the dry



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soil on a weighing balance and record the total weight. To get the weight of soil alone deduct the weight of tin and its lid; then,

(f) Calculate the soil moisture by using the following formula:

$$MC = \frac{W_1 - W_2}{W_2} \times 100$$

Where:

MC = Soil moisture content

W_1 = Weight of fresh soil

W_2 = Weight of dry soil

Soil management in relation to soil physical properties

For proper soil management, it is important to point out farming activities that may disturb soil structure and those which may improve soil structure as outlined hereunder:

Practices that disturb the soil structure

(a) Deep ploughing: Using farm implements that go beyond the root zone, may reduce soil structure stability by disturbing the subsoil horizon which acts as a soil profile framework and hence renders it less stable to agents of erosion;

(b) Cultivating using heavy machinery leads to soil compaction, which reduces pore spaces and subject soil to reduced biological and chemical activities. Reduced pore spaces, limits air and water movement, and root penetration;

(c) Continuous cultivation: This reduces the ability of the soil to regenerate natural cover and involves the reduction of top soil nutrients, and organic matter if replacement is not done properly;

(d) Heavy irrigation: This causes the leaching of important mineral nutrients including basic cations from top soil, which may cause soil acidity;

(e) Continuous application of acid-forming mineral fertilisers: This practice creates an unfavourable environment for soil organisms which help in soil structure improvement as they decompose soil organic matter;

(f) Uncontrolled burning: This practice also destroys soil organisms; and

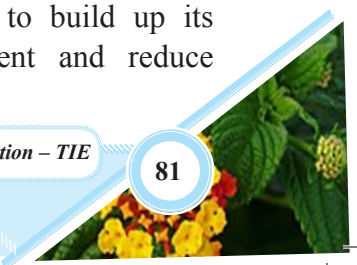
(g) Overgrazing/overstocking: Keeping a large number of animals exceeding the area carrying capacity (overstocking): This practice may leave the soil bare and loose, making it more prone to soil erosion agents.

Practices that improve soil structure and porosity

(a) Reduced tillage or no-till farming method: These methods help to minimize soil disturbance and hence reduce soil structure distortion;

(b) Cultivating using light implements that reduces soil compaction;

(c) Crop rotation and fallowing: These help to give the soil a considerable amount of time to build up its organic component and reduce



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excessive mining of soil nutrients by rotating shallow roots with deep-rooted crops and heavy feeders with light feeder crops. The inclusion of leguminous crops in the rotation helps to fix nitrogen and stimulate microbial activities;

(d) Use of crop cover: This helps to reduce direct impacts due to erosion agents. It reduces water runoff and improves soil water infiltration. It also helps to regulate soil temperature;

(e) Addition of soil organic amendments: This improves both physical, chemical and biological properties of the soil;

(f) Avoidance of continuous and heavy application of mineral fertilisers;

(g) Practice controlled burning and bush clearance; and

(h) Avoid mono-cropping.

Activity 3.8

In a group, perform the following field work:

(a) Select two field plots around your school with different soil texture, one should be sandy and another be a different type;

(b) Plant similar horticultural crops that take short time to mature e.g., *Amaranthus spp;*

(c) Take note on the:

  (i) easiness of cultivation;

  (ii) frequency of watering;

  (iii) growth performance, like plant height over time and leaf colour; then,

(d) Write a brief summary of your observation and share it in class

Activity 3.9

In a group or individually under supervision of the teacher, perform the following tasks:

(a) Collect soil samples and fill them into two separate containers A and B (use perforated bucket or bag);

(b) Keep one of the loose soil sample in a container, and compact another soil sample in another container by pressing it several times using a heavy substance;

(c) Apply equal amount of water to both containers and sow four seeds of the same crop in each container;

(d) Observe the containers for seven or maximum of ten days;

(e) Count number of seeds emerging from each pot;

(f) Count number of days taken for seeds to emerge; then,

(g) Summarise your observations and share it in class.

Exercise 3.2

1. Describe the physical properties of soils.

2. Account for importance of soil structure, texture and porosity.

3. Describe how the knowledge of physical properties of soil can be used to manage a field which is:

  (a) sandy in nature;

  (b) clayey soil in nature.

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4. The soil sample with a weight of 500 g and a volume of 320 cm^3 was collected and oven dried to a constant weight of 300g. If the volume of the soil solid is 200 cm^3 calculate:
   (a) the bulk density;
   (b) particle density; and
   (c) porosity of this soil.

Soil chemistry

Soil chemistry is a branch of soil science that deals with studying soil chemical properties that have both direct and indirect influences on plant growth and development. Soil chemical properties are reflections of the interaction of various chemical constituents of soil particles and in the soil solution. Chemical transformations are the ones that determine soil chemical properties. Soil pH and cation exchange capacity (CEC) are examples of soil chemical properties. The properties, largely influence nutrient availability to plants, populations and activities of micro-organisms and nutrient absorption by plant roots.

Soil chemical and mineralogical composition

The inorganic or mineral component of the soil carries around 40-45% of all soil components. It is the largest component of the soil. The mineral part of the soil is made up of different types of minerals. These minerals are categorised into primary minerals and secondary minerals. Primary minerals come directly from rocks while secondary minerals are derived from the chemical alteration of primary minerals. Mineral elements like potassium (K), calcium (Ca), sodium (Na) magnesium (Mg), iron (Fe), sulphur (S), nickel (Ni), cobalt (Co), cupper (Cu), manganese (Mn), zinc (Zn), and molybdenum (Mo), are released after weathering of primary minerals. These are the ones that are taken by plants as nutrients.

Weathering processes and soil forming factors are important in the determination of soil chemical and mineralogical composition. About 75% of the soil is composed of silicon, oxygen, iron and aluminium. The next in abundance are potassium, calcium, magnesium, hydrogen, carbon, nitrogen, phosphorus and sulphur. The rest is small amounts of sodium, manganese, titanium and chlorine and traces of boron, zinc, molybdenum, barium, zirconium, copper, iodine, cobalt, chromium, strontium and other elements (Figure 3.7).

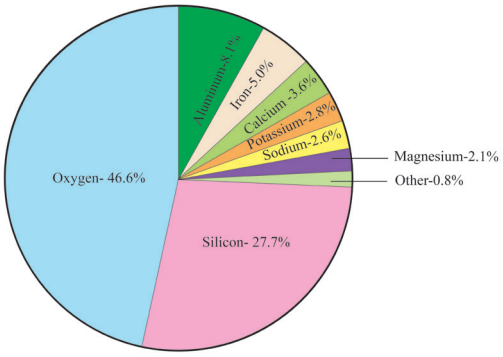

Figure 3.7: Mineralogical composition of the earth's crust.

Primary minerals

Primary minerals are minerals formed at elevated temperatures from cooling

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magma during the original solidification of rock or metamorphism. These are usually derived from igneous and metamorphic rocks. They are prominent in the sand and silt fractions of soils and contain many nutrient elements which are required by plants. Silicate minerals are rock-forming minerals made up of silicate groups. They are the largest and most important class of minerals making up approximately 90% of the earth's crust. They contain several nutrients that plants require for growth and development and all have the same basic unit silicon-oxygen tetrahedron structure. The structure is composed of four oxygen atoms with a smaller silicon atom (SiO_4) positioned in the space between them (Figure 3.8).

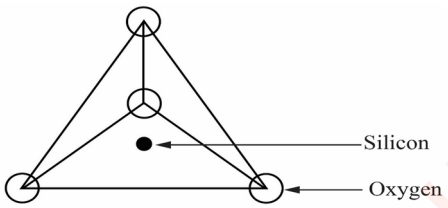

Figure 3.8: The basic structure of silicate minerals (silicon-oxygen tetrahedron structure)

Silicate minerals include minerals such as Quartz, Feldspar, Mica, Amphibole, Pyroxene, Olivine, Hornblende and a great variety of clay minerals. The minerals such as K-feldspars (orthoclase, sanidine, and microcline), micas (Muscovite, Biotite, and Phlogopite) and clay-size micas (illite) are widely distributed in most soil types, except in highly weathered sandy soils. Silicate minerals are of great importance in agriculture, as they release many important mineral nutrients after weathering. For example, Hornblende can include sodium, potassium, calcium, magnesium, iron, aluminium, silicon, oxygen, fluorine, and hydroxyl ion (OH^-). Sand and silt fractions that are not highly weathered are mostly dominated by Quartz and Feldspars. These minerals act as an important reservoir for K, where over 90% of K in soils exists in the structure of these minerals. Significant amounts of Ca, Na, and Si and smaller amounts of Cu and Mn are also present in the feldspars. Micas and illite are the most important source of K in many soils, and they also contain Mg, Fe, Ca, Na, Si, and several micronutrients. Amphiboles and pyroxenes are vital reservoirs of Mg, Fe, Ca, Si, and most of the micronutrients. Carbonate minerals, including those derived from soil parent material and those formed in the soil through pedogenic processes, serve as both a source and a sink for Ca and Mg in soils.

Secondary minerals

These are minerals which are formed at low-temperature reactions during weathering of primary minerals in the aqueous environment on the earth's surface. They are predominantly found in clay, and in some cases in silt fractions, and largely determine the chemical properties and general fertility status of most soils. These minerals serve as sources of nutrients themselves, though they can also precipitate or adsorb essential nutrient elements, making them not readily available for plant uptake. In many cases, they serve as important reservoirs where nutrients

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are held strongly enough to prevent leaching and weakly enough to allow plants to absorb them to meet their nutritional needs. There are two major types of secondary minerals which are non-silicate clays (Hydrous oxide clays) and silicate clays. Both are chemically active and are responsible for many chemical properties of soils. These are further described hereunder:

(a) Non-silicate clays (Hydrous oxide clays)

Non-silicate clays are hydrous oxides of iron and aluminium which are responsible for the reddish or yellowish colour in tropical and subtropical soils. Its general formula is represented by $Fe_2O_3.n\ H_2O$ and $A1_2O_3\ nH_2O$. The electrostatic, adsorptive capacity and plasticity properties of non-silicate clays are less obvious than that of silicate clays. Most oxides act as cementing agents in the maintenance of soil aggregates in subtropical and tropical soils.

Non-silicate clays are comprised of modified octahedral in Fe^{3+} or Al^{3+} sheets. They have neither tetrahedral sheets nor silicon in their structures. These clays have dominantly positive charges. In this group oxides of Al^{3+} and Fe^{3+} such as [Al $(OH)_3$], (FeOOH), and (Fe_2O_3) are common. Gibbsite [Al $(OH)_3$], is common in highly weathered soils like Oxisols and Ultisols. Oxides of Al^{3+} and Fe^{3+} clays are found in many soils but in much greater quantities in old soils of tropical and sub-tropical regions such as Acrisols, Alisols, Lixisols, Luvisols, and Nitisols.

(b) Silicate clays

The dominant secondary minerals in the soils are silicate clays. Silicate clays, also called layered silicates or phyllosilicates where 'phyllo' means sheet, are electro-microscopic clay minerals, with a diameter of less than 2 microns (<0.002 mm). The framework of these minerals which is also called crystal structure or lattice is made up of two basic structural units named silica tetrahedron and alumina octahedron. The silica tetrahedron structure is composed of four oxygen atoms with a smaller silicon atom positioned in the space between them. The alumina octahedron consists of one aluminium atom surrounded by six hydroxyl ions to form an octahedron structure. This structure can be practically seen by placing four balls in a square fashion and one on the top and the other at the bottom of the square arrangement. Aluminium is positioned in the centre interspace. The basic structural units of silica tetrahedron and alumina octahedron are shown in Figure 3.9 (a) and (b).

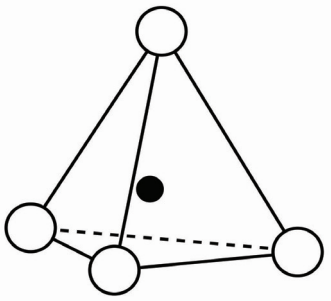

Figure 3.9 (a): Silica tetrahedron structure

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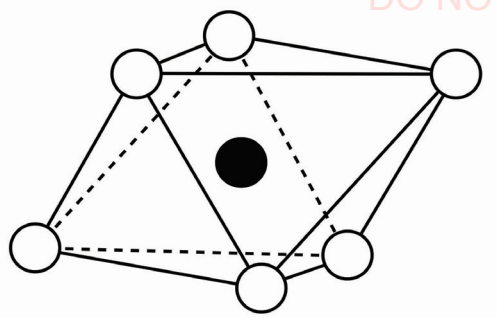
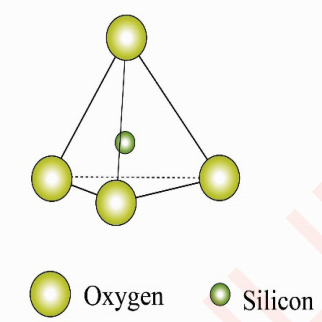


Figure 3.9 (b): Alumina octahedron structure

Two or more silica tetrahedral joined together through chemical bonds to form the silica tetrahedral sheet or layer which may be extended horizontally or laterally. The octahedral are joined by chemical bonding along their edges to form a triangular array of octahedral sheet. The tetrahedral and octahedral structures of silicate clays and their respective sheets are shown in Figure 3.10 (a) and (b).



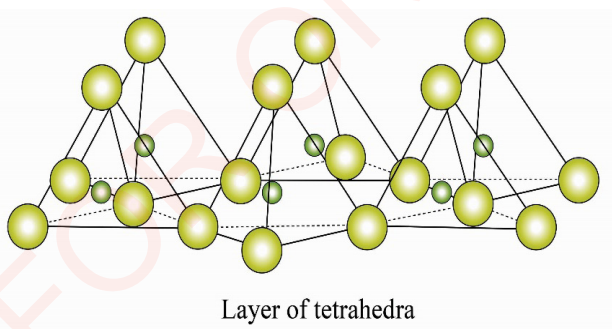
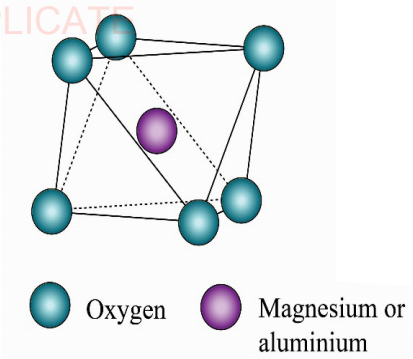


Figure 3.10 (a): The tetrahedral structures silicate clays



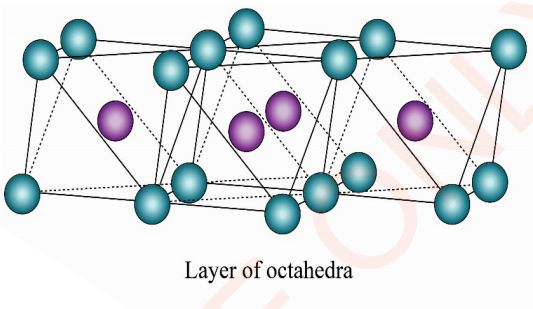


Figure 3.10 (b): octahedral structures and their respective silicate sheets

Classification of the phyllosilicate minerals

Phyllosilicates minerals can be classified based on the following criteria:

(a) **Composition of the unit structures:** Based on the number and arrangement of silica and alumina octahedral sheets available in the crystal structure. Based on this criterion, phyllosilicates are divided into three main classes: 1:1, 2:1 and 2:1:1 phyllosilicate. Phyllosilicates with one silica tetrahedral sheet bonded to one octahedral sheet in their crystal structure are called 1:1 phyllosilicate. Examples of these minerals are kaolinite and halloysite. The structure of these minerals is shown in Figure 3.11.

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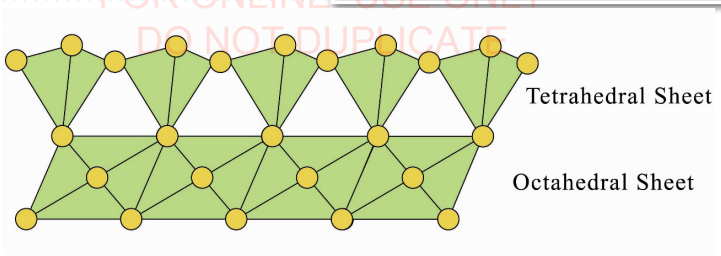

Figure 3.11: Structure of 1:1 Phyllosilicates

Phyllosilicates with one octahedral sheet 'sandwiched' between the two tetrahedral sheets are called 2:1 phyllosilicate. Examples of these minerals are talc, vermiculite, smectite and illite. The structure of these minerals is shown in Figure 3.12.

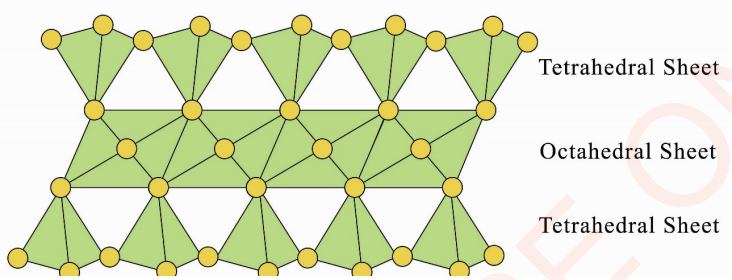

Figure 3.12: Structure of 2:1 Phyllosilicates

Phyllosilicates which consist of two silica tetrahedral sheets and one octahedral sheet together with a magnesium hydroxide sheet (brucite layer) in the interlayer space between 2:1 sheet are called 2:1:1 phyllosilicate for example, chlorite. The structure of this mineral is shown in Figure 3.13.

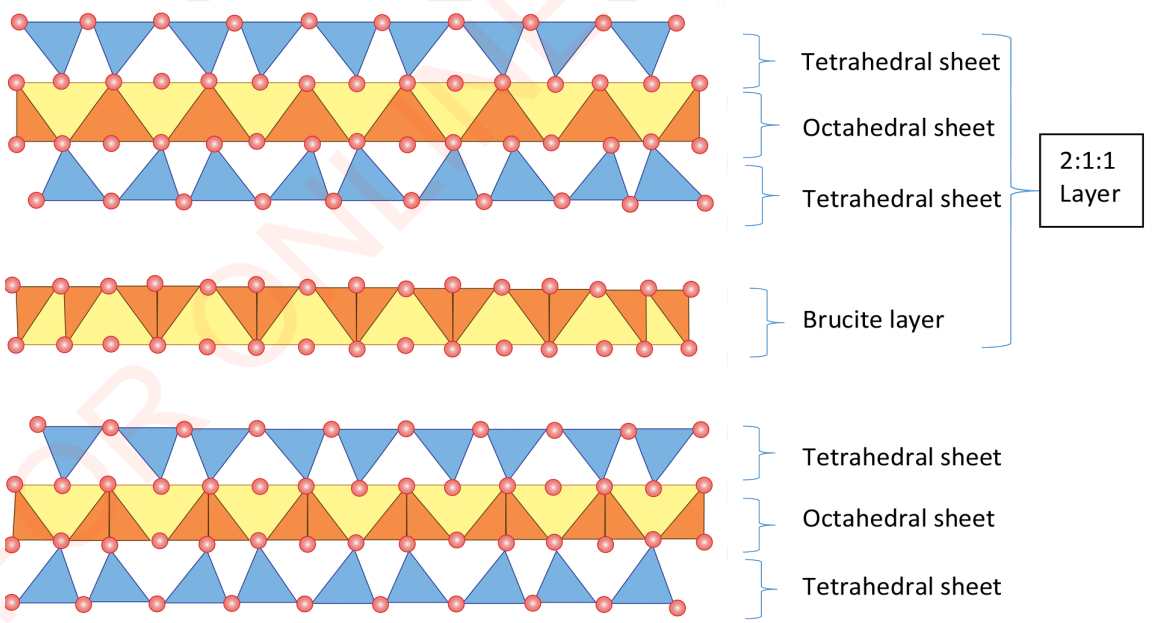

Figure 3.13 The structure of 2:1:1 Phyllosilicate

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(b) **Dominant octahedral cations:** Based on the dominant octahedral cations, phyllosilicates are classified based on the dominant cations in either octahedral or tetrahedral structure following isomorphic substitution of these cations in the mineral structure. Isomorphic substitution is the replacement of one atom by another of similar size in a crystal lattice without disrupting or changing the crystal structure of the mineral. This process tends to occur in minerals, particularly in octahedral or tetrahedral sheets. Fe3+, Fe^{2+}, and Mg^{2+} can substitute Al^{3+} in the octahedral sheet. Phyllosilicates with trivalent cations (Al^{3+} or Fe^{3+}) as the main octahedral cations are called di-octahedral, whereas those with divalent cations (Mg^{2+} or Fe^{2+}) are called tri-octahedral.

Differences between 1:1 and 2:1 phyllosilicate mineral

The following are the difference between 1:1 and 2:1 phyllosilicate minerals.

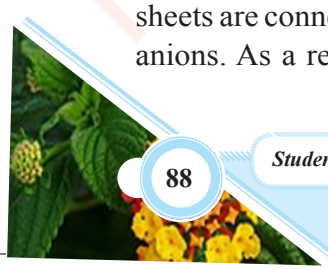
1:1 phyllosilicate minerals

The layers of 1:1 phyllosilicate are composed of one silica tetrahedral on one side combined with one alumina octahedral sheet on the other side to form a 1:1 type of crystal. Kaolinite is the main typical mineral of this group. It is the major clay mineral in most weathered tropical soils like Oxisols and Ferrasols. In a given layer of kaolinite, the silica tetrahedral and alumina octahedral sheets are connected by common oxygen anions. As a result of this, the lattice is fixed and there is no expansion and little isomorphic substitution with low cation exchange capacity (CEC) in kaolinite minerals usually occurs between layers when the clay is wetted.

2:1 Phyllosilicates minerals

The crystal layers of these minerals occur when an octahedral sheet is bounded (sandwiched) between two tetrahedral sheets. This class consists of Mica, Vermiculite, and Smectite clay minerals which have a 2:1 structure. But Smectite and Vermiculite are further grouped as expanding type 2:1 phyllosilicate minerals while fine micas and biotite are relatively non-expanding 2:1 phyllosilicate minerals. Expanding types of clay minerals are those with interlayer surfaces which are free and capable of allowing water movement. Smectite and Vermiculite are good examples of expanding types of 2:1 clay minerals, while fine-grain mica is non-expanding 2:1 clay mineral. These are further detailed in the following section:

(i) **Smectite:** Is a member of silicate clays in the 2:1 type which have a high shrinking and swelling properties because of its interlayer expansion in dry and wet conditions. It has high CEC because of its high negative charges on its large surface area. Montmorillonite is the most prominent member of the Smectite group in soils In Tanzania, soils dominated by montmorillonite minerals are found in semi-arid regions, particularly the Dodoma region.



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(ii) **Fine-grained mica:** These are the typical minerals in the non-expanding category. Muscovite and biotite which exist in the sand and silt particles, are examples of this group. These minerals are non-expansive because the interlayer is occupied by significant potassium that binds the layer together. This limits swelling and CEC when silicon is replaced by aluminium. Fine-grained mica has high negative charges due to excessive (about 20%) substitution of Al^{3+} for Si^{4+} that take place in the tetrahedral sheet.

(iii) **Chlorites:** These are the other non-expanding categories of 2:1 silicate clay because Mg-octahedral is hydrogen-bonded to the oxygen atoms of the two adjacent tetrahedral sheets closely binding the layers together. Magnesium is dominating the trioctahedral position of chlorite as a result, the structure has two silica tetrahedral sheets and two magnesium trioctahedral sheets that give rise to the term 2:1:1 type structure. Chlorite is characteristic of old soils like Ultisols and Oxisols.

Soil colloids and their properties

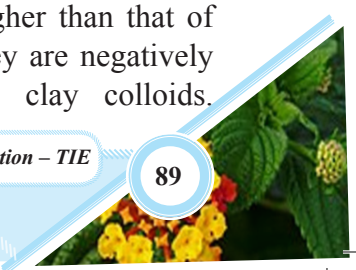
Soil colloids are fine-sized fractions of the soil with a diameter of less than one micrometre (1μm). They have a large surface area and chemical structure that makes them the most chemically active portion of the soil. Clays, humus, and metal oxides are good examples of colloidal particles. Colloids are also described as 'glue-like' organic or inorganic matter with too small particle size but a large surface area per unit mass or volume. The surfaces of soil colloids (both mineral and organic) exhibit electromagnetic charges that attract positive and negative ions as well as water. Soil colloidal fraction is the site of important processes in soil, governing ion exchange, nutrient availability and fixation, and soil physical properties (including soil texture, structure and colour).

Types of soil colloids

Soil colloids are broadly classified into organic colloids represented by humus and inorganic colloids represented by clay particles. The two are aggregated to each other and it is not easy to segregate them. The soil colloidal complex fractions display most of the properties of the ordinary colloidal structure, like adsorption, Tyndall effect, Brownian movement, coagulation, electrophoresis and dialysis. Types of soil colloids are discussed hereunder:

(a) Organic colloids

Organic colloids also called humus which is the dark-coloured, stable colloidal organic decomposed plant and animal remains. Humus is a mixture of various complex compounds like lipoproteins, polysaccharides, and polyuronides. In sandy soils, humus is present in small amounts while in peaty soils, humus may be present at greater than 50%. Organic colloids exhibit an adsorptive capacity higher than that of inorganic colloids. They are negatively charged colloids like clay colloids.



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When they are added to the sandy soils, it will increase the moisture and nutrient-holding capacity of the soil. Because of the high negative charges available on the surface of the humus it can attract different positively charged organic and inorganic constituents. Organic colloids have high CEC to clay and they can store and slowly release essential nutrients for plant growth.

An organic colloid is normally amorphous or shapeless. The source of negative charges for humus is the dissociation of carboxylic (-COOH) and phenolic (-OH) groups. This type of colloid is mostly pH-dependent because the CEC process depends on the replacement of hydrogen and CEC normally increases at higher pH values. The organic colloids consist of convoluted chains (i.e., non-crystalline) and rings of carbon atoms bonded to hydrogen, oxygen, and nitrogen. Humus particles are often among the smallest of soil colloids and exhibit a very high capacity to absorb water but almost no plasticity or stickiness. They have a net negative charge per unit mass because of partly dissolved hydroxyl, carboxyl, and phenolic content but the charge is pH-dependent and becomes extremely high in neutral to alkaline soils.

(b) Inorganic colloids

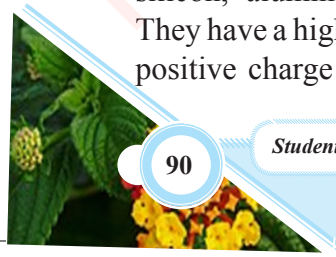
This category is composed of clay particles namely; crystalline silicate clays, non-crystalline silicate clays and iron-aluminium oxides. Non-crystalline silicate clays contain tightly bonded silicon, aluminium and oxygen atom. They have a high amount of negative and positive charge and high-water holding capacities. They have a high ability to adsorb phosphate and another anion, especially under acidic conditions. They do not possess crystalline sheets. Crystalline silicate clays have layers like pages in a book. The majority of them are negatively charged. Iron and aluminium oxides contain either iron or aluminium atoms coordinated with oxygen atoms. Some are crystalline and others are amorphous.

Properties of soil colloids

Soil colloids have two main chemical properties. First, they possess charges on their surface, which helps to attract oppositely charged ions. For example, negatively charged soil colloids attract many positively charged ions called cations. Second, they exhibit ion exchange. Ion exchange is a reversible process whereby cations or anions are exchanged between solid and liquid or between solid and solid phases. In exchange, the free cations in the soil solution are continuously replenished from the solid fraction as soon as they have been taken up by the plants, or lost by drainage to maintain the equilibrium. This system of replacement is called cation exchange. Other colloidal characteristics such as size, shape, surface area, plasticity, cohesion, swelling, shrinkage, dispersion, and flocculation are of considerable importance and are explained hereunder.

(a) Size

The organic and inorganic soil colloids are extremely small in size less than 0.001 mm or less than one micrometre in diameter. These particles cannot



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be viewed using an ordinary light microscope but can be visualised only with an electron microscope. The soil colloidal particles never pass through a semi-permeable membrane. Colloids in natural systems are characterised by a continuous particle size distribution of complexity and diversity. The allocation of shapes, densities, surface chemical properties and chemical composition might differ extensively with size.

(b) Shape

The shape of colloidal clay particles is seen as spherical, crystalline and/or amorphous. Clay particles that are composed of plates of layers and have an internal structure are crystalline. Colloidal shapes mainly depend on their mineralogical arrangement.

(c) Surface area

Soil colloids expose large surface areas due to their small sizes. The total surface area of soil colloids is the sum of both internal and external surfaces. For instance, the surface area of fine-grained mica is about 10^5 m^2 kg^{-1} on average, whereas the vermiculite and smectite surface area can approximate 8 x 10^5 m^2 kg^{-1} concerning the number of structured layers in an aggregate. All clay particles have a high external surface area because of their small size. The external surface area of one gram of colloidal clay minerals is expected to be 1 000 times greater than that of one gram of coarse sand.

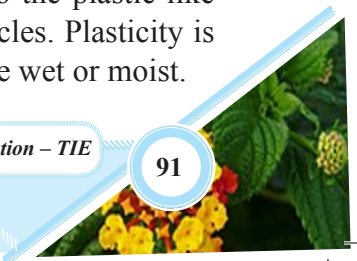
(d) Surface charge

Colloidal particles carry net negative or positive (though mostly negative) charges on their surfaces. Soil colloidal particles are always in movement due to their charged particles. Colloids are reactive because of their total surface area and increased reactivity related to rough surfaces and highly energetic sites, and the effect of electrostatic charges. Surfaces of clay colloids have positive or negative charges to attract charged ions, but negative charges predominate. Soil colloidal particles can absorb different phases such as solid mixed into the liquid, gas mixed into liquid or any other combination of the two phases from their suspension. Humus and clay mineral cations and anions are adsorbed on their surfaces because of permanent negative charges of clays formed by isomorphous substitution.

The charge on the mineral surface is calculated as the difference between the moles of charge donated per unit mass of mineral by the positive and negative anions adsorbed from an electrolyte solution of known pH. The positive and negative charges adsorbed, give rise to a cation exchange capacity (CEC) and anion exchange capacity (AEC) in centimol charge per kg. Clay minerals such as kaolinite, and the surfaces of Fe and Al oxides have pH-dependent charges. Permanent charges of silicate layers resulted from isomorphous substitutions.

(e) Plasticity

Plasticity is the capacity of clay particles to be easily moulded when it is moist or wet. Soils that contain greater than 15% clay show a plasticity feature. This property may be due to the plastic-like nature of the clay particles. Plasticity is exhibited when soils are wet or moist.



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(f) Cohesion and Adhesion

Soil colloidal particles have cohesion and adhesion properties. When the water content of very wet clay is decreased, the attraction among colloidal particles will increase. This characteristic of the clay particles to aggregate is probably due to the attraction of the clay particles to the available water held between the clay particles.

(g) Swelling and shrinkage

Fine-grained clay-rich soils can absorb large quantities of water after a rainfall, becoming sticky and heavy. Conversely, they can also become very hard when dry, resulting in shrinking and cracking of the ground. Swelling is the process of expansion of crystal layers that occurs because of water moving between crystal layers.

Swelling is considered by water attracted to ions and adsorbed by clays and water entered in soil pore spaces soils. Swelling occurs when the soil has small particle sizes like smectite (e.g., montmorillonite) upon which extreme expanding happens after wetting. However, kaolinite, chlorite, and fine mica do not show this characteristic to any extent, and also vermiculite is in between. The swelling property of certain clays can change volume by adsorbing water into their structure.

(h) Dispersion and flocculation

The term flocculation refers to the action by which individual fine soil particles stick together to form flocculates. A principal manner of a dilute colloidal suspension in water is complete dispersion which means that the particles repel one another.

Activity 3.10

In a group or individually, perform the following tasks:

(a) Collect sand soil and fill into 4 little plastic pots. Perforate them underneath. Label the first two ports A1 and A2 and the remaining two pots B1 and B2;

(b) In pots, B1 and B2, reduce half of the soil, and replace half of the pot volume with well-decomposed animal manure then mix well;

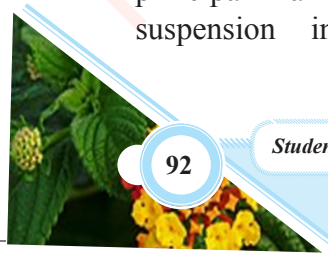
(c) Plant four bean seeds in each, and after germination uproot some seedlings leaving only one seedling in each pot;

(d) Water and observe the seedlings for a maximum of 20 days. Take note of plant height and number of leaves then, answer the following questions:

  (i) Did you notice any differences in water-holding capacity between the two pots? Explain your answer (Refer to the drying rate of the pots which required irrigating);

  (ii) What do you think might have happened to the nutritional composition of pot B1 and B2, following the addition of decomposed organic matter in relation to CEC?

(e) Summarize your responses and share them in class for discussion.



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Soil reaction

One of the chemical properties of soil solution is its reaction. The reaction of the soil may be acidic, alkaline or neutral. Soil reaction is determined by the concentration of H and OH ions in the soil solution. The soil is said to be acidic when there are more H ions than OH ions and alkaline when there are more OH than H ions which results in an alkaline soil reaction. When H ions and OH ions concentrations are in balance, the soil reaction is said to be neutral. Soil reaction is an important and informative soil parameter which affects the suitability of soil as growth media. The growth and activity of plants and soil organisms depend on soil reactions and the associated factors which are influenced by it.

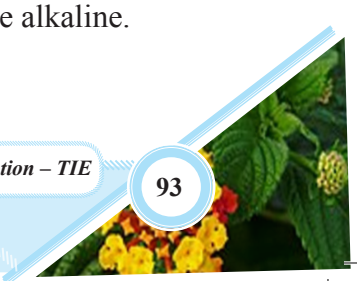
(a) Soil acidity

Soil becomes acidic when the concentration of the hydrogen (H^+) ions becomes more than the hydroxyl (OH^-) ions in the soil solution. When rainfall is high, leaching of exchangeable bases from surface soil layers occurs and contributes to acidic conditions. The two cations hydrogen and aluminium will be highly absorbed resulting in soil acidity. Hydrogen ions in the soil may be due to the presence of insoluble acids in the soil solution, Al ions adsorbed in soil colloidal particles and H^+ ions adsorbed on the soil colloidal particles. The aluminium ions in the soil solution react with water and result in the formation of H ions.

Aluminium ions in the soil get accumulated when the soil pH is very low due to their increased solubility in acidic conditions. It should be noted that the amount of any element that is adsorbed on the colloids is in equilibrium with the amount of that particular element which is present in the soil solution. Similarly, when a large amount of H ions is adsorbed in soil colloids, implies that the H ions in the soil solution are too high. Other sources of soil acidity include the CO_2 evolved from the root and microbial respiration, the occurrence of some anions NO_3^+, Cl^- and HPO_4^{2-} in the soil and the decomposition of organic matter.

Highly acidic soil may have a pH value of 4.5 and below calcium and magnesium, the high solubility of iron, manganese, and aluminium but low availability of nitrogen and phosphorus. The activity of microorganisms responsible for nitrification is adversely affected in acid soil. Generally, limes are used for the reclamation of acid soil.

The amount of annual rainfall in a given area has a strong influence on the soil pH. Soil acidity occurs in places where heavy rain washes away exchangeable bases from the upper layer of soil to the bottom layers (leaching). The exchange position left will be occupied by H ions. With time the amount of H ions becomes higher and soil tends to be acidic. Areas with low rainfall are associated with topsoil layers containing a high number of bases, and the presence of some salts such as magnesium, sodium and calcium carbonates. All these favour the formation of OH ions in the soil and cause the soil to become alkaline.



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(b) Soil alkalinity

There are chemical processes taking place in the soil which result in the release of OH ions in the soil solution. An example of such reactions is those which occur when basic cations held in soil colloids dissolve in water to form free basic cations and OH ions in the soil solution. As a result, the soil becomes alkaline in reaction. A high quantity of exchangeable sodium in the soil makes the soil alkaline. The soil that contains absorbed sodium is known as alkali soil. The high amount of sodium interferes with normal plant growth. Sodium ion easily displaces calcium ion from clay colloid and makes the sodium mixed clay particles.

This sodium is converted into sodium hydroxide by hydrolysis as per the following reaction;

$2Na + CO_3^{-2} + 2H_20 \rightarrow 2Na^+ + 2OH^- + H_2CO_3$.

The formed OH– ions, increases the soil pH.

Activity 3.11

Assume that you were given the assignment to manage and observe two plots, plots A and B (each plot had sandy soil grown with maize crop). Plot A was being heavily irrigated and plot B was irrigated moderately. After some time, general plant performance in plot A was relatively poor compared to performance in plot B.

(a) With reasons, explain what you think could have happened in plot A in terms of its pH as compared to plot B.

(b) Briefly describe what can be done to correct the problem.

Soil pH determination

Soil reaction is expressed in terms of the pH scale which is the measure of soil acidity or alkalinity. It is one of the most important soil properties that determine nutrient availability and general crop performance. The pH scale runs from 1 to 14. Values from 1 up to 6 represents acidic soil, 7 is neutral whereas value 8 up to 14 represents alkaline soil. However, most soils have a pH lying between 3.5 and 11. Most crops do well in slightly acidic soil with a pH range of about 6.0 up to 6.9, because at this pH range, most of the plant nutrients become available. There are several methods which can be used in the determination of the soil pH. These include:

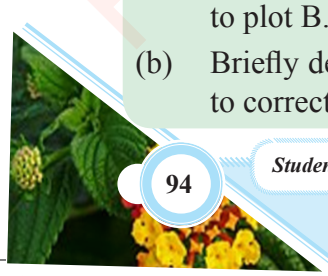
(a) Acid-Base indicators for example use of vinegar and baking soda.

(b) Calorimetric methods for example the use of colour cards/litmus paper and soil pH test strips. These are strips of paper that have been treated with an indicator.

(c) The strips tend to change colour in response to different pH values. Many dyes change colour with an increase or decrease in pH making it possible to estimate soil pH. In pH determination, the sample is saturated with the dye for a few minutes and the colour observed.

(d) They then use the pH meter method.

Acid-base indicators and calorimetric methods tend to give an estimate of the dominant reaction in the particular soil (whether the soil is acidic/alkaline or neutral) depending on the concentration of hydrogen or hydroxide ions in the soil solution but not the real numerical value



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of the pH. These methods are simple, fast, and can be performed in the field and the laboratory by any person without any technical knowledge of soil and they do not need any special equipment. But these methods are old and less accurate when compared to the pH meter method. The other limitation of these methods is on reliability and availability of strips and indicators. The use of a pH meter in the determination of soil pH is the current, most common and accurate method. The method is somehow laborious and needs calibration every time. This limits its applicability at the field level in some areas. However, following the advancement of technology, pH meter sensors for pH determination in laboratories and fields have been developed. A mobile lab (soil analysis kit) with all essential equipment for soil analysis including the pH meter for rapid pH measurement at the field level has been developed.

Activity 3.12

Aim: To determine soil pH using Vinegar and backing soda test

Requirements: Vinegar solution, backing soda, soil samples, two 50ml beakers, distilled water,

Procedure: under the supervision of your teacher, work in a group to perform the following tasks:

(a) Prepare one bottle of vinegar and one packet of baking soda;

(b) Collect the soil sample from the school garden, and put the soil into two containers (of the same size);

(c) To each container add an equal amount of distilled water to make the soil paste;

(d) In container 1, add baking soda to the prepared soil paste (soil to baking soda ratio should be 1:2) and stir it lightly for 2 minutes; and

(e) In container 2, add vinegar to the prepared soil paste (soil to vinegar ratio should be 1:2) and stir it lightly for 2 minutes.

Observation and interpretation

(i) Comment on the observed changes in the soil in both containers.

(ii) What could be the possible soil reaction in each container?

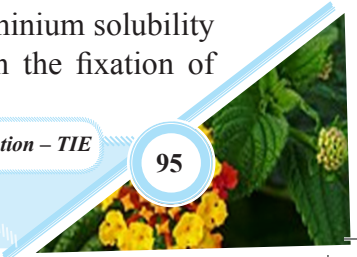
(iii) If there are no changes in soil appearance in any containers, what could be the possible reason?

(iv) Summarize what you have learnt from this activity with regard to the types of soil reactions.

Significance of soil pH

Soil pH is an important soil property because it affects the chemical, biological, and physical processes of the soil. Thus, pH is often considered the "master variable" of soil. Its importance in nutrient management cannot be underestimated.

The solubility of different elements in a given soil depends on its pH value. When soil pH is very low, iron, aluminium, manganese and boron become highly soluble and easily absorbed by plants to toxic levels for some plants. If pH is raised, they become less soluble. Increased iron and aluminium solubility in acid soils, results in the fixation of



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phosphorus thus reducing its availability for plant uptake. Normally acidic soils are deficient in calcium and magnesium because the two are less soluble in acidic conditions. Soil pH also determines the type of phosphate ions to be found in the soil. In the soil, phosphorus occurs in form of H_2PO_4 or HPO_4 ions. In very acidic conditions, soluble Iron, Manganese and Aluminium react with phosphate ions to form Iron or Aluminium Phosphate complex insoluble substances. Likewise, when soil pH is very alkaline, calcium in the soil reacts with phosphate ions to form insoluble Calcium-Phosphate. Under these conditions, phosphorus is said to be fixed and not available for plant uptake. This process is called phosphate fixation.

Soil pH also affects the population and activeness of soil organisms. Each kind of soil organism has its pH requirement to survive. However, the majority of them are favoured by slightly acidic to neutral (6.1 to 7.0) conditions.

Activity 3.13

Aim: To determine soil pH using a portable pH meter

Requirement: portable pH meter, small hand hoes, ruler, water bottle and the nearby school field/ farm/ garden environment.

Procedure: under the teacher's supervision, work in a group to perform the following tasks:

(a) Locate three points in the field in the beginning, middle and far end;

(b) Remove dead leaves or grasses covering the soil top by using a hand hoe. Set aside at least 3cm of topsoil;

(c) Dig a shallow hole in the soil, and mix up the soil properly within the hole. Remove big stones and root debris;

(d) Add a little amount of water to make a soil solution;

(e) Calibrate the pH metre and insert the probe of a pH meter into the soil and wait until the pointer arrow stabilizes while tilting left and right;

(f) Record the pH reading shown by a pointer in a pH meter screen;

(g) Repeat up to three times and find the average reading;

(h) Repeat the same procedure in the remaining stations of the field;

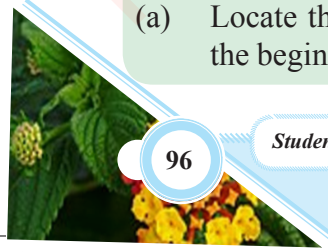
(i) Find the overall average pH of the field; and

(j) Comment on the pH status of the field.

(k) Recommend the types of crops and any appropriate corrective measures on the soil pH for crop production.

Salt affected soils

Salt-affected soils are those soils which contain a sufficient amount of salts to negatively affect the growth of crop plants. Salt-affected soil is a worldwide problem. Salts tend to concentrate over the soil surface causing a severe decline in crop yields. High concentration of salts in soils causes poor plant growth due to the increase in osmotic pressure which prevents the absorption of adequate



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amounts of water and nutrients from the soil. Salt-affected soils are found in diverse climates though, they commonly dominate arid and semi-arid areas where evaporation exceeds precipitation.

All soils have some soluble salts consisting of various proportions of the cations (Na^+, Ca^{2+} and Mg^{2+} and the anions (Cl^- and $SO4^{2-}$). The K^+, HCO^{3-}, CO_3^{2-} and NO^{3-} are present only in very small amounts. The source of all types of salts in soil are primary minerals present in soils and the direct sources of salts in soil are surface and ground waters. Weathering of primary minerals and upward movement of the soil solution through capillary rise from the lower horizon to the surface horizon causes accumulation of salts on the soil surface throughout sometimes as water evaporates.

Processes causing the formation of salt-affected soil

There are two major processes which result in the formation of salt-affected soils

(a) **Salinization:** A natural process of undue accumulation of soluble salts resulting in the formation of saline soil; and

(b) **Alkalization:** A natural process of undue accumulation of exchangeable sodium resulting in the development of alkali soil.

Other processes which may result in salt accumulation in the soil are irrigation with water containing a substantial amount of sodium or soluble salts, excessive irrigation and leakage of canals which may raise the groundwater table and poor drainage condition of the topsoil.

Classification of salt-affected soils

Salt-affected soils can be categorized into three classes namely: saline, alkaline and saline-sodic. These are explained hereunder:

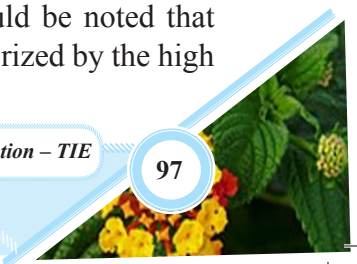
(a) **Saline soils:** These are soils with a white crust appearance on the surface after evaporation of water, and they are formed due to the accumulation of soluble salts such as chloride and sulphate of calcium, magnesium and sodium.

(b) **Alkali soils (Sodic soils):** These are soils dominated by sodium carbonates (Na_2CO_3) which hydrolyses into NaOH. They are also called black alkali soil because the surface appears black or brown due to the reaction of organic matter with sodium hydroxide which finally breaks down the organic matter.

(c) **Saline sodic soil:** These are soils containing many types of soluble salts and exchangeable sodium. It is a transitional category between saline and alkali soils.

Determination of salts in soils

Salt concentration in the soil is determined by measuring the electric conductivity (EC) of the soil using an electrical conductivity meter. The SI unit is decision per meter (dSm^{-1}) and by measuring the sodium exchangeable percent (ESP) from the soil extract of a given soil. It should be noted that saline soils are characterized by the high



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electrical conductivity of soil (EC > 4 dSm^{-1}). Thus:

(i) Sodic soils are characterized by high exchangeable sodium percentage (ESP > 15%) but low EC (< 4 dSm^{-1}); and

(ii) Saline-sodic soils: A combination of saline and sodic soils which is characterized by high electrical conductivity and Exchangeable Sodium Percent (EC > 4 $dSm^{-1}$and ESP > 15 %).

Activity 3.14

Aim: To determine salt concentration in the soil by using EC meter

Requirement: Soil sample, 100 ml beaker, Ec meter, distilled water, 0.01 M KCl solution, and glass rod.

Procedure: Under the supervision of your teacher, work in a group to perform the following tasks:

(i) Put 10 g of the soil sample in a 100 ml beaker;

(ii) Add 25 ml of distilled water into it (1:2.5 soil: water ratio);

(iii) Stir the suspension with a glass rod intermittently for 30 minutes or continuously shake the suspension of soil on a reciprocating shaker for 5 minutes;

(iv) Keep the suspension till the soil particles settle down;

(v) Calibrate the electric conductivity meter using 0.01M KCl solution. Adjust the reading of the electric conductivity meter to 1.41 dS/m;

(vi) After that, remove the conductivity meter from 0.01M potassium chloride solution and wash it with distilled water. Wipe it with tissue paper and dip the conductivity meter in distilled water;

(vii) Now, dip the conductivity electrode in the supernatant part of the sample and record the reading;

(viii) The soil-water suspension prepared for pH determination can also be used for the measurement of electrical conductivity;

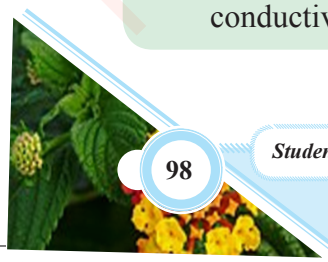
(ix) The soil water ratio should be specified with conductivity readings as it influences the salts content in the extract; then,

(x) Record your observation in your portfolio and present in class for discussion (The discussion should aim at interpreting the measured EC values).

Note Soil salinity can also be measured in situ by using buried porous electrical conductivity sensors. The suitable method should be selected on the basis of the specific conditions, needs and equipment and manpower availability. The choice of a method depends upon the number of samples and the time available.

Methods of correcting soil acidity, alkalinity, and salinity

When soil reaction is either too high or too low it impairs nutrients availability, microbial activities and general plant performance. Thus, it is very important to take appropriate measures to create favourable soil reactions. The best



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solution for reducing soil acidity is liming. This is achieved by the addition of agricultural limes. These include oxides, hydroxides or carbonates of calcium or magnesium. Liming materials need to be applied at the depth of 0-30cm, at least three months before planting. It should be evenly distributed and thoroughly mixed with soil. Generally, 1.65 tonnes per hectare of a liming material is sufficient to raise soil pH from 5.5 to 6.5 depending on the nature of the soil, type and properties of liming materials. If soil is alkaline, though this is not a common phenomenon, the pH can be decreased by using fertilisers such as ammonium sulphate or urea to some extent. The addition of gypsum or sulphur in large amounts helps to lower soil pH due to the formation of sulphuric acid. Flooding or heavy irrigation can be opted to facilitate leaching of basic cations. Sometimes scooping of the soil surface is used to eradicate accumulated salt on the earth's surface. In large-scale farming, acidifying soil can be very expensive or impractical.

Activity 3.15

In a group or individually, perform the following tasks:

(a) Using a pH meter, locate a portion of the school field with acidic soils;

(b) Measure the area of your school field with acidic soils;

(c) Calculate the amount of lime to be applied based on the recommendation that one hectare requires 1.65 tons of lime;

(d) Apply the required amount of lime evenly and mix it thoroughly with the soil at a depth of 30 cm. Apply water to keep the soil moist and monitor changes in soil pH if any;

(e) What do you think will happen if there is an over application of liming material because of a wrong calculation? What would have happened if the amount was underestimated?

(f) Assume that the initial soil pH was very low, what will you advise the farmer who wants to use DAP fertiliser? What will happen if the farmer opts to use sulphate ammonia fertiliser?

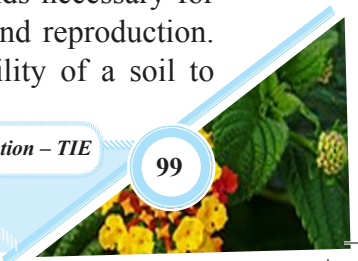
(g) Write a summary of the expected benefits of liming your school field.

Exercise 3.3

1. Describe the chemical and mineralogical composition of soil.
2. Outline the properties of soil colloids.
3. Explain the meaning of soil reaction.
4. How is soil reaction classified?
5. Outline methods of correcting soil reaction.

Plant nutrition and soil fertility

With respect to crop production, plant nutrition is the study of chemical/nutrient elements and compounds necessary for plant healthy growth and reproduction. Soil fertility is the ability of a soil to



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supply all required plant nutrients in sufficient amounts, right proportions and at the right time. Plant nutrient elements are those elements that are required by the plant to be able to meet its nutritional requirements and complete its life cycle. These are supplied by the soil air and water or can be supplemented through the addition of fertilisers and other amendment materials.

Based on their functions and quantities required by the plants, plant nutrient elements can be grouped into three groups (namely structural nutrient elements (C, H and O), macro/nutrient elements (N, P, K, Ca, Mg, and S), and micro/nutrient elements (Fe, Zn, Mn, Cu, B, Mo, Cl and N). The groups are further described in the following section.

Structural nutrient elements

Carbon, hydrogen and oxygen are the structural nutrient elements as they form the building blocks for any living cell. In this sense, they are required in the largest amount as they constitute 90-95% of plant dry matter. It should further be noted that the three are non-mineral nutrient elements. They naturally are always readily available for plants and therefore are not a part of fertiliser formulations. For instance, Carbon is available from the atmosphere as well as in the soil in form of C_2O. Oxygen is available from the atmosphere. Hydrogen is available from the atmosphere and in the soil solution. The basic function of each Structural non-mineral nutrient element are described herein.

(a) **Carbon:** It's a basic molecular component of carbohydrates, proteins, lipids, and nucleic acids. The major constituent of organic materials is involved in enzymatic processes and oxidation-reduction reactions.

(b) **Hydrogen:** Hydrogen plays a central role in plant metabolism, and energy relations in cells and it is important in ionic balance as the main reducing agent.

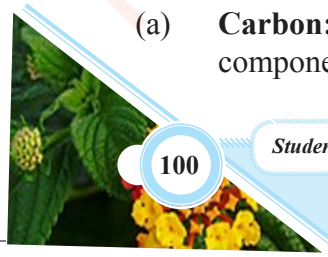
(c) **Oxygen:** Oxygen is a major constituent of organic material and it is involved in enzymatic processes and oxidation-reduction reactions.

Macronutrient elements

These are mineral nutrient elements which are required in large quantities by plants. The functions of a given element cannot be replaced by another mineral element. Examples in this group are. N, P, K, Ca, Mg, and S. basic function of these element are described hereunder.

(a) Nitrogen

The basic function of nitrogen is to facilitate proper vegetative plant growth. Nitrogen is taken in larger quantities than other essential plant nutrients for various functions. Green pigmentation in plant leaves is highly related to their nitrogen content because N is a constituent of chlorophyll molecules. Nitrogen is needed for the synthesis of all proteins in plants which parts are needed for the synthesis of enzymes. These enzymes control all the essential processes such as photosynthesis, respiration and growth in a plant. The main forms of N absorbed by plants are ammonium (NH_4^+) and nitrate (NO_3^-) ions, although small quantities of urea,



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water-soluble amino acids and amides can be absorbed by plants.

(b) Phosphorus

Phosphorus is the primary mineral required for proper root initiation and development. It plays an important role in energy production and transformation in plant cells. It is required for the synthesis of energy-rich compounds that releases energy which enables various biochemical reactions such as photosynthesis, glycolysis, amino acid metabolism, fat metabolism, sulphur metabolism, and biological oxidations. Phosphorus is also a component of all cell membranes. Plants also need phosphorus for good root development, seed formation, and straw strength which increases the number of tillers in cereals, an effect which increases the number of ear grain-bearing shoots. It hastens crop maturation through its effects on the enhancement of plant growth. Phosphorus also improves the quality of certain fruits, forage, vegetable and grain crops and increases plant resistance to diseases.

(c) Potassium

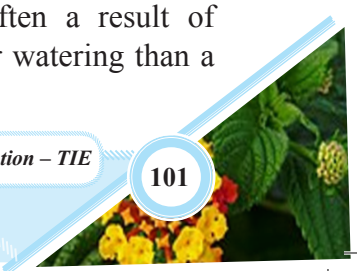
The quantities of potassium found in most plant tissues are close to those of nitrogen, thus, making potassium the second element needed by plants in large quantities. Potassium increases the efficiency of the leaf in manufacturing sugars and starch. It is, thus required in greater amounts by root crops and cereals. The action of potassium is considered to be complementary to that of nitrogen. The latter increase the size of the leaf and the former its photosynthesis efficiency. Potassium is present in the solution of all plant cells and is important in regulating their water balance. It is also essential in the development of fruits including tomatoes and cucurbits. Plants that produce fruits are often benefiting from a later potash nutrient especially, those growing in pots that quickly exhaust their nutrient supply.

(d) Magnesium

Magnesium fulfils several functions within the plant; it is a central component of chlorophyll molecules which absorb sunlight for photosynthesis. Magnesium acts as a phosphorus carrier in plants and is essential for phosphate metabolism. Magnesium deficiency shows up as dark patches between the veins but is often a result of drought or excess potash rather than soil deficiency. If Mg deficiency is a severe problem, plants respond well to a foliar spray of Magnesium sulphate (Epsom salts).

(e) Calcium

Calcium is a component of plant cell walls and a regulator of biochemical processes. Calcium helps in increasing the stiffness of straws or plant stems. Calcium is required in adequate amounts for optimum cell division. Due to its involvement in a meristematic activity, calcium promotes early root development, earliness and good seed production. Calcium is not very mobile in the plant, so a deficiency often manifests itself as brown lesions within or at the far ends of large structures e.g. blossom end rot of tomatoes, bitter pit in apples and internal rust spot of potatoes. Deficiency is more often a result of insufficient or irregular watering than a



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lack of calcium in the soil. It can also be a result of the soil being too acidic. This can be corrected by adding agricultural lime and Ca- containing fertilizes to correct the acidity.

(f) Sulphur

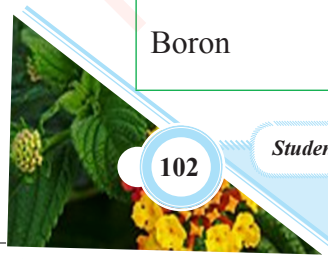
Sulphur is used in the formation of amino acids, proteins, and oils. It is necessary for chlorophyll formation, promotes nodulation in legumes, helps develop and activate certain enzymes and vitamins, and is a structural component of three of the 21 amino acids that form protein. Plants deficient in sulphur are small and spindly with short and slender stalks, their growth is retarded, maturity in cereals is delayed, nodulation in legumes may be poor and nitrogen-fixation reduced, fruits often do not mature fully and remain light-green in colour, forages contain an undesirably wide (N: S) ratio.

Micro-nutrient elements

These are mineral nutrient elements which are required in by plants. They are sometimes called trace elements. Examples in these groups are (Fe, Zn, Mn, Cu, B, Mo, Cl and N). In addition, Sodium and Silicon have recently been established as essential elements for some plant species. Although they improve yields and do not meet the criteria for essentiality thus termed beneficial nutrient elements. Note that, macro and micronutrient elements are mineral elements that are normally not freely available, therefore, they have to be supplied. Table 3.1 summarizes mineral micronutrient elements and their basic functions in plants.

Table 3.1: A summary of basic functions of micro nutrients elements in plants

Nutrient	Basic functions
Iron	An essential component of many hemes and non-heme Iron (Fe) enzymes and carriers including, the cytochromes (respiratory electron carriers) and the ferredoxins. The latter are involved in key metabolic functions such as Nitrogen (N) fixation, photosynthesis, and electron transfer.
Zinc	An essential component of several dehydrogenases, proteases, and peptidases, including carbonic anhydrase, alcohol dehydrogenase, glutamic dehydrogenase, and malic dehydrogenase, among others.
Manganese	Involved in the O_2-evolving system of photosynthesis and is a component of the enzymes arginase and phosphotransferase
Copper	Constituent of some important enzymes, including cytochrome oxidase, ascorbic acid oxidase and laccase.
Boron	Involved in carbohydrate metabolism and synthesis of cell wall components.



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Molybdenum	Required for the normal assimilation of N in plants, it is an essential component of nitrate reductase as well as nitrogenase (N_2 fixation enzyme).
Chlorine	Essential for photosynthesis and as an activator of enzymes involved in splitting water it also, play role in the osmoregulation of plants growing on saline soils.
Nickel	It is a constituent of the plant enzyme urease, the enzyme that catalyses the degradation of urea to carbon dioxide and ammonia.

Sources and uptake of nutrient elements in plants

Originally plants obtain their nutrients from the soil solution, and partly from the atmosphere (Table 3.1). When the amount required by the plant from the soil is not sufficient, external sources from mineral or organic fertilisers can be added. Some of the nutrient elements like oxygen and carbon can be obtained from the atmosphere, through plant leaves. Hydrogen is obtained from water. The rest are obtained from the soil. Mineral nutrient elements from the soil solution are absorbed by plant roots, along with water and translocated to other plant parts through xylem vessels. Moving water and nutrients up the plant go against the force of gravity, thus osmosis and evapotranspiration pull plays a big role in moving nutrients from the soil to other plant parts. When plant water is lost through evapotranspiration, it creates a deficit of water in the plant tissues and thus forcing water movement from the region of high concentration (soil) to the region of low concentration (plant tissue) see Figure 3.14 (b). Likewise, when mineral nutrient in the soil solution has been taken up by the plant, the replacement from soil colloids is done to ensure the equilibrium balance. While in the plant tissue, water and nutrients move from cell to cell following the same principles as shown in Figure 3.14 (a).

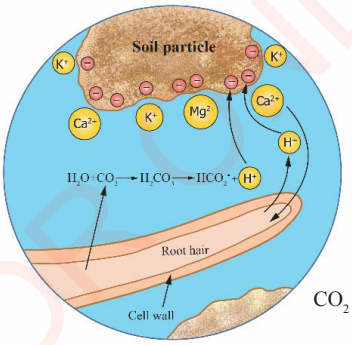

Figure 3.14 (a): Cation exchange between roots and soil particles

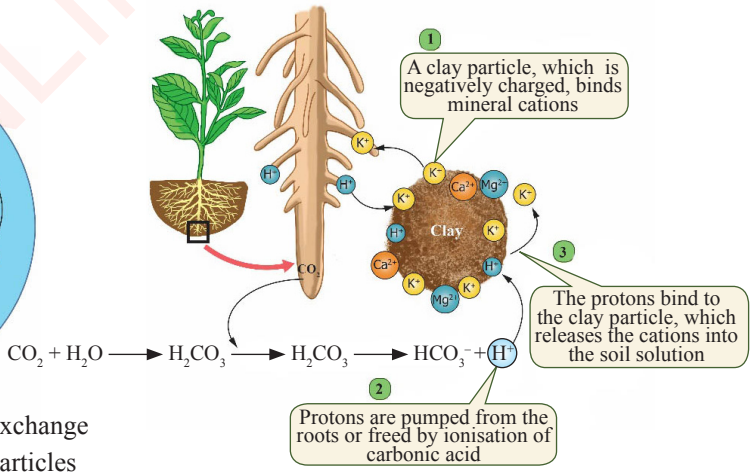

Figure 3.14 (b): Uptake of nutrients by plants

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Table 3.2: Some plant nutrients, their categories, sources and forms taken by plants

Nutrient	Category	Source	Form taken by the plant
Carbon	Non-mineral Macronutrient	Air	CO_2
Hydrogen	Non-mineral Macronutrient	Water	H_2O
Oxygen	Non-mineral Macronutrient	Air/ Water	H_2O, O_2
Nitrogen	Mineral Macronutrient	Soil/air	NH_4^+, NO_3
Phosphorus	Mineral Macronutrient	Soil	$H_2PO_4^-$, $(HPO_4)^{2-}$
Potassium	Mineral Macronutrient	Soil	K^+
Calcium	Mineral Macronutrient	Soil	Ca^{2+}
Magnesium	Mineral Macronutrient	Soil	Mg^{2+}
Sulphur	Mineral Macronutrient	Soil	SO_4^{2-}, SO_2
Iron	Mineral Micronutrient	Soil	Fe^{2+}, Fe^{3+}
Zinc	Mineral Micronutrient	Soil	Zn^{2+}
Manganese	Mineral Micronutrient	Soil	Mn^{2+}
Copper	Mineral Micronutrient	Soil	Cu^{2+}
Boron	Mineral Micronutrient	Soil	H_3BO_3
Molybdenum	Mineral Micronutrient	Soil	MoO_4^{2-}
Chlorine	Mineral Micronutrient	Soil	Cl^-
Nickel	Mineral Micronutrient	Soil	Ni^{2+}

Deficiency symptoms of selected essential mineral elements

When essential mineral elements are not sufficiently supplied to plants, the normal physiological functioning of the plants is impaired. This can be indicated physically by deficiency symptoms. Every nutrient deficiency has its specific symptoms as described hereunder:

(a) Nitrogen

The most obvious symptoms of nitrogen deficiency in plants are leaf yellowing, stunted growth, and a reduced number of leaves or tillers (Figure 3.15). Because nitrogen is mobile in the plant, deficiency symptoms will start to be observed in older leaves as compared to younger ones as N is translocated from older leaves to younger leaves.

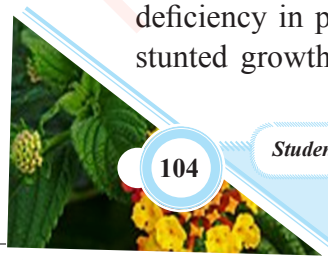

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Figure 3.15 (a): Nitrogen deficiency symptoms in beans

Figure 3.15 (b): Nitrogen deficiency symptoms in maize

Figure 3.15 (c): Nitrogen deficiency symptoms in a weed plant

(b) Phosphorus

Phosphorous-deficient plants appear stunted, thin and spindly with dark green leaves. The number and size of stomata in leaves are decreased. Root growth is drastically reduced. Phosphorus is mobile in plants and under short supply conditions, it is easily mobilised from older to younger leaves. The deficiency symptoms appear first and become more severe on older leaves while young leaves usually remain normal under mild deficiency (Figure 3.16 (a)). Old leaves changes from dark green to bluish-green colouration. Under severe deficiency conditions, purple or purple-red colours develop in older leaves. Purpling usually start from the margins of older leaves. In acute deficiency, the purpling may cover the entire plant (Figure 3.16 (b)). In the most advanced stage, affected leaves burn and die (see Figure 3.16 (c)).

Figure 3.16 (a): Mild deficiency

Figure 3.16 (b): Severe deficiency

Figure 3.16 (c): Pattern of P-deficiency on maize leaf

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(c) Potassium.

Potassium deficiency causes shortening of the internodes and dwarfing of plants with a general loss of the dark green colour of foliage. Affected plants produce small, very pointed ears and are underdeveloped at the tip. Potassium moves readily from old to young leaves, therefore deficiency symptoms appear first on old leaves. Younger actively growing leaves draw potassium from old parts of the plant, therefore young leaves usually remain green and healthy. Symptoms begin as pale-yellow chlorosis on the tip of old leaves covering marginal tissue. The chlorosis is followed by pale brown necrosis and both chlorosis and necrosis advance down the margins towards the base. Marginal chlorosis and necrosis of older leaves are the specific symptoms of potassium deficiency. In severe deficiency conditions prominent red strips develop on the lower stem and leaf sheaths (Figure 3.17 (a) and (b)).

Figure 3.17 (a): Potassium deficiency in maize plant

Figure 3.17 (b): Potassium deficiency and its patterns distribution in a leaf

(d) Magnesium

Magnesium-deficient maize plants are stunted with thin, spindly stems and pale green foliage with rust-brown lower leaves. Magnesium deficiency may cause severe losses to crop yields as deficient plants bear very small ears or pods with reduced seed size. Magnesium is mobile in plants and under short supply conditions, it is easily mobilized from older to younger leaves. The deficiency symptoms appear first and more severely on older leaves. The symptoms begin with pale-yellow interveinal chlorosis in the mid-section of the older leaves. As the symptoms advance, interveinal chlorosis proceeds towards the tip and base of the leaf, ultimately covering the entire leaf. The youngest leaves usually remain unaffected and healthy. If the deficiency persists and becomes more severe, the symptoms advance towards the upper leaves and rust brown strips appear on affected older leaves. In advanced stages, the interveinal tissue dies and appears as whitish-to-brown necrotic strips in the interveinal areas of the leaf. The affected older leaves eventually burn and die (Figure 3.18 (a) and (b)).

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Figure 3.18 (a): Magnesium deficiency in maize leaf

Figure 3.18 (b): Magnesium deficiency in tomato leaves

(e) Calcium

Calcium-deficient plants are very stunted with distorted, torn and ragged foliage. Plants develop small cobs or pods and distorted tassels, but if deficiency is severe, plants fail to grow and die before maturity. In maize and other cereal plants, Calcium is immobile and under short supply, it is not easily mobilized from older to younger leaves. The deficiency symptoms appear first and more severely on younger leaves. Calcium deficiency symptoms begin with yellow to white interveinal lesions on young leaves. If the deficiency persists and becomes more severe, the newly emerging leaves fail to unroll and make a 'bull-whip-like' structure. As symptoms advance, the new leaves develop holes in the lamina. The torn and malformed leaves give the plant a ragged appearance. (Figure 3.19 (a)). In acute deficiency conditions, the tips of the youngest leaves are glued together and do not separate from the whorl. This gives the plant a 'ladder-like' appearance. Blossom end rot, which affects the fruit, is a typical sign of calcium insufficiency in tomato plants. The fruit's bottom (blossom end rot) will develop a flat tan, brown, or black mark (Figure 3.19 (b). These blemishes may be entry for bacteria and fungi to attack the fruit, causing further degradation and mushy, rotting tomatoes.

Figure 3.19 (a): Calcium deficiency in maize

Figure 3.19: (b) Calcium deficiency in tomato

(f) Sulphur

Sulphur-deficient maize plants are stunted with uniform pale green to yellow leaves. Deficient plants lack vigour and produce small ears with few kernels, resulting in poor crop yields.

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Nitrogen application does not correct sulphur deficiency. Sulphur deficiency, even if severe, does not produce any type of necrosis or burning of leaves. The change in leaf colour is the only indicative symptom of sulphur deficiency. Sulphur is immobile in plants and under short-supply conditions, it is not easily mobilized from older to younger leaves. So, the deficiency symptoms appear first and become more severe on the younger leaves. Deficiency symptoms appear as an even and uniform, pale green to pale yellow chlorosis across the lamina of young leaves (Figure 3.20). The youngest leaves are the lightest in colour. In acute deficiency conditions, a red-purple colour sometimes develops on affected younger leaves as suffusion over the yellow colour.

Figure 3.20 (b): Pale green leaf

Figure 3.20 (c): Pale yellow leaf

(a) **Figure 3.20 (a):** Uniform yellowing

Activity 3.16

Under the teacher's guidance, perform the following tasks:

1. Walk around your school environment, and identify weeds, or crop plants showing nutrient deficiency symptoms for N, P, K, Ca, Mg and S;
2. Collect them and write the distinguishing feature for each nutrient deficiency in one album;
3. Write the observed similarities and differences between sulphur, magnesium and nitrogen deficiency symptoms; then,
4. Prepare your summary and present it in class for discussion

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Exercise 3.4

1. Explain the meaning of plant nutrient elements.
2. Name and categorize essential mineral nutrient elements in the soil.
3. Outline the basic functions of N, K, P, Ca, Mg and S in plants.
4. Point out the distinguishing deficiency symptoms for N, K, P, Ca, Mg and S.
5. Explain sources of plant nutrient elements.
6. Explain the mechanism of nutrient uptake in plants.

Soil conservation and maintenance of soil fertility

Soil conservation and fertility maintenance are important aspects for enhancing soil productivity. Soil productivity is the capacity of the soil to give a specified crop yield when provided with all good agronomic practices. A productive soil is always fertile soil but fertile soil may not necessarily be productive. For soil to be productive, properties, like adequate soil depth, good internal drainage, sufficient organic matter content, and proper pH range in addition to its nutritional composition should be in place. Fertile soil may fail to give good yield due to unfavourable soil temperature or the presence of toxic substances. Soil fertility is a manageable property. Soil conservation is the application of various practices that aims at maintaining soil fertility and productivity. These practices may include crop rotation, manuring and applying fertiliser, controlling soil erosion and employing soil moisture retention practices.

Causes of soil and fertility losses

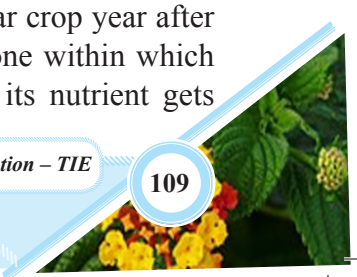
Usually, topsoil is the one containing a large amount of decomposed organic matter and mineral nutrients. When this soil is displaced by various agents of erosion, soil fertility is lost along with it. Bare soil is more prone to losses as compared to covered ones. Loss of soil and its fertility may be due to the following factors:

(a) Continuous cultivation without replenishment of plant nutrients. Harvested plants are left with a nutrient element that they absorb from the soil. With time, nutrient reserve in the soil is reduced as land is continuously cultivated. This results in a reduction of soil fertility;

(b) Soil erosion due to wind and water runoff results in reduced soil fertility. Fine soil particles that help to hold nutrient elements are carried away by soil erosion agents;

(c) Heavy rainfall is associated with the leaching of basic cations from topsoil to subsoil, resulting in soils that are acidic and less fertile; and

(d) Poor farming systems like mono-cropping involve continuous cultivation of the same piece of land with a similar crop year after year. The root zone within which the crop obtains its nutrient gets



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exhausted and leads to low soil fertility.

Soil fertility and plant nutrition may be improved by following methods:

(a) Soil fertilization. This involves the addition of mineral or organic fertilisers;

(b) Control soil erosion and runoff through contour ploughing, construction of terraces, strip cropping and the use of cover crops;

(c) Employing crop rotation, fallowing and reduced or zero tillage practices; and

(d) Employment of good agronomic practices such as timely weeding helps to minimize the wastage of plant nutrients which may be taken by weeds.

(e) Avoidance of burning of vegetation helps to sustain microbial population and protection of organic matter.

Soil conservation methods

These include practices which are done specifically to preserve and improve the physical, chemical and biological properties of soil. They include cover cropping and mulching, crop rotation, conservation tillage, ridges, terraces and contours, strip cropping, planting/ windbreaks and residue management. Some of the conservation methods are described hereunder:

(a) Cover cropping and mulching

Cover cropping involves the growing of less-competitive crops in empty spaces between rows of plants to cover such spaces. Crops with good covering ability, drought tolerant, and of a different specie/family with the intended crop are highly recommended. Some cover crops such as leguminous crops help to fix nitrogen in the soil and hence improve soil fertility status. Mulching is the application of organic or synthetic soil covers over exposed soil. Organic mulches may include a layer of dry grass; straw or plant remains. Polythene sheets are good examples of synthetic mulches. Mulching helps to preserve soil moisture, and reduce the impacts of soil erosion and weed control.

(b) Crop rotation

Crop rotation is the practice of growing different types of crops on the same or each piece of land after each cropping season. This is done by rotating crops of different families in a manner that the same cycle may be repeated. It helps to improve soil health and minimise pests and diseases. This method improves the structure of the soil, and increases the soil organic matter and rooting depth as well. Leguminous crops such as peas and chickpeas, help in modifying soil functional microbial communities. In the rotation, cover cropping, mulching, and zero tillage may be used. Crop rotations can provide better opportunities for the growth of some soil-functional microorganisms. Nutrients are not easily exhausted because of differences in the rooting zone of the rotated crops

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especially when deep-rooted ones are rotated with shallow-rooted crops. Heavy feeder crops (with high nutrient requirements) should be alternated with lighter feeders (crops with low nutrient requirements). Rotating crops of different families helps to cut off the chances of diseases and pests spreading by breaking the disease or insect pest cycles.

(c) Conservation tillage

This method is aimed at preserving soil aggregates, organic matter and crop residues. Conservation tillage includes changes in making use of less destructive tillage implements (for instance, instead of using a mouldboard plough, use a chisel plough), minimum tillage (that is, one turn instead of two), leaving crop residue on the soil surface to prevent erosion. The method improves soil structure drainage and reduces soil erosion. Soil water holding capacity, soil organic matter accumulation and microbial activity are also enhanced. In addition, leaving crop residues on the soil surface increases the chances of crop diseases and pest spread.

(d) Uses of ridges, terraces and contours

The ridges are made against the land slope and they consist of tall lifted seed beds that are formed over the entire field or as trap strips which are in a position perpendicular to the direction of the run-off and prevailing wind. The formation of an earthen embankment along a common elevation contour gives an elevated terrace structure that can directly reduce erosion by checking runoff and wind speed. Ridges, terraces and contours, help to control erosion and increase water storage in the soil.

(e) Strip cropping/planting windbreaks

This is another method of conserving the soil and controlling wind erosion. A windbreak serves as a barrier to deflect the flow of air and reduce leeward wind speed is done by growing different plant materials. The crops may be cultivated in strips perpendicular to the prevailing wind where field orientation is not restricted as a means to reduce the near-surface wind speed.

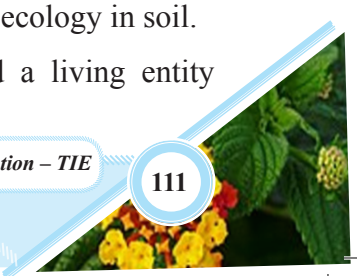
Exercise 3.5

1. Explain the meaning of soil fertility, soil productivity and soil conservation.
2. Outline the causes of loss in soil fertility.
3. Recommend methods of improving soil fertility and plant nutrition.
4. Describe the characteristics of a fertile soil.

Soil biology

Soil biology is a branch of soil science that studies soil organisms, their activities and ecology. In other words, soil biology is the study of microbial and faunal activity and ecology in soil.

The soil is considered a living entity



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because it is filled with millions of different organisms (Figure 3.21). Soil organisms have attracted extensive attention in recent years because of their essential ecosystem functions, such as nutrient cycling, decomposition, and maintenance of soil fertility. The decomposition of organic matter by soil organisms has an immense influence on soil fertility, plant growth, soil structure, and carbon storage. Also, soil organisms play a vital role in soil formation and determine several other soil properties. Understanding key interactions between soil organisms and other components of the soil are important in reducing the cost of production through integrated nutrient management and increasing the nutrient and water use efficiency of crop plants. This knowledge is also important in the management of plant diseases and other pests.

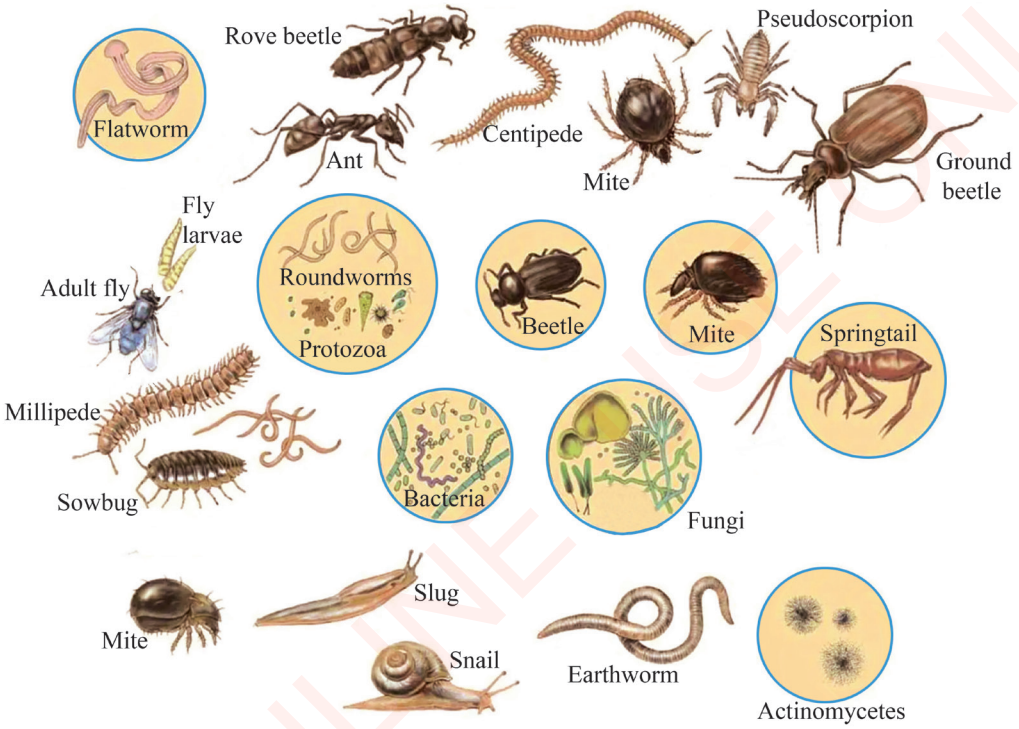

Figure 3.21: Different types of soil organisms

Soil organisms perform a variety of functions, including soil stabilization (aggregate formation), decomposition of organic matter, nutrient cycling, facilitation of nutrient uptake by plants, disease suppression, plant growth promotion, production of antibiotics and hormones, breakdown of pesticides residues other pollutants.

Classification of soil organisms based on their sizes

Based on their size, soil organisms are commonly divided into three arbitrary groups namely micro, meso and macro fauna and flora groups as described here under:

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Micro-fauna and flora

These are less than 100 microns in length and generally feed upon other microorganisms. Include protists and nematodes. Protists, for the most part, feed off soil bacteria. Nematodes are a diverse group, including plant parasites and predators that feed on bacteria, fungi or other nematodes. They release nutrients and make them available for plant uptake.

Meso-fauna and flora

These are somewhat larger and are heterogeneous, including creatures that feed on microorganisms, decaying matter, and living plants. The category includes nematodes, mites, springtails (wingless insects so called for the springing organ which enables them to leap), the insect-like proturans, which feed on fungi, and the pauropods.

Macrofauna

These are animals that can be seen with naked eyes, they include moles, earthworms, ants, millipedes, spiders, and beetles. The group also includes slugs and snails which feed on plants, centipedes, beetles and their larvae, and the larvae of flies, which feed on other organisms or decaying matter. They are considered 'structural engineers' of the soil, and also improve soil aeration. Earthworms incorporate organic material into the soil and provide channels for root growth.

Description of representative phylogenetic groups of soil organisms

Archaea

These are unicellular, prokaryotic organisms (lack a membrane-bound nucleus) usually 0.5-1 micrometre in length. They consume various exudates (sugars, carbons, carbohydrates) of the roots. Many have a thick mucilaginous film around the body that protects them from abrupt changes in pH. They are rod-shaped, round or wavy (Figure 3.22).

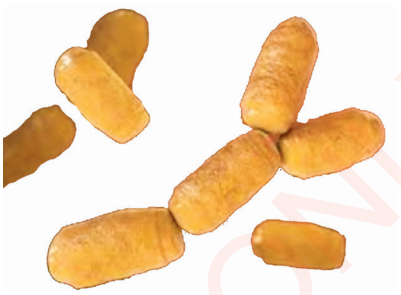

Figure. 3.22: Rod-shaped archae

Bacteria

Bacteria are single-celled soil microorganisms with different shapes (Figure 3.23 (a), (b) and (c)). They may or may not be mobile, and may grow in clusters. They feed on organic matter that is easy to break down and release plant nutrients, they store and cycle nitrogen, contribute to stabilising the soil and decomposing pesticide residues in the soil thus, reducing environmental pollution risks.

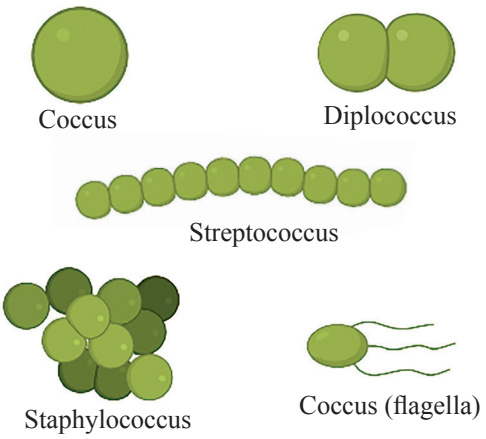

Figure. 3.23 (a): Round-shaped bacteria

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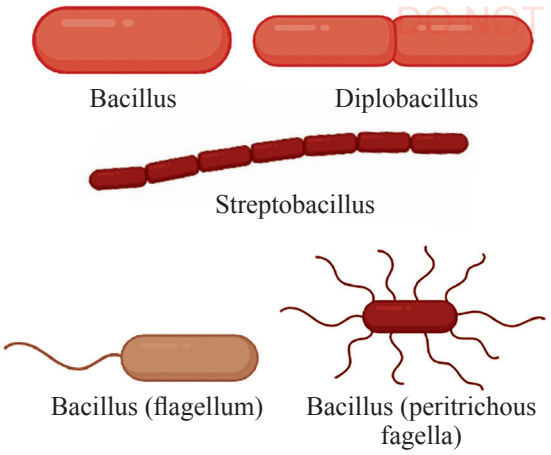

Figure. 3.23 (b): Rod-shaped bacteria

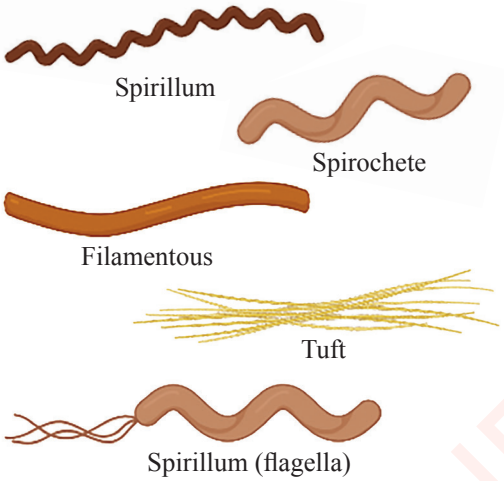

Figure. 3.23 (b): Spiral-shaped bacteria

Fungi

Fungi are eukaryotic organisms that include microorganisms such as yeasts and moulds, as well as mushrooms. These organisms are grouped into two main types: saprophytes (i.e. decomposers) and mutualists (those which live in association with other organisms, like the plant). Saprophytes feed primarily on residue and decomposing organic matter. Mutualists on the other hand trade food for nutrients with other organisms in the association. Mycorrhizal fungus is an example of mutualistic fungi. They are classified into two major types namely endomycorrhizas and ectomycorrhizas (Figure 3.24 (a) and (b)). Endomycorrhizas also known as arbuscular mycorrhizal fungi penetrate the root cell walls while ectomycorrhizas surround the root mantle to form club-shaped roots and are associated with many tree species, especially conifers.

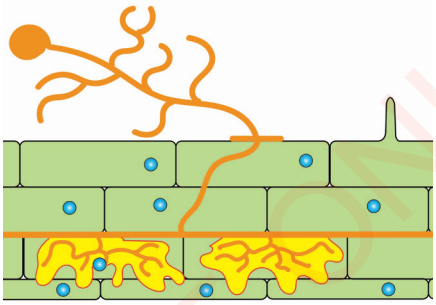

Figure. 3.24 (a): Endo (Abuscular) mycorrhizal fungi

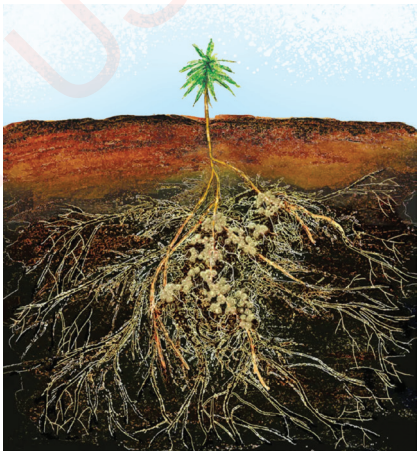

Figure. 3.24 (b): Ecto mycorrhizal fungi on pine tree seedling roots

Mycorrhizal fungal hyphae grow out into the soil, typically 1 to 2 inches and obtain nutrients which are exchanged with the plant for carbon. This allows the roots to efficiently acquire nutrients from outside of depletion zones and deliver these nutrients to the plant in exchange for carbon.

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Many fungi are parasitic, often causing diseases to their living host plant, although some have beneficial relationships with living plants. In terms of soil and humus creation, saprotrophic fungi are the most important as they live on dead or decaying organic matter, thus breaking it down and converting it to forms that are available to higher plants. A succession of fungi species colonizes the dead matter, beginning with those that use sugars and starches, succeeded by those that can break down hard parts of organic matter (cellulose and lignins). It is important to note that there are fungi species with nutritional importance for example different types of mushrooms.

Nematodes

Include fungal, and bacterial feeders, root feeders, predators and omnivores (Figure 3.25 (a) and (b)). Their population and activities are impacted by soil management practices including tillage operations, pesticides and food sources.

Figure. 3.25 (a): Soil nematode

Figure. 3.25 (b): Plant roots affected by parasitic soil nematodes

Protozoa

Soil protozoa include naked amebae, testate amebae, flagellates, ciliates and microsporidia (Figure 3.26). Several species of soil protozoa have been recorded from the soil, many of which have special adaptations to the soil environment. Depending on soil type, the number of protozoa varies from 10 000 –10 00 000 individuals per gram dry mass of soil. Protozoa have important functions in the decomposer cycle and plant growth and are valuable bio indicators natural and anthropogenic influences in the soil system.

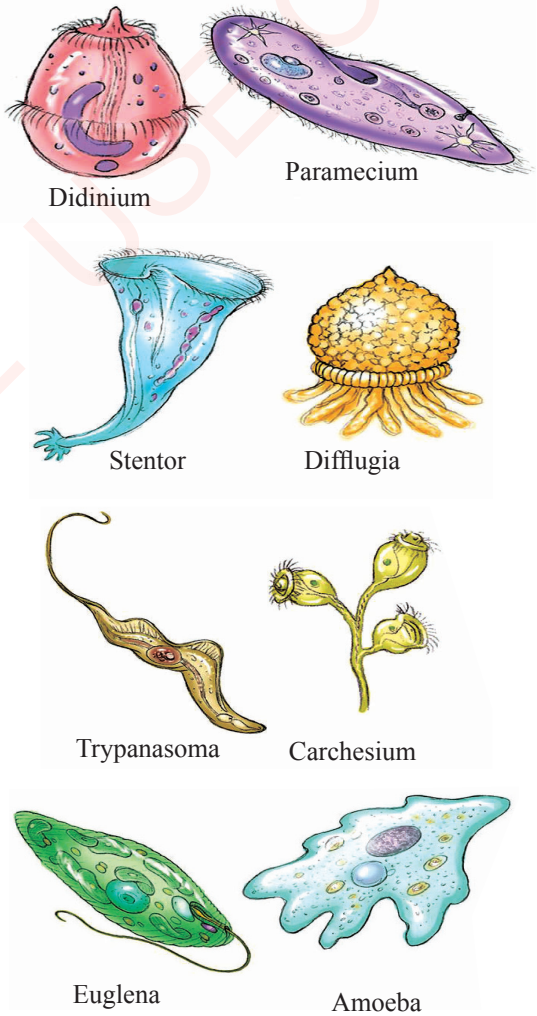

Figure 3.26: Soil protozoa

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Micro-arthropods

Micro-arthropods include mites, spiders, pseudo-scorpions, centipedes, millipedes, symphylans, crustaceans, springtails, and insects (Figure 3.27). Arthropods have segmented bodies, jointed legs, and a cuticle that acts as an exoskeleton. Insects, mites, and spiders belong to arthropods. The two most abundant groups of soil micro arthropods are the collembolans (Animalia; Arthropoda, Insecta) and mites (Chelicerata: Arachnida). They are found on or near the surface of the soil as well as in plant litter. Among the insect micro arthropods, termites play a significant role in disintegrating organic materials into small fractions, initiating the decomposition process and mixing it with the soil or weathered parent material. Soil micro arthropods can impact soil and plant health directly by feeding on pest organisms or serving as alternate prey for larger predatory arthropods. Indirectly, micro arthropods mediate the ability of crop plants to resist or tolerate insect pests and diseases by triggering induced resistance and/or contributing to the optimal nutritional balance of plants

Figure 3.27: Representative soil micro arthropods

Earthworms

Earthworms are terrestrial invertebrate that belongs to the phylum Annelida. They exhibit a tube-like body, externally segmented with corresponding internal segmentation; and they usually have setae on all segments (Figure 3.28). Earthworms are commonly found in soil, eating a wide variety of organic matter including plant matter, living protozoa, rotifers, nematodes, bacteria, fungi, and other microorganisms.

Figure 3.28: Earthworm

Moles

Moles play a beneficial role in the management of soil and the control of undesirable grubs and insects. By tunnelling and shifting soil particles, moles permit better aeration of the soil, help dry out sod, and enable humus (organic matter) to travel deeper into the soil. Their tunnelling also allows subsoil material to be moved closer to the surface, where nutrients may be more available to plant roots. Moles are often blamed for the destruction of bulbs, seeds, and garden plants although they rarely consume plants or plant parts. Moles may, however, damage plants by disrupting their roots as they tunnel underneath them.

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Activity 3.17

In a group, visit a nearby forest area and do the following:

(a) Identify a spot with decaying litter and mark an area of $1m^2$.

(b) Using a hand hoe, scrap the litter and soil underneath to a depth of 15 cm. While doing so, collect and identify soil organisms seen by your naked eyes.

(c) Present your findings in class and discuss specific roles played by each identified organism (b).

Agricultural and environmental application of soil biology

Nutrient cycling

The key nutrients for life are cycled by both microorganisms and macro-organisms. However microbial activities dominate in cycling any given nutrient. The oxygen cycle and carbon cycle are interconnected through the complementary activities of autotrophic and heterotrophic organisms.

The N and S cycles are also mediated by soil microorganisms. Chemical elements such as P, Ca, and Si are also cycled by microorganisms primarily in the aquatic environment. Efficient nutrient cycling reduces the cost of agricultural production because nutrient losses are minimized thus external inputs (fertiliser) are not required, biological control agents become more active thus pesticides are not frequently used. In addition, the water and nutrient use efficiency of crop plants is improved as a result of improved soil physical properties.

Biofertiliser, compost and biogas production

Biofertilisers are substances that contain microorganisms, which when added to the soil increase its fertility and promote plant growth. There are various types of biofertilisers including Nitrogen fixing biofertilisers (Figure 3.29 (a)), Phosphorous solubilising and Phosphorus mobilizing biofertilisers (Figure 3.30 (a) and (b)).

Bacteria and fungi are widely used in agricultural systems to improve the availability of N, S, P and some other nutrients for plant uptake. Nitrogen-fixing bacteria convert nitrogen gas into plant-available forms. The primary source of N for plants is nitrogen gas N_2 which is plenty in the air but not readily available for plant uptake. It is only made available for plants after being fixed into NH_3 by N-fixing microorganisms and subsequently transformed into plant-available forms (NH_4^+ or NO_3^{-1}) by nitrifying bacteria. Sulphur oxidizing bacteria on the other hand convert elemental sulphur (or sulphur dioxide gas (SO_2) into the most oxidized form of sulphur (SO_4) which is available for plant uptake.

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Figure. 3.29 (a): Nitrogen fixing liquid fertilisers

Figure. 3.29 (b): Nodules formed by N fixation bacteria on legume roots

Phosphate bio-fertilisers solubilize rock P or mobilize soil P for plant uptake. The primary source of P is phosphate rock but P in this source is complex and often fixed by Ca making it less available for plant uptake. Phosphate solubilising bacteria are widely used to solubilise phosphate rocks while P mobilizing fungi are employed to scavenge the soil, mobilize soil P and bring it to the plant root hair surfaces thus improving P availability for plant uptake.

Figure 3.30 (a): Phosphate solubilizing bio-fertiliser

Figure 3.30 (b): Phosphate mobilizing bio fertilisers

Decomposers and other microorganisms mediating transformation reactions in the soil are widely exploited for the production of biofertilisers. Compost production (Figure 3.31 (a)) relies on the role of decomposers which use organic wastes as a source of carbon and energy hence releasing nutrients contained in the biomass for plant uptake. Phosphate-solubilizing microorganisms are also used in the production of phosphate-enriched composts (phospho-composts).

Production of biogas (methane gas) also termed as methanogenesis (Figure 3.31 (b)) is catalysed by a group of strictly anaerobic Archaea called methanogens. These organisms are present in freshwater sediments, sewage sludge

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digesters and other bioreactors, as well as in the intestines of warm-blooded animals including human beings. Methanogenesis involves the reduction of carbon dioxide (CO_2) produced by decomposers with hydrogen (H_2) to form methane (CH_4). Methane is used as an energy source and the by-product of decomposition (bio-slurry) is used to fertilize crop plants (Figure 3.31 (b)).

Figure 3.31 (a): Preparation of compost from plant biomass

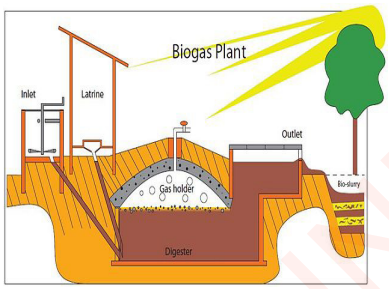

Figure 3.31 (b): Cross section of the biogas production plant

Exercise 3.6

1. How different is Soil biology from the other two branches of soil science?
2. What are the practical applications of soil biology in Agriculture?
3. What would happen to the soil if there were no organisms in it?
4. How different are the bio-fertilisers from mineral fertilisers?

Biological control of soil-borne plant pathogens and Nematodes

Soil microorganisms and plants are in a dynamic equilibrium that reflects biological interactions among organisms. Such interactions can be beneficial, neutral or detrimental to the plant. Soil is the source of many organisms including microorganisms such as bacteria, fungi, nematodes and protozoa; viruses, insects and mites some of which are plant pathogens. Biological control of plant diseases results from the reduction of the inoculum of the pathogen or its disease-producing activity accomplished by one or more organisms other than humankind.

The rhizosphere is a narrow zone of the soil surrounding the plant roots. This zone contains root exudates, sloughed roots, and a large population of soil microorganisms of various nutritional groups. Some of these microorganisms are natural enemies of disease pathogens thus used as biological control agents. Biological control agents reduce the inoculum or disease-producing activities of the pathogen through competition, antibiosis, or hyper parasitism. Biological control is an environmentally sound and effective means of reducing or mitigating soil-borne diseases; and a component of an integrated plant disease management strategy. Examples of soil-borne plant diseases successfully

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controlled using biological agents include Take–all diseases of wheat, crown gall and other diseases infesting belowground plant parts such as seed rots, dumping-off of seedlings, foot rots, root rots and wilts. Biological control agents have also been effectively used to control cereal cyst and root node nematodes.

Bioremediation

This is a strategy or process that uses microorganisms, plants, or specific enzymes produced by microorganisms, plants or both to transform or degrade contaminants in the soil, water and other environmental parameters. Microbial bioremediation is usually achieved by stimulating the activities of native microorganisms in some ways. Although bioremediation is proposed for many pollutants, the technology has recorded great success in cleaning up spills of crude oil and leakages of hydrocarbons from bulk storage tanks. Biological treatments that exploit the ability of some bacteria to reduce soluble uranium (U^{6+}) to immobile U^{4+} have been employed in the bioremediation of uranium contaminated soils and water, thus reducing its movement into groundwater and potential contact with humans and other animals. Microbes are also used in the bioremediation of organic pollutants such as hydrocarbons, pesticides and plastics, polychlorinated biphenyls, dyes, and chlorinated solvents among others because of their capabilities to degrade such compounds.

Soil quality monitoring

The living soil is instrumental to key life support functions that safeguard life on earth. The soil microbes have a main role as a driver of these life-supporting functions. Soil microbes thus can indicate the nature of deleterious changes in the soil system and therefore soil quality change. Several methods have been employed to study microbial populations and their activities in relation to soil quality change. Such methods include microbial biomass-direct microscopy; microbial biomass-dilution plating; microbial biomass-chloroform fumigation/extraction; microbial biomass-substrate-induced respiration.

Revision exercise 3

1. Describe any five managerial practices that result in the poor soil structure.
2. Outline any three disadvantages of cultivating on a sandy soil
3. Describe the following terms:
   (a) soil
   (b) weathering
   (c) soil formation
   (d) soil texture
4. Explain any five management practices that help to improve soil structure.
5. Describe five features of clayey soil.

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6. Outline five steps to be followed in conducting soil separation analysis in a laboratory.

7. Outline any (a) five causes of soil alkalinity (b) five agronomic practices that help to conserve soil (c) differentiate between soil fertility and soil productivity

8. Write short notes on the following:
   (a) soil colloid;
   (b) cation exchange capacity;
   (c) plant nutrition; and
   (d) soil reaction.

9. Explain (a) five characteristics of fertile soil and (b) three causes of soil acidity.

10. Describe (a) five features of soil colloids. (b) Procedures to be followed when measuring soil pH in the field

11. What are the major groups of soil organisms?

12. Outline the applications of soil biology in:
   (a) agriculture;
   (b) industry; and
   (c) environment.

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Chapter Four

Crop pests

Introduction

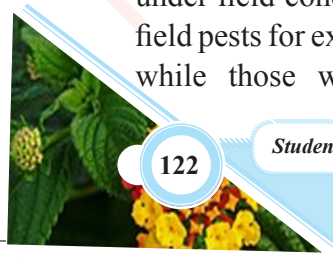
Heavy pest infestation, lowers crop growth rates leading to reduced yields and poor-quality products. If crop pests are not controlled may cause crop yield loss of up to 100 % in the field and 20-30 % during storage. In this chapter, you will learn about the concept of crop pests, with emphasis on morphology, destructive insect pest orders, field and storage insect pests, and their control. You will also learn about non-insect pests and their control. The competencies developed will enable you to identify pest damages and apply principles of pest control for the maximization of crop yield and quality.

The concept of crop pests

A crop pest refers to any organism that causes damage or loss or poses a risk to a desired crop. Therefore, a crop pest can be considered as an organism that is noxious, destructive, or troublesome to man or his interests. Crop pests include some insects, mites, pathogens that cause plant diseases, weeds, some nematodes, snails, slugs, rodents, monkeys, wild pigs and many others. These belong to different taxonomic groups of living things such as plant kingdom (weeds), animal kingdom (insects, nematodes, rodent, molluscs) fungi, protozoans (bacteria virus, mycoplasma). Crop pests occur at any point along the crop production chain that is, from field to storage. Pests that predominantly occur under field conditions are referred to as field pests for example maize leaf hopper while those which occur in storage are termed storage pests for example maize weevil. Infection and infestation of these pests have significant negative impacts on the quantity and quality of the produced crops. In this chapter, insects, rodents, and molluscs pest categories are covered while weeds will be discussed in Chapter Six; and fungi, bacteria, virus, and nematodes as causes of plant diseases, will be covered in Chapter Seven.

Effect of crop pests on crops

Crop pests cause direct damage to crop plants by eating plant leaves and burrowing into fruits, roots and stems. Since the damage caused by pests is visible, it is direct damage. However, the levels and intensity of damage differ, with the most crucial type of direct damage being in the plant part to be harvested. Several insects belonging



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to the orders Coleoptera, Diptera, Deteroptera, Homoptera, Lepidoptera, and Orthoptera cause direct damage to crops, in the larvae and adult stages. The direct damage also predisposes crops to infections leading to plant diseases. It is well established that almost all viral diseases in crop production are spread through insect feeding.

Insect pests like aphids (Aphididae), leaf hoppers (Cicadellidae), plant hoppers (Delphacidae) and other bugs are some insects that do not inflict injury on crops, but they transmit infections (viral, bacterial and fungal) to crops. When such damage is caused by an insect, it is called an indirect damage or injury. For example, aphids, belonging to the order Hemiptera are known to transmit the viral diseases of potato and sugar beet. Crop plants infestation by pests reduces its quality and thus, the market value of their products. Pests feeding on parts of crop plants, especially the leaves, lower the photosynthetic activity of the plant. Leading to reduced amount and quality of photosynthetic/metabolic products produced by the plant.

Classification of most destructive crop pests

Generally, crop pests, are classified based on different criteria such as biological, occurrence, nature of infestation, injury levels and taxonomy as described hereunder:

(a) Biological

Biologically, pests can be categorized as vertebrate (rodents, birds and monkeys), invertebrate (insects, mites, nematodes, molluscs), pathogens (fungi, bacteria, virus, mycoplasma) and weeds. The vertebrate pests which are mammals and birds are collectively called vermin.

(b) Occurrence

Based on frequency of occurrence, pests are categorised as regular pest. These are pests which frequently occur and have close association with the crop. For example, rice stem borer and fruit borer. Regular pest can be occasional, seasonal, persistent or sporadic pests.

(i) Occasional pest: occurs infrequently and have no close association with particular crop. For example, case worm on rice, mango stem borer.

(ii) Seasonal pest: Occurs during a particular season in every year e.g., red hairy caterpillar on groundnut and mango hoppers.

(iii) Persistent pests: Occurs on the crop throughout the year and are difficult to control, for example, chilli thrips and mealy bug on guava.

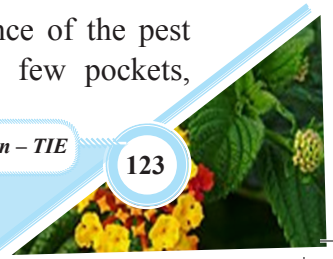
(iv) Sporadic pests: Pest occurs in isolated localities during some period, for example, coconut slug caterpillar.

(c) Infestation

Based on level of infestation pests are categorised as:

(i) Epidemic: Sudden outbreak of a pest in a severe form in a region at a particular time.

(ii) Endemic: Occurrence of the pest in a low level in few pockets,



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regularly and confined to particular area. For example, fruit flies in mango growing areas of eastern zone of Tanzania

(iii) Pandemic, has global occurrence infecting large farm area hence affecting large human population for example, locust.

(d) Injury levels

The damage caused by crop pests sometimes depend on the population levels. Hence there are different parameters used to explain pest population levels. They include general equilibrium position (GEP), economic threshold level (ETL), economic injury level (EIL) and damage boundary (DB). Equilibrium position (GEP) is the average population density over a long period of time around which the pest population tends to fluctuate due to biotic and abiotic factors; and in the absence of permanent environmental changes. The ETL is the population density at which control measure should be implemented to prevent an increase of pest population from reaching pest economic damage. Economic Injury Level (EIL), is the lowest population density that causes economic damage, while, damage boundary (DB), is a lowest level of damage which can be measured. ETL is always less than EIL hence provides sufficient time for control measures. Based on these population parameters, crop pests can be categorised as:

(i) Key pest: A category of most severe and damaging pests, its GEP lies above EIL always and therefore pesticide spray temporarily bring population below EIL. These are persistent pests that the environment must be changed to bring GEP below EIL. e.g., cotton bollworm and diamond back moth.

(ii) Major pest: They have their GEP lying very close to EIL or coincides with EIL for example, rice stem borer. Their economic damage can be prevented by timely and repeated pesticide spraying.

(iii) Minor/Occasional pests: Usually have their GEP below their EIL. They rarely cross EIL and can be controlled by pesticide spraying. Minor pests include cotton stainers, rice hispa and ash weevils.

(iv) Sporadic pests: They have GEP generally below EIL and sometimes crosses EIL and cause severe loss in some places/periods. They include sugarcane pyrilla, white grub and hairy caterpillar.

(v) Potential pests: These are not pests at present and their GEP is always less than EIL, however, if the environment changes may cause economic loss.

For clarity, crop pests are further described under two main categories namely invertebrates and vertebrates:

Invertebrate crop pests

Insect pest being the largest group in the invertebrate pest category, is discussed hereunder with respect to their taxonomic groups of most destructive

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insect pests. Insect pests are classified basing on their characteristic features in relation to their crop destruction. The features include feeding mouth parts, life cycles and insect taxonomy.

Feeding mouth parts

Insect mouth part is one of the criteria used to classify insect pests because they have implications in insect management. Insect mouthparts are of two main types chewing and piercing-sucking (Figure 4.1). Mouth parts determine how an insect feeds and therefore play a role in determining the type of insect control method that is most effective. Insect pests feed on internal or external parts of crop plants which include leaves, buds, stems, roots, fruits and seeds, as well as on plant tissue at various stages of decay. Insect pests that restrict their feeding to one type of plant, are referred to as monophagous. Others may be general feeders and include a diversity of plants in their diet, these are referred to as polyphagous. Insects that are moderately selective in their tastes are referred to as oligophagous. An example is the Colorado potato beetle, which feeds only on plants in the genus Solanum. The common feeding mouth parts of insects are:

(i) **Chewing mouth parts:** Allow the insect to bite or rasp off and swallow solid food. Symptoms of the damage caused by chewing insects include holes in plant tissue, missing leaves, "windowpane" leaves showing bared veins, and scraped areas. Insects with chewing mouth parts feed externally on the plant parts and have strong mandibles. Caterpillars use their chewing mouthparts to consume many times their own weight in plant tissue in the course of their development.

(ii) **Piercing-sucking mouth parts**: Many insect pests which feed on liquid food have a beak, referred to as a proboscis, that is modified to suck up liquids. The "piercing-sucking" mouth parts of such insects have evolved into fine stylets that can pierce plant tissue to extract fluid nutrients. Insect pests with piercing-sucking mouth parts feed on plant sap by piercing plant tissue and extracting plant fluids. Their delicate stylets can penetrate leaves, stems and even tree bark, and are flexible enough to pass between fibrous plant elements and probe to find phloem or vascular bundles. Because they are removing plant fluids, symptoms of their feeding damage include spotting, curling, wilting and ultimately tissue death. Insects with piercing-sucking mouth parts feed internally on plant tissue. Damage results from the removal of plant fluids, the toxicity of insect saliva to the plant, or diseases transmitted by the insect mouth parts. Insects with these mouth parts ingest primarily plant fluids, and their faeces are watery and

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sticky (referred to as honeydew in some insect pests like aphids and a nymph, which resembles a miniature adult (less destructive). Insect pests undergoing complete metamorphosis include wasps, ants, and fleas. Those undergoing incomplete metamorphosis include termites, praying mantis, and cockroaches. Caterpillars of some insect pests are the most destructive stages and in case of a delayed control; the damage can cross the economic injury level within very short time. Hence, in insect pest management, larvae are in most cases the target.

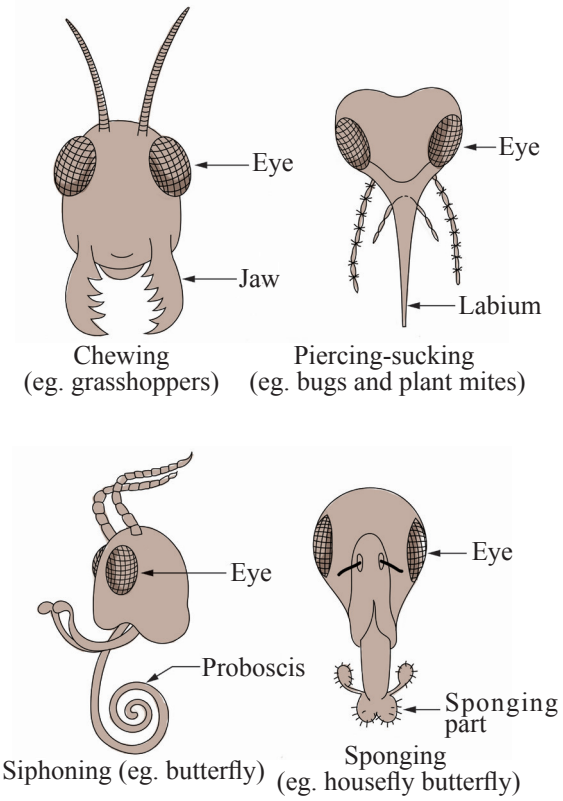

Figure 4.1: Feeding adaptation of insect pests

Life cycle

Based on their life cycle, there are two groups of insect pests, those undergoing complete metamorphosis and those undergoing incomplete metamorphosis. Complete metamorphosis (Figure 4.2 (a)), consists of four stages egg, larva, pupa and adult while, incomplete metamorphosis (Figure 4.2 (b)), consists of three stages: egg, nymph and adult. The main difference between the two life cycles is that, complete metamorphosis consists of a very active, ravenously eating larva and an inactive pupa whereas incomplete metamorphosis consists of

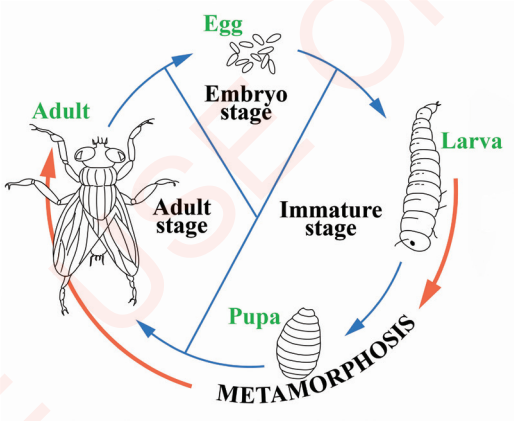

Figure 4.2 (a): Complete metamorphosis

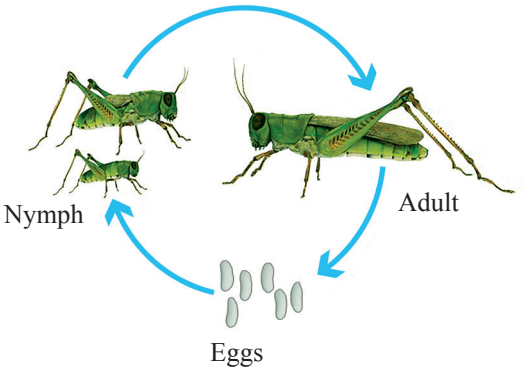

Figure 4.2 (b): Incomplete metamorphosis

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Insect taxonomy

There are over one million species of insects globally that have been described to date. Therefore, the classification of insects can be complex but it is very important to group and identify insect pests into pollinators, and those which provide other ecosystem services so that they can be studied reliably. The scope of insects of agricultural importance in this chapter is limited to arthropods and specifically the class Insecta. The class Insecta is sub-divided into two sub-classes which are Apterygota (wingless insects) and Pterygota (winged insects as well as secondarily wingless insect group whose ancestors once had wings but that have lost them as a result of subsequent evolution) (Figure 4.3).

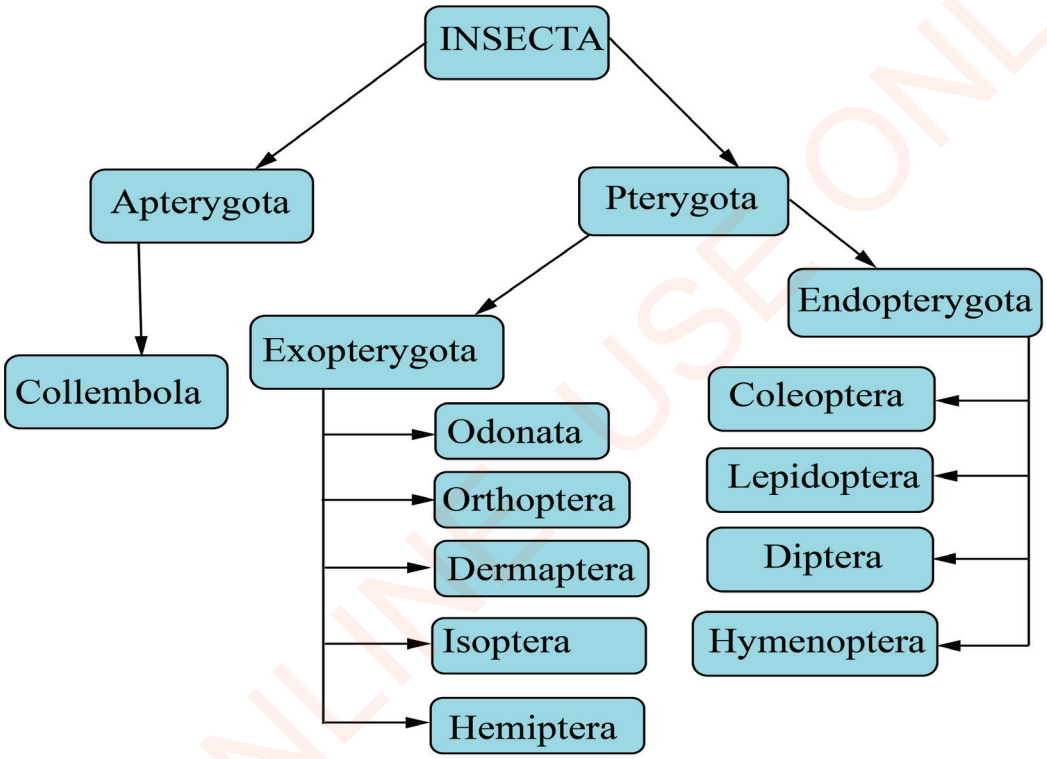

Figure 4.3: Insect classification

The exopterygota refers to the development of the wings outside the body. Insects that belong to this division are said to show incomplete metamorphosis. In the orders of insects that make up the exopterygota, the larvae are usually called nymphs. After one or two moults, developing wings can start to be seen in sheaths on the outside of the nymphs. A time comes when they stop growing and moult again to become adults. They become sexually mature at this final stage (adult stage).

The endopterygota denotes the development of the wings inside the body. Insects that belong to this division are said to show complete metamorphosis.

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In the Endopterygota, the larval stage is completely different from that of the adult and it is wingless until it reaches the last instar. In many cases, the larva feeds on quite different foods and lives in quite different environments from the adult. This gives the species a survival advantage as it does not depend on the same foods or locations throughout its life cycle. The most destructive insect orders are Hemiptera, Orthoptera, Thysanoptera and Isoptera (from Exopterygota division) as well as Lepidoptera, Coleoptera, Hymenoptera and Diptera (from Endopterygota division).

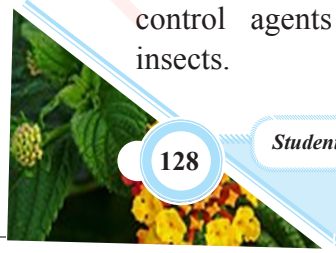
Coleoptera order of insects

The term Coleoptera, is derived from the Greek words 'koleos' meaning sheath and 'ptera' meaning 'wings'. The insects in this order have modified hard front wings which serve as protective cover for the membranous hind wings. This is order of beetles such as long horned beetle, leaf beetle (bean leaf beetle), lady beetle (Mexican bean beetle), snout beetles, weevils, billbugs, click beetles and blister beetles. Many beetles are regarded as major pests of agricultural plants and stored products. They infest all parts of living plants as well as processed fibres, grains and wood products. Scavengers and wood boring beetles are useful as decomposers and recyclers of organic nutrients. The predatory coleopteran species such as lady beetles are important biological control agents of aphids and scale insects.

Generally, the coleopteran insects undergo complete metamorphosis (holometabolous). They are found in soil, water or in fruits. Adults and larvae have biting and chewing mouth parts which sometimes are located at the tip of a beak or snout. They have uniformly leathery or rigid, veinless pair of fore wings and membranous pair of hind wings. They have hard front wings (elytra) which meet in a line down the middle of the back. These elytra wings serve as covers for the hind wings. Their hind wings are relatively large, membranous and folded beneath the elytra. The adult coleopterans have hardened dense exoskeleton. Some coleopteran crop pests including maize weevil, rice weevil, large grain borer, lesser grain borer, red flour beetle, saw-toothed grain beetle, cadelle beetle and coconut beetle, have been selected and elaborated hereunder.

(a) Maize weevil

The maize weevil (*Sitophillus zeamais)* is a pest that destroys stored maize, wheat, rice and paddy. The adults and larvae feed internally on stored maize grains or in the field. Adults are reddish-brown and their elytra are usually with four reddish spots. The weevil also has a well-defined snout and elbowed or clubbed antennae. The larvae are legless and they remain inside the grain. Early detection of infestation is difficult as the pest's larvae feed on the interior of individual grains, often leaving only the hulls. A speck of flour-like grain dust mixed with frass is obvious in severe infestation. The infested grains



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contain holes through which adults have emerged. A possible indication of infestation is grain when placed in water it floats to the surface. In large stores of grain, an increase in temperature may be detected. The most obvious sign of infestation is the emergence of adults. Both adults and larvae feed but larva cause the most damage. Figure 4.4 (a) and (b) are shows maize weevil and its damage in maize grains. This pest can be controlled by fumigation.

Figure 4.4 (a): Maize weevil

Figure 4.4 (b): Maize grains damaged by maize weevil

(b) Rice weevil

The rice weevil (*Sitophillus oryzae*) is a stored product pest which infests seeds of several crops including paddy, wheat, sorghum and maize. Adults weevil have a long snout. They have brown/ black coloured body with four orange/ red spots arranged in a cross on the wing covers. It can easily be confused with the maize weevil, however, maize weevil is larger than the rice weevil. The female adult weevil drills a tiny hole in the grain kernel through which it deposits its egg and then plugs the hole with a gelatinous substance. In the grain kernel, the egg hatches into a young larva which migrates toward the centre of the grain kernel, feeds, grows and develops into a pupa. Surface drilling of grain may result into dampness which may even cause germination. Since rice weevil transform from egg to adult and isolate themselves in the grain kernel, they can be difficult to control. Therefore, an effective way to control them is to kill the adults on contact with an appropriate pesticide or use hermetic storage bags which prevent an entry and kill the weevil by suffocation. Figure 4.5 (a) and (b) shows rice weevil and its damage to rice grains.

Figure 4.5 (a): Rice weevil

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Figure 4.5 (b): Rice grains damaged by rice weevil

(c) Large grain borer

The large grain borer (*Prostephanus truncatus*) is one of the major pests of stored crops such as maize, dried cassava and yam tubers throughout Africa. Even though it is considered as a post-harvest pest, the pest infests maize both before and after harvest. The adult pest has cylindrical body which is dark brown in colour. It has rows of teeth on the front edge of the thorax. Head turned downwards beneath thorax. The ends of wing covers are flattened with two curved ridges at the tips. The larvae are white, grub-like, thinly covered with hairs and have three pairs of legs. Figure 4.6 (a) and (b) shows larger grain borer and its damage to grains.

Figure 4.6 (a): Large grain borer

Figure 4.6 (b): Maize grains damaged by larger gram borer

The adult larger grain borer, bores into maize cobs, husks and grains leaving tunnels and empty grain shells producing large quantities of grain dust. The pest prefers grains that are still attached to the cob rather than loose-shelled ones, therefore their damage is often greater on unshelled maize. The pest often bore into the wood used to construct stores in which the grains are kept. The adult females lay eggs inside the tunnels or near the food source. The larvae bore into the grains or feed on the dust produced by the adults and pupate in the grain, cob or dust.

(d) Lesser grain borer

The lesser grain borer (*Rhyzopertha dominica*) is a cosmopolitan pest which eat a wide variety of food including cereals and cassava. It is a small reddish-brown to black-brown beetle. The overall shape of its body is slim and cylindrical. It has a hood shaped rounded neck shield which extends over the head. It has pits on the shield which gradually become smaller towards the rear. The last three segments of its antennae form

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a loose club. The adult pest can fly. They bore hole in the grain leaving behind a powder from chewed-up grain. During the initial stage of infestation, maize stacks show a sprinkling of white spots of grain dust. In advanced stage of infestation, the entire outside of the bags become covered with dust. Figure 4.7 (a) and (b) shows lesser grain borer and its damage to grains.

Figure 4.7 (a): Lesser grain borer

Figure 4.7 (b): Grains damaged by lesser grain borer

(e) Red flour beetle

The red flour beetle (*Tribolium casteneum*) infests stored cereal grains, groundnuts and other food products including flour, oil seedcakes and rice bran causing damage and loss. Their larvae do not form cocoon and they feed on flour, grain dust and broken grain kernels. Adults rarely fly. These beetles cannot feed on whole undamaged grain therefore, they often find flour and dusts resulted from infestation of primary pests. In undamaged grains, these beetles do not cause damage by feeding but they contaminate the grain. Large numbers of dead bodies, cast skins, faecal pellets, and liquids (quinones) can lead into pungent odours in grain. The nauseous smell and taste caused by infestation of *T. casteneum* can result in poor feed consumption and rejection by grain buyers. Figure 4.8 (a) and (b) shows red flour beetle and its damage to grains.

Figure 4.8 (a): Red flour beetle

Figure 4.8 (b): Grains damaged by red flour beetle

(f) Saw-toothed grain beetle

The saw-toothed grain beetle (*Oryzaephilus surinamensis)* is a common worldwide pest of cereal grains

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and milled products. It is a slender, dark brown beetle with characteristic 'large teeth' running down the side of the prothorax. Adult beetles have small eyes as well as triangular head and are unable to fly. The larvae are yellow-white with brown heads and they crawl freely around the food mass. These larvae feed on broken pieces of grain or grain kernels damaged by other insects and they pupate by constructing cocoon-like coverings using broken pieces of grain. Feeding results in shrinkage of the dry mass of the infested product and increased water content due to the metabolic activity of the insects which can result into mould growth. The beetle damage in grain, decreases value of the crop and can make it unfit for economic use. The presence of insect remains fragments or live insects can result in rejection of the grains by the buyers. Figure 4.9 (a) and (b) shows saw-toothed grain beetle and its damage to grains.

Figure 4.9 (a): Saw-toothed grain beetle

Figure 4.9 (b): Grains damaged by Saw-toothed grain beetle

(g) Cadelle beetle

The cadelle beetle (*Tenebroides mauritanicus)* is a cosmopolitan and common pest in storehouses and granaries as it affects most cereals and flours. It is also one of the largest and longest-lived insects that infests stored grain. It is a very destructive insect pest which is easily dispersed. Adults are dark brownish to black with narrow prothorax at its junction with the elytra. Larvae are white with distinct black spot behind the head. *T. mauritanicus* can sometimes produce irregular holes in undamaged kernels as it prefers the seed germ but will also eat endosperm. This beetle is commonly found in wooden bins. Both larvae and adults will bore into wood surfaces during their development cycle. Adults predate upon other insects infesting grain. Both adults and larvae feed on grain and grain products and damage feedstuff rich in protein or fat such as the embryos of cereal grain. Figure 4.10 shows (a) cadelle beetle and (b) its damage to wheat grains.

Figure 4.10 (a): Coconut beetle

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Figure 4.10 (b) Wheat grains damaged by cadelle beetle

Figure 4.11 (a): Coconut beetle

Figure 4.11 (b): Damaged coconut plant

(h) Coconut beetle

The coconut beetle (*Oryctes rhinoceros)* is a pest species occurring throughout the tropical regions of the world. It is also called coconut rhinoceros beetle. Adults can cause extensive damage to economically important wild and plantation palms. The larvae feed on rotten wood (oil palm and coconut stem in particular) and rotting plant matter (empty bunches, compost) provided there is enough moisture. *Oryctes rhinoceros* mainly infests coconut and oil palm. The adults attack the terminal buds in the crown of coconut palms eating unopened leaves and occasionally destroying the growing point. If the leaves are eaten, the result is reduction in photosynthetic area. If the growing point is eaten, the coconut plant dies. Figure 4.11 (a) and (b) shows coconut beetle and its damage to coconut plant, respectively.

Activity 4.1

Perform the following tasks:

(a) Consult different literatures/ internet search to find other destructive orders of insect;

(b) Collect insect pests in surrounding environment and group them according to their destructive insect orders classify them to species level.

Lepidoptera order of insects

The name Lepidoptera is derived from two Greek words 'lepido' for scale and 'ptera' for wings thus refers to the flattened hairs (scales) that cover the

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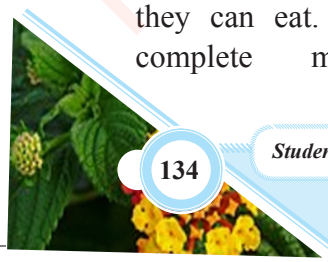
body and wings of most adults. The main insects included in this order are moths and butterflies. For example, the diamond backmoth *(Plutella xylostella),* American bollworm (*Helicoverpa armigera*), Tropical warehouse moth *(Ephestia cautella)*, maize stalkborers (*Busseola fusca*), cutworms (*Agrotis ipsilon),* and armyworms (*Spodoptera exempta*). Although many lepidopterans are valued for their beauty and a few are useful in commerce e.g., the silkworm (*Bombyx mori*), the larvae of these insects are more destructive to agricultural crops and forest trees than any other group of insects. Nearly all lepidopteran larvae are called caterpillars. They have a well-developed head with biting and chewing mouth parts. Most lepidopteran larvae are herbivores. While the larvae of some species eat foliage, some burrow into stems or roots, and some are leaf-miners.

Generally, the lepidopteran insects are important order of pollinators and destructive pests. While some adults have plumose antenna particularly butterflies, others have capitate antennae especially moths. Adult's front wings are large, triangular and hind wings are large and fan-shaped. Adult's body and wings are covered with small and overlapping scales. At adult stage, they have siphoning mouth parts and they feed on flowers nectars as well as juices. At larval stage, they have biting and chewing mouth parts and they feed on plant leaves as well as other parts that they can eat. Lepidopterans undergo complete metamorphosis. Some lepidopteran crop pests will selectively be elaborated here. These include African maize stalk borer, American bollworm, black cutworm, black armyworm, and warehouse moth.

(a) African maize stalk borer

The African maize stalk borer *(Busseola fusca)* is indigenous to Africa. It is widespread pest but its distribution and pest status vary with the regions. In East and Southern Africa, it is a pest at higher altitudes about 600 m above sea level (ASL) but in Central Africa it occurs from sea level to over 2000 m. African maize stalk borer infests maize, sorghum, millet, sugarcane and wild grasses. The damage of the pest is caused by the caterpillars which first feed on young leaves (leaving holes and windows) then enter into the stems. At early and heavy infestation, the growing points can be damaged resulting into 'dead-heart effect' where the youngest leaves can be easily pulled off. At a later stage of growth, they make extensive tunnels inside the stem. This interrupts the flow of nutrients to the grain. Tunnelling can weaken plant stems to the extent that they break and fall off.

In older plants, the first-generation caterpillars bore in the main stem but later some of the second generation bore into the maize cobs. Caterpillars also tunnel into the peduncles of sorghum and millet inflorescences and may seriously affect grain production. To manage African maize stalk borer, cut maize stalks after harvest to ground level and leave them to dry. Clear all remains of



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the previous maize crop after harvest if the field was heavily attacked by stalk borers. Plough deeply, then harrow. Plant early, at the beginning of the rains or in the next two weeks. Figure 4.12 (a) and (b) shows African maize stalk borer and its damage to maize stalk/stem.

Figure 4.12 (a): African maize stalk borer

Figure 4.12 (b): Damaged maize stalk by the borer

(b) American bollworm

The American bollworm *(Helicoverpa armigera)* is an insect that can adapt in a wide range of temperatures from temperate to tropical climate. It is a strong flier and it can fly for hundreds of kilometres. The bollworm larva looks like a grub and is about the size of a match stick. The larva has two lines on its back running from its head to its tail. The worm infests and feeds on the inside of buds, flowers and bolls of several crops including maize, cotton, beans, sorghum, tobacco, legumes as well as various vegetables and flowers. The caterpillars bore into young maize cob or seeds to other crops when they are in milk ripe condition. Silk of a cob appears to be eaten in case of maize.

Secondary infections by fungi and bacteria are common and may lead to rotting of fruits, seeds or cob. Clear circular holes are bored in flower bud in case of cotton plant and blooms that have been attacked may open prematurely and stay fruitless. When the bolls are damaged, some will fall off and others will fail to produce lint or produce lint of an inferior quality. Injury to the growing tips of plants may disturb their development, maturity may be delayed, and the fruits may be dropped. The larvae of the worm can be controlled by use of proper insecticides which are safer to environment under the advice of extension workers or other reliable experts. Figure 4.13 (a) and (b) shows American bollworm and its damage to a fruit plant.

Figure 4.13 (a): American bollworm

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Figure 4.13 (b): Fruit damaged by American bollworm

(c) Black cutworm

Black cutworm (*Agrotis ipsilon*) is a small noctuid moth found worldwide. Caterpillars of this moth live in the upper layers of the soil and eat through the stems of young plants at ground level. Cutworms hide under litter or soil during the day, coming out in the dark to feed on plants. They infest vegetables, maize, sugarcane, tobacco, coffee, sunflowers and others. During the day the caterpillars remain in the ground where they feed on the roots of the host plant. At night they emerge and feed on the stems of young plants that fall over as a result. The cutworms, also damage tuber crops and seedlings leading into stunted growth, wilting and falling down of plants. In small farms, black cut worms can be controlled by manual collection of the larvae whereas in large farms, application of suitable granular insecticide to soil is recommended. Figure 4.14 (a), (b) and (c) shows black cutworm and its damage to a seedling plant, respectively.

Figure 4.14 (a): Adult black moth

Figure 4.14 (b): Larval black cutworm

Figure 4.14 (c): Damaged plant

(d) African armyworm

The African armyworm *(Spodoptera exempta)* lives in tropical and subtropical environments. Larvae of armyworms, are obligatory migrants, that is, all individuals emigrate from the site of their emergence. The symptom of armyworms attack, is gross feeding damage to foliage, growing points and young stems. Severe infestation results

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in total defoliation or destruction of the plant to ground level. The caterpillars defoliate the entire crop. They infest crops such as maize, sorghum, rice and forage crops. Ultra Low Volume (ULV) spraying is the most efficient method of armyworm control as it allows rapid treatment of large areas with low volumes of insecticide. Figure 4.15 (a), (b) and (c) show African armyworm and its damage to maize field.

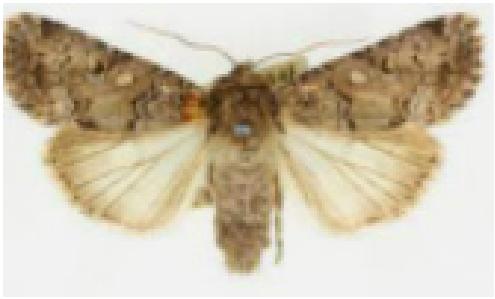

Figure 4.15 (a): Adult African Armyworm

Figure 4.15 (b): African army worm

Figure 4.15 (c): Maize damaged by African armyworm

(e) Warehouse moth

The warehouse moth *(Ephestia cautella)* is a storage pest of rice, sorghum, oil seeds, spices and animal feeds. The body of adults is pale-brown. The forewings are brown with elongated pale or greyish stripes and short fringes. The hind wings are whitish with brown veins and pale fringes. The larvae are pink-grey with black heads and dorsal dark spots that bear short setae. In heavy infestations, larva leaves the grain and pupates in places such as walls or cracks. The larvae of the moth can infest whole grain however, it prefers broken, damaged grain or meal. They may also result into dense silk webbing and silk cocoons. An additional damage to stored products is due to the need to remove the abundant or dense webbing which also contains faecal pellets, cast skins and egg shells. This pest can be controlled by fumigation followed by an insecticide treatment of all associated cracks and crevices that may serve as a hiding place for the pest. Figure 4.16 (a), (b) and (c) show warehouse moth and its damage.

Figure 4.16 (a): Warehouse moth

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Figure 4.16 (b): Damages on maize grain by warehouse moth

Activity 4.2

1. Search or consult relevant literatures, identify five field insect pests and five storage insect pests; then, based on their characteristic features, classify them into orders:
   (a) Coleoptera; and
   (b) Lepidoptera.
2. Summarise your observations in your portfolio and share it in class.

Hemiptera order of insects

The order Hemiptera is very large, previously it consisted of two suborders namely Heteroptera and Homoptera. Currently, the sub-order Homoptera is no longer used and the insects within it have been reclassified into three new suborders which are Auchenorrhyncha, Coleorrhyncha and Sternorrhyncha. Therefore, current suborders of Hemiptera are Heteroptera (bedbugs), Auchenorrhyncha (leaf hoppers), Coleorrhyncha (peloridiidae) and Sternorrhyncha (aphids). Figure 4.17 (a), (b) and (c) show different insect species in the order Hemiptera.

Figure 4.17 (a): Green leafhopper

Figure 4.17 (b): Bedbug

Figure 4.17 (c): Aphids

The name heteroptera comes from the Greek words ‘hetero’, which means different and ‘ptera’ which means wings. This is because their front wings have various textures whereby, near the

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base it is leathery, while at the apex it is membranous. This sub-order includes pests such as shield bugs, assassin bugs, water striders, stink bugs and bed bugs. The name auchenorrhyncha, comes from the Greek words 'auchen' which means neck and 'rhyncos' which means nose or snout. It refers to the position of the mouth parts which arises from the back of their head near the neck region. It includes insects such as cicadas, spittle bugs, treehoppers and leafhoppers. The name 'sternorrhyncha' comes from the Greek words 'sterno' which means chest and 'rhyncos' which means nose or snout. This refers to the position of the mouth parts which reside between the front legs and near the chest. This suborder includes insects such as the peloridiidae. The suborder coleorrhyncha comes from the Greek words 'koleos' which means sheath and 'rhyncos' which means nose or snout. These insects have a sheath that surrounds their mouth parts and they include aphids, scale insects and whiteflies.

Generally, hemipteran insects bear two pairs of wings; however, a small percentage do not have hind wings. They have either leathery or membranous forewings that are noticeably thicker and opaquer on the front half than on the rear half. Their hind wings are membranous. When the insects are at rest (not flying), the hind wings are folded flat and concealed beneath the fore wings, that is, fold together over the back in a roof-like shape. When the insects are at rest, the forewings (known as hemelytra) lie on one another in such a way that they create a triangular shape over the back. The hemipteran insects have piercing and sucking mouths parts and they undergo incomplete metamorphosis.

Maize leafhopper (*Cicadulina mbila)* is a hemipteran which is among the field insect pests. The adult leafhoppers are about 3 mm long, slender and cream to pale yellow green. They have two small black spots between the eyes and brown marks behind the eyes extending along the body. and brown lines along the wings. They usually hop away when disturbed. They directly cause damage to plants by sucking. Although their direct damage is insignificant, but the indirect damage is high, this is because maize leafhoppers are the most importer vectors that transmit maize streak virus Figure 4.18 (b).

The maize streak virus causes maize streak virus disease which is one of the major diseases of maize. The disease causes extensive damage to maize in most parts of Tanzania. The major host plants of the leafhopper are maize, sugarcane and other cultivated and wild grasses. Generally, the attacked plants show no signs of insect damage. Maize leafhoppers can be controlled by using persistent systemic insecticides applied either as a seed dressing or soil application at planting. However, the safeness to environment and cost effectiveness should be assessed before application. Figure 4.18 (a) shows maize leafhopper.

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Figure 4.18 (a): Maize leaf hopper

Figure 4.18 (b): Symptoms of maize streak virus disease

Activity 4.3

Conduct a field visit in a nearby farm and:

(a) Find out more insect pest which fall in the order Hemiptera;

(b) Write description on their economic importance in crop production; then,

(c) Present your findings in class for discussion.

Orthoptera order of insects

'Orthoptera' means straight wings. This means the front wings, called tegmina, are stiff, straight and not used for flying. The back wings are membranous and are folded like a fan under the front wings when the insect is not flying. Many species use their wings to make sounds which we usually call 'chirping' noises. Orthoptera contain important pest species such as; locusts (*Locusta migratoria)* and grasshopper (*Zonocerus elegans* and *Zonocerus variegatus*) which attacks crops such as cassava, cucurbits, citrus and grasses. Figure 4.19 (a) and (b) show some species of insects in the order Orthoptera.

Figure 4.19 (a): Locusts

Figure 4.19 (b): Grasshoppers

Generally, orthopteran insects feed on foliage of many cultivated crops. They have typical biting and chewing mouth parts. Nymphs resemble adults but they have wing pad or are wingless. They undergo incomplete metamorphosis (hemimetabolous). They have enlarged hind legs which assist them in working

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and jumping. Their eggs are laid in grass sod and incubated in the soil.

Activity 4.4

Conduct a field visit on either field or grain store to perform the following tasks:

(a) Observe the effects of Othopterans feeding on different plants or grains;

(b) Identify plant parts/grain which are mostly preferred by the respective insect;

(c) Based on the nature of damaged observed, suggest the feeding adaptation of the responsible pest; then,

(d) Write a precise report on your observation and share it in class.

Thysanoptera order of insects

This refers to insects with two pairs of slender wings that bear a dense fringe of long hairs. This is the order of thrips. Most of Thysanoptera species have rasping and sucking mouth parts that can cause damage to plants. They feed on plant tissues often in flower heads by puncturing and sucking up the contents but some are predators of mites and various small insects. Many Thysanoptera species are parthenogenetic. Adults may be winged or wingless however, immature Thysanoptera are always wingless. When present, the wings are slender and rod-like with a dense fringe of long hairs. Their heads are narrow anteriorly forming a conical mouth opening. They have cylindrical or spindle-shaped bodies (Figure 4.20). They undergo incomplete metamorphosis (hemimetabolous). Many thrips are destructive pests of plants especially grain crops, fruits, vegetables and ornamentals. Their feeding activities result in plant deformities, scarring and loss of yield and in some cases transmission of plant pathogens.

Figure 4.20: Thrips

Activity 4.5

Conduct a field visit and do the following tasks:

(a) Identify plants attacked by Thysanopterans;

(b) Find out which deformities are caused by Thysanopterans;

(c) From the collection, identify all insects belonging to order diptera then,

(d) Write a report and present in class for discussion.

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Diptera order of insects

The name diptera is derived from the Greek words 'di' meaning two and 'ptera' meaning wings. This order includes all true flies. They live in aquatic (fresh water), semi-aquatic or moist terrestrial environments. They are commonly found in the soil, plant or animal tissues as well as carrion and dung. The diptera insects probably have a greater economic impact on humans than any other group of insects. On one hand, some flies are pests of agricultural plants while others transmit diseases to humans and domestic animals. On the other hand, many flies are beneficial particularly those that pollinate flowering plants and those that assist in the decomposition of organic matter or serve as bio-control agents of insect pests. Dipteran larval is the most destructive stage as they destroy root and seeds and some are leaf miners. The larvae of diptera differ from other insects as they are legless and will either have a head with chewing mouth parts (culiciform) or no head but having rudimentary mouth hooks (vermiform) for feeding. Figure 4.21 (a) and (b) show fruit fly and its larva respectively.

Figure 4.21 (a): Fruit fly

Figure 4.21 (b): Fruit fly larva

In general, the adults' fore wings of dipterans are membranous and clear. Their hind wings are represented by a pair of slender, club-shaped structures called halters which is used to form balancing organs (stabilisation during flight). The adults' mouth parts are formed for rasping, sponging, sucking or piercing and sucking. Some of dipterans are parasites of mammals. Some members of the order cause a great amount of damage to crops, e.g., root maggot flies (vermiform larvae type). The flies also have complete metamorphosis.

Activity 4.6

1. Conduct a farm visit to perform the following tasks:
   (a) Collect some winged and wingless insects;
   (b) Keep them dry by pinning them on boards in the laboratory for identification and further studies; then
2. Summarize your observations in the portfolio and share it in class.

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Isoptera order of insects

The term isoptera is derived from two Greek words 'iso' meaning equal and 'ptera' meaning wings, thus it refers to the similar size, shape and venation of the four wings. Termites are the only hemimetabolous insects that exhibit true social behaviour. They build large communal nests that house an entire colony. Each nest contains reproductive adults (one queen and one king) plus hundreds or thousands of immatures that serve as workers and soldiers. Termites are an important part of the community of decomposers. They are abundant in tropical and subtropical environments where they help to break down and recycle up to one third of the annual production of dead wood.

Termites become economic pests when their appetite for wood and wood products extends to building materials, forests, and other commercial plant products. This order includes the eastern subterranean termite (*Reticulitermes flavipes*), the western subterranean termite (*Reticulitermes hesperus*), and the Formosan subterranean termite (*Coptotermes formosanus*), Pacific dampwood termite (*Zootermopsis angusticollis*), western drywood termite (*Incisitermes minor*) and forest tree termite (*Neotermes connexus*). Figure 4.22 (a), (b) and (c) show different species of termites.

Figure 4.22 (a): Formosan subterranean termite

Figure 4.22 (b): Forest tree termite

Figure 4.22 (c): Eastern subterranean termite

Generally, the immature isopterans have pale coloured bodies which are somewhat ant-like in appearance but with a broader junction between thorax and abdomen. They have small or absent compound eyes. They have large and cylindrical head or small and round with beaded antennae. They have biting and chewing mouth parts and sometimes with large mandibles. They also undergo

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incomplete metamorphosis. The mature or adult isopterans have darkly pigmented bodies. They have two pairs of membranous wings, both similar in shape and size and always shed after mating.

Hymenoptera order of insects

The term hymenoptera, is derived from two Greek words 'hymen' meaning membrane and 'ptera' meaning wings. The name is appropriate not only for the membranous nature of the wings, but also for the manner in which they are joined together as one by the hamuli. This order includes ants, wasps, bees, sawflies and horntails. Although some species are regarded as pests (e.g., sawflies, gall wasps and some ants), most members of the hymenoptera are beneficial. This is because they are either natural enemies of insect pests (parasitic wasps) or pollinators of flowering plants (bees and wasps). Figure 4.23 (a), (b) and (c) show different insect in the order hymenoptera.

Figure 4.23 (a): Wasps (*Apidinocarsis lopez*)

Figure 4.23 (b): Ants (*Solenopsis invicta*)

Figure 4.23 (c): Bee (*Aidae curcubilata*)

The hymenopteran insects have some general characteristics. The immature sawflies are eruciform (caterpillar-like) with well-developed head capsule, chewing mouth parts and fleshy abdominal pro-legs. The immature bees and wasps are grub-like and have well-developed head with chewing mouth parts and have legs and eyes. The immature parasitic wasps have a body form that is highly reduced and they lack head, eyes and appendages. The adult hymenopterans have chewing and lapping mouth parts except in bees where maxillae and labium form a proboscis for collecting nectar. They have well developed compound eyes, their hind wings are smaller than front wings

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linked together by small hooks (hamuli). They undergo complete metamorphosis.

Activity 4.7

Re-visit the collected pests in the laboratory (refer Activity 4.6) then:

(a) Identify hymenopterans of agricultural importance.

(b) Discuss in a group how the insects can be managed both at school and home environment.

(c) Summarise your deliberations and present in class for discussion.

Mites

Mites are actually arachnids and more closely related to spiders. They have eight legs and a two-segmented body. Mites in crop plants are difficult to diagnose due to their tiny size. Spider mites and cassava green mites are the easiest mite varieties to recognise. These are discussed hereunder:

(a) Spider mites

Mites are prolific breeders and their populations can reach a damaging level very quickly. They hibernate as adults or eggs on leaf debris, bark crevasses, or even on stems. These versatile little insects not only reduce plant vigour but can also transmit some dangerous viruses and diseases. Plant mites feed by piercing plant cells and feeding on internal fluids. This kind of feeding, leave necrotic or yellowing spots in plants. Speckling on foliage is a classic sign of mite activity. These insects produce fine webbing that lightly nets leaf tips and stems. Spider mites attack a wide range of plants from indoor to outdoor specimens. There are also plant specific mites such as spruce mites or honey locust and spider mites. Figure 4.24 (a) and (b) show spider mites and its effect.

Figure 4.24 (a): Spider mites

Figure 4.24 (b): Webbed plant leaf

(b) Cassava green mites (*Mononychellus tanajoa)*

The cassava green mite is an important pest of cassava in Africa that can cause significant yield loss. The mite can easily be spread by wind on leaves of the plants from one place to another. An integrated approach is required to control the pest and reduce the damage. Cultural practices, such as using clean planting material, planting early in the rain season and intercropping with pigeon pea, can reduce populations

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of the pest. The host plants of cassava green mites are cassava plants.

Damage symptoms of cassava green mites

Mites attack the plant by sucking fluids out of the cells of the plant tissue, which causes chlorotic spots (yellow spotting) to appear on leaves due to the loss of chlorophyll (green pigment); The leaves may become mottled and die. These symptoms can be confused with cassava mosaic virus, but cassava mosaic virus causes larger greenish-yellowish patches and leaf distortion. A severe attack by Cassava green mite causes the terminal (or newest) leaves to die and fall off, and the shoot tip to look like a 'candle stick'. Figure 4.25 (a) and (b) show cassava green mites and its damage to cassava plant.

Figure 4.25 (a): Cassava green mite

Figure 4.25 (b): Damaged cassava leaves

Molluscs

Molluscs are invertebrate of a large phylum Mollusca which includes snails, slugs, mussels and octopuses. They have a soft un-segmented body, they live in aquatic or damp habitats, and most kinds have an external calcareous shell. Many aquatic and terrestrial molluscs are pests. Certain snails act as intermediate hosts of human and animal diseases. Also they destroy plants by eating roots, seedling, seeds and tuber of nearly all vegetables, oil plants, field crops, ornamental plants as well as fruits in field, garden and green houses. Terrestrial molluscs damage vegetables, potatoes, cereal, lettuce, cabbage, carrots, maize, clover as well as other horticultural and agricultural crops.

Most of the slugs eat a wide array of broadleaf plants and grasses including most crops and weeds by killing seedlings, hence, causing poor stands and damage to the leaves of young plants. They feed by scraping the surface of host plants. Molluscs feed by means of a file-like tongue (radula) which cuts through plant tissue held by the soft mouth, and scoops out cavities in affected plants. In moist warm weather they may cause above-ground damage on leaves of plants such as border plants, establishing turf, lettuce and Brussels sprouts. Slugs move slowly by means of an undulating foot, the slime trails from which may indicate the slug's presence. Figure 4.26 (a) and (b) show effects of molluscs (slugs and snail) on plants.

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Figure 4.26 (a): Slugs

Figure 4.26 (b): Snail

Activity 4.8

In a group or individually, perform the following tasks:

(a) Visit any nearby crop field and storage facility to observe effects of non-insect pests such as weeds, pathogens, mites and molluscs;

(b) Propose possible control measures of each observed non-insect pests in (a) above; and

(c) Write a precise report on your observation and share it in class.

Vertebrate crop pests (vermin)

There is no common definition of the term vermin, however, most people have referred to vermin as animal pests ranging from, rodents (rats, moles, squirrel, mice, gerbils and porcupines), birds (*Quelea quelea*, weaver bird and mouse bird) to large animals (wild pigs, monkeys, hippopotamus, warthogs, elephant, buffaloes, antelopes and apes). Animals are referred to as vermin when they invade crop plants and cause damage. Otherwise, when they are in their natural habitats, they do not qualify to be called vermin. It is important to note that some of the animals categorised as vermin, are useful to man for example, elephant and hippos, and their control must be authorised by the Natural Resource Department. The habitants for most vermin species are wilderness where they usually live in harmony with most other animal species than with man.

Rodents

Rodents are vermin but deserve a special attention here due to their abundance and the damage they cause on crop and other properties. There are many species of rodents worldwide, only few of which are considered important pests. Field mice occasionally eat newly planted seed or new seedlings of crops such as maize and beans and rats can be a serious pest of grain crops in the field. Squirrels eat sown seeds, dig up and eat roots and tubers. And sometime, climb up maize stalk to eat grains/cob. Porcupines and hedgehogs are serious pests to green maize, roots and tubers crops such as potatoes, cassava and cocoyam. Moles live in burrowed tunnels under the ground, it eats the roots and pulls plant materials underground and causes damage to almost all crops in this way.

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Rodents are versatile feeders as they feed on grasses, roots, leaves, shoots, seeds, grains and fruits. Extent of their movement depends upon the distribution of food, water, harbourage, barriers, predators, radical changes of habitants, and finding mates. Rodents have been a successful group of animals as they can essentially adapt to a variety of environmental conditions. Their small body size, make them to hide easily from predators, their high reproduction rate and feeding on almost all food stuffs, help to maintain their population. Rodents also serve as a suitable reservoirs or carriers of various diseases including those caused by micro-organisms, such as viruses, bacteria, protozoa, fungi, helminths and rickttsia. Most of these microorganisms are transmitted between and within rodents.

Despite their negative effects, some rodents have social economic benefits. For example, African giant pouched rat (*Cricetomys spp)* 'panyabuku' in Swahili, are trained and used to diagnose human diseases such as TB. Also they are used in detecting landmines in post conflict areas, and used as lab animals Figure 4.27 (a), (b) and (c) show different types of rodents.

Figure 4.27: (a) Rat

Figure 4.27: (b) Moles

Figure 4.27: (c) Squirrel

Birds

In most countries, most species of birds are considered to be a valuable part of the fauna. There are some species of bird that have feeding and roosting habits which conflict seriously with agriculture. These species include, *Quelea quelea*, weaver, mouse bird and domestic fowl. They are widely spread and cause a significant damage to crops including corn, sorghum, rice, and fruits. While birds are not necessarily considered obvious pests, like insect and rodents, they can cause significant damage to property, especially when they occur in higher numbers which makes them pests.

The most abundant and important wild birds found only in Africa, especially in

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semi-arid zones is *Quelea quelea*. It is a seed-eater, both of wild grasses and cereals such as sorghum, rice and wheat, but also eats insects, including pests of crops. *Quelea quelea* attack crops when other natural food sources are exhausted. Always *Quelea quelea* move in large flocks and if not controlled, it can wipe out whole fields of grain crops. Other birds like weaver birds, cause serious damage to maize crops during the milk stage. Mouse bird causes damage on fruit crops and is the most serious fruit eating bird pests. It can also damage bean seedling at the early stage. Domestic fowl if not properly reared can cause damage to wide variety of cultivated crops as they feed on flowers, pods, grains, leaves and tubers. Figure 4.28 (a), (b) and (c) show different birds.

Figure 4.28 (a): *Quelea quelea* bird

Figure 4.28 (b): weaver bird

Figure 4.28 (c): Mouse bird

Large animals

The degree of damage caused by large animals is variable depending on the type of animal and crop infested. Wild animals are a special challenge for farmers throughout the world. Animals such as wild pigs, hippopotamus, elephant, monkeys, warthogs, buffaloes, antelopes, apes, and many others may cause serious damage to crops. They can damage the plants by feeding on plant parts or simply by running over the field and trampling over the crops. Therefore, wild animals may easily cause significant yield losses and provoke additional financial problems. Wild pigs can destroy crops by rooting around and stomping through fields. Domestic animals, if not looked after, can infest crops and cause a considerable loss. For example, if domestic pigs are not controlled, may cause great losses in cassava, sweet potatoes, sugarcane, maize, round potatoes and vegetables etc. Figure 4.29 (a), (b) and (c) show different animals known for infesting crop farms.

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Figure 4.29 (a): Wild pig

Figure 4.29 (b): Hippopotamus

Figure 4.29 (c): Elephants

Activity 4.9

In a small group, visit a library or search on internet about:

(a) Other vermin not mentioned in this chapter under the categories of rodents, birds and large animals (at least five for each category);

(b) Distinguishing characteristics and damages of vermin under each category in (a) above;

(c) Management practices for each category of vermin; then

(d) Summarise your responses in your portfolio and share it in class.

Principles of pest management

Reduction in the amount or extent of damage caused by crop pests is referred to as pest management. There are four fundamental principles adhered to in pest control or management. These include exclusion, eradication, protection, and avoidance. Ideally, all control measures are carried within these principles. Crop yield value due to pest management should be appreciably higher than the cost incurred. In pest control consideration, minor pests may be tolerated by the plant and it may not be economical to control them. When pest population causes damage beyond what can be tolerated by plants, the infestation is said to have reached economical injury level. At EIL, pests may be controlled by appropriate management measures including cultural control, physical control, biological control, chemical control, IPM and legislative pest control measures. Common pest management principles are explained hereunder:

(a) Exclusion

This refers to the prevention of entrance and pest establishment in the field or country. These may include quarantine, use of certified seeds, seed treatments, and relying on trusted sources of seedlings or other vegetative plant parts.

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(b) Eradication

It refers to pest elimination once the pest has already established in a field or storage facility. Complete removal of pests is not possible but there are practices which may help to minimize their population. This can be achieved by practices such as roughing, cutting off infested plant parts, moving out infested bags in case of storage or disinfection by chemical or heat treatment. Practices such as crop rotation helps to starve pests and hence lower their population. Pesticide application and trapping are also effective methods of managing established pests.

(c) Protection

These are all practices that are done ahead or before pest establishment. Practices like creation of protective barrier between hosts and pests in case of field or pre-treatment of stored products are good examples of protective measures.

(d) Avoidance

This involves spatial separation between pests and their hosts. It can be achieved by adaptive practices such as growing crops during periods when pest population is low or absent in the field. Planting of early maturing and resistant varieties are also avoidance mechanisms.

Cultural control measures

Cultural control involves manipulation of the environment, making it unfavourable for survival of pests. The basic principle of cultural control is the disruption of the development cycle of the pests by exposing them to adverse conditions which may kill them or deny them feed. Cultural control measures include the use of clean planting materials, timely planting, proper seed bed preparation, use of resistant crop varieties, observing field sanitation/hygiene, mulching, close season, crop rotation, trap cropping, proper spacing, timely harvesting, destructions of alternative hosts, observing crop nutrition and alteration of environmental conditions.

Activity 4.10

Work in a group or individually to perform the following tasks:

(a) Through enquiry, library and other information sources, identify and discuss more cultural pest control measures involved in controlling pests. (your discussion should base on how each control measure work, its usefulness, as well as related challenges and how can be overcame;

(b) Revisit your local community study and discuss cultural pest control measures that are practiced in the area; then

(c) Summarise your responses in your portfolio and share it in class.

Physical control measures

This is also known as mechanical control measures, it involves using mechanical means to kill pests and creating physical barriers to prevent pests from getting into contact with their target crops. Mechanical control measures include use of lethal temperature, proper drying

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of produce, flooding/irrigating, destructing, using physical barriers, pest scaring, hand picking, trapping, killing and use of explosives.

(a) Use of lethal temperatures

This involves application of extreme temperature to control pest development especially in post-harvest management practices. For instance, hot water is used to control the pink bollworm in cotton seeds and ratoon stunting diseases in sugarcane.

(b) Proper drying of produce

Crops to be stored for long periods must be properly dried to very low moisture levels. This ensures the produce is hard enough to limit pest damage on the grains. Cereal crop are best stored after proper drying to a moisture content of 11-13%. Table 5.1 Shows the expected moisture content (EMC) for storage of cereals and pulses.

Table 4.1: Expected moisture content for storage of cereals and pulses

Crop	Expected moisture content (EMC %)
Shelled maize	12-13.5
Maize flour	11.5
Wheat	13.5
Wheat flour	12
Sorghum	13.5
Millet	16
Paddy	15
Rice	13
Pulses	15
Groundnuts	7

(c) Irrigation and flooding

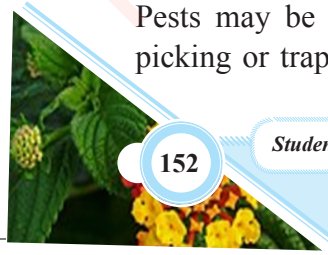
Overhead and flooding irrigation drowns pests such as leaf miners and aphids from cabbages while flooding suffocates moles in the soil.

(d) Hand picking, trapping and killing

Pests may be controlled through hand picking or trapping followed by killing them. Examples include picking and killing of giant hoppers, trapping of rats and birds or moles in the garden. This method is restricted less useful for very small sized pests.

(e) Use of physical barriers

These include materials that prevent pests from getting to the crops for example, rat proofing in the store or



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using metal plates on posts for raised granaries. It also includes construction of fences around the fields and trenches to control large animals.

(f) Scaring of pests

Scarecrows are human figure-like objects used to scare away birds and other large animals from the crop field. Animals such as monkeys and squirrels have been successfully controlled by this method. Distress calls involve using sound of a captured pest or that of its predator is replayed from a loud speaker scaring away pests.

(g) Use of explosives

This involves throwing explosives at breeding places of birds at night so as to kill or scare them off. However, it should be noted that the use of explosives is controlled by the government. Thus, before applying them, you need to consult the responsible authority first.

Activity 4.11

In a group, perform the following tasks:

(a) Discuss usefulness and limitations of physical control measures you have learnt in real life situations;

(b) Re-visit your nearby local community study and discuss physical pest control measures that are practised in the community; then,

(c) Summarise your responses and share them in class.

Chemical control measures

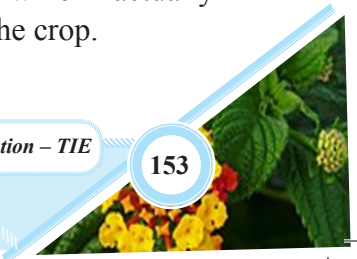
This is the use of chemicals (pesticides) to control pests. These pesticides are applied in a number of ways including dusting, spraying, fumigating of the soil and produce, and sterilisation of implements. Pesticides are classified according to formulation, target pest and mode of action.

(a) **Formulation:** This is the form in which a pesticide is available, for example soluble powders, fumigants, aerosols dusts, liquids, pastes, granules and emulsions.

(b) **Target pest:** Classified depending on the specific pest it kills. For example, insecticide (kills insects), nematicide (kills nematodes), rodenticide (kills rodents) and fungicide which kills fungi.

(c) **Mode of action:** Pesticides are also classified according to the way they function. Basing on this classification, pesticide may be grouped into stomach poisons, systemic poisons contact poisons and pests suffocants.

(i) Stomach poisons: These are pesticides which kills pests when the part of the plant sprayed or dressed with the chemical is eaten by the pest. Stomach poisons are relatively selective in the sense that they only kill pests which actually consumes the crop.



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(ii) Systemic poisons: are pesticides that once the sprayed part of a plant is eaten, the poison circulated to all parts of the pest and kill it, by inhibiting vital processes of the pest. The pesticide is selective to only pests with systems that can circulate them.

(iii) Contact poisons: are pesticides that kill the pests when they are absorbed in the body through the skin or cuticle. They are either sprayed on the pest or on the crop and are more effective when applied directly on the target pest. Contact poisons are normally, non-selective poisons hence may kill many beneficial organisms such as predators, pollinators, decomposers, birds and small animals.

(iv) Pests suffocants: They kill by interfering with the breathing system of a pest after being inhaled. Majority of them changes into gaseous form after being applied. Pests with a tough cuticle that make it difficult for contact poison to penetrate can be killed by use of suffocants. Anti-feeders inhibit (prevent) feeding in insects and other pests thus starving them to death. Repellants keep the pests away from the plant.

Activity 4.12

In a group perform the following tasks:

(a) Account for factors affecting efficiency of pesticides;

(b) Highlight precautions to be taken before, during and after using pesticides;

(c) Discuss usefulness and limitations of chemical control measure you have learnt in real life situations; then,

(d) Summarise your responses in your portfolio and share them in class.

Biological control measure

This is a measure that involves the use of living organisms to control pests. It is based on predator- prey relationship. A predator is a living organism that kills another (prey) for food. This method therefore takes advantage of the natural enemies of a particular pest. It is believed that every living organism has its own natural enemy e.g., parasitic wasp predates on whitefly in citrus and coffee mealy bug, lady bird beetle predates on aphids and cottony cushion scale, praying mantis predates on giant loopier, cats predate on moles, rats, mice and other rodents and chicken predates on cotton strainer and termites.

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Activity 4.13

In a group perform the following task:

(a) Study and discuss useful predator-prey associations existing in your local environment that are useful for controlling pests.

(b) Discuss usefulness and limitations of biological control measure you have learnt in real life situations.

(c) Summarise your responses in your portfolio and share in class.

Integrated pest management

Integrated Pest Management (IPM), also known as Integrated Pest Control (IPC) is a broad-based approach that employs various practices for economic control of pests. IPM aims to suppress pest populations below the economic injury level (EIL). Therefore, IPM can be defined as the careful consideration of all available pest control methods and subsequent integration of appropriate measures that discourage the development of pest populations. It also, ensure that pesticides and other interventions are kept to the levels that are economically justified and reduce or minimise risks to human health and environment. IPM emphasises the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms.

Therefore, Integrated Pest Management (IPM) can be considered as a sustainable, science-based, decision-making process that combines biological, cultural, physical and chemical tools to identify, manage and reduce risk from pests and pest management tools and strategies in a way that minimizes overall economic, health and environmental risks. Figure 4.30 presents the Integrated Pest Management pyramid (IPM). The use of IPM denotes collaborative efforts that help to achieve the goal of preventive and sustainable pest management.

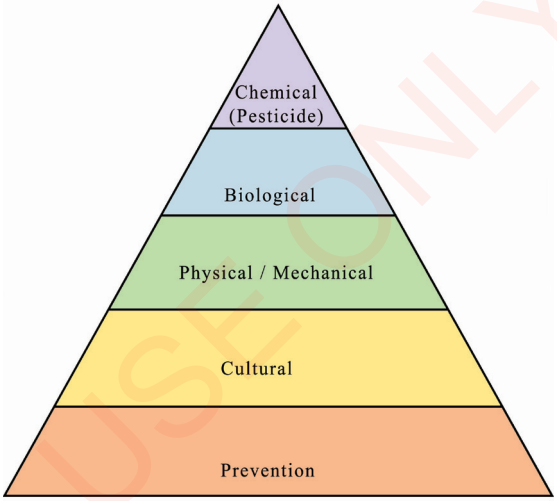

Figure 4.30: Integrated pest management pyramid

IPM can be implemented by adhering to the following components:

(a) **Prevention**: Preventing pest problems eliminates the need to take further action. For instance, appropriate planting time is an avoidance measure to manage maize ear rot disease. Such measures may also mitigate the severity of any pest problems that do arise.

(b) **Inspection/monitoring:** Routine examination of indoor and outdoor areas to identify if pests are present or if conditions existing

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are conducive to pest infestations. A major inspection is done when starting an IPM program; regular inspections continue as part long-term commitment to IPM.

(c) **Identification:** If inspections reveal the presence of rodents or insects, determination of the type (species) of pest is critical for establishing effective management methods. For example, rodent control methods would be different for common rats versus squirrels.

(d) **Establishment of threshold levels:** Elimination of all pests may not be practical in many situations. Thresholds should be established by which enhanced management methods will be used. When pest populations reach a predetermined level based on potential health impacts or damage to property or the environment, strict management actions should be taken.

(e) **Implementation of two or more control measures**: The foundation of IPM is managing the environment to eliminate pest access to food, water, and shelter. Using management techniques that are appropriate to pest that its damage has reached EIL will result in substantial reductions in pest populations with the least possible disruption to agro-ecosystems.

(f) **Measurement and evaluation:** Regular follow up to determine whether treatments are successful and what should be done next. Evaluation is one of the most critical components of an IPM plan.

Activity 4.14

Aim: To assess qualitative and economic losses due to insect pests on stored grains

Requirements: any stored grains (for at least three years) from store and weighing balance.

Procedure: In a group, perform the following tasks:

(a) Measure 100 g of a well-mixed grain sample;

(b) Sort out all damaged grains due to storage pests and weigh them;

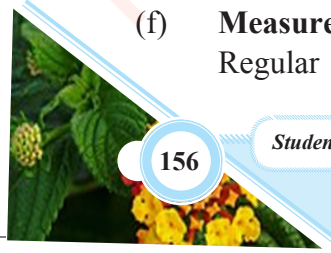
(c) Calculate the percentage of damaged grains by taking weight of damaged grains divided by total weight of grains multiplied by 100;

(d) Assume the current price is TZS 50 000 per bag, estimate the economic losses as a result of the insect damage; then,

(e) Summarise your responses and share them in class.

Legislative pest control measure

This involves imposition of rules and regulations that aim to prevent introduction and spread of pest infected materials across borders. Government imposes phytosanitary rules and regulation that any planting materials from pest infested areas, must be tested



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before they are imported into pest free ones. This prevents the spread of foreign pests into the country.

Activity 4.15

Objective: To practise an integrated pest management

Requirement: School farm, mulches materials, farm tools, bean seeds

Procedure:

(a) Prepare a land to a fine tilth;

(b) Plant bean seeds in two plots;

(c) Apply mulching materials in one plot;

(d) Count insect pest occurrence in the two plots; and

(e) Present your results in class for discussion.

(f) Write a summary of what you have learned in this chapter in your portfolio.

Revision exercise 4

1. Write short notes on:
   (a) Vermin
   (b) Insect pest
   (c) Economic injury level (EIL)
   (d) Integrated pest management (IPM)

2. Describe:
   (a) Five host plants of American boll worm (*Helicoverpa armigera*);
   (b) Four non-insect pests; and
   (c) Three secondary pests.

3. Explain any five effects of pests on stored grains.

4. Outline three principles of crop pest management.

5. Discuss (a) general characteristics features of pests in the order orthoptera
   (b) the damage symptoms of *Busseola fusca.*

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Chapter Five

Weed science

Introduction

Any plant which is out of place in agricultural perspective is considered a weed even if it is edible. Crop plants cannot efficiently compete with weeds in the field because ecologically, weeds are in most cases native by nature, well adapted to the field environment and hence more aggressive than crop plants. Therefore, if weeds are not managed properly, a good harvest cannot be attained. In this chapter, you will learn about the biology and ecology of weeds, and the principles of weed control. The competencies developed from this chapter will enable you to manage weeds in crop farming and hence increase crop production.

The concept of weeds

A plant is considered a weed depending on circumstances and one's point of view. Generally, weeds are plants that interfere with the growth of desirable plants. A volunteering crop plant in another field crop of interest is also considered a weed. Likewise, a plant which its use has not been discovered is also regarded as a weed. Weeds are usually persistent and negatively impact human activities. They are natural plants growing in an area where they are not wanted.

Weeds are typically adaptive, resilient species of plants. They can live in a variety of habitats. They adapt to changing environments, thrive under extreme conditions, establish populations in strange places, and succeed in disturbed environments where other plants cannot. Some weeds have specialized, modified plant parts to help them thrive where cultivated plants cannot. Some have shallow roots to help them grow in compacted soil and others have prostrate growth patterns to avoid being damaged by mowing while others survive in drought conditions because they have reduced leaf area and aerial parts. Weed can produce thousands, sometimes ten thousands of seeds during a growing season. Many have evolved in a way that their seeds can remain buried and dormant for years until conditions are favourable for germination. Wind, water, and animals such as birds or humans help to spread their seeds. Some weed seeds have tufts of hair or wing-like structures enabling them to be carried by the wind. Others are lightweight and or have an oily film allowing them to be carried by rainwater runoff.

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Economic importance of weeds

Weeds have both negative and beneficial effects on agriculture. The worst weeds of major crops worldwide include *Cyperus rotundus, Cynodon dactylon, Echinochloa colonum, Eleusine indica* and *Sorghum halepense.* Others are *Imperata cylindrica, Eichhornia crassipese, Portulaca oleracea,* and *Chenopodium album*. Major crops affected by these weeds include maize, rice, wheat, sorghum, cassava, groundnuts, soybeans and coffee. Others are cotton, sugarcane, tea, grapes, potatoes, pineapple, and sugar beets.

Weeds reduce crop yields by competing for water, light, soil nutrients, and space. Other challenge associated with weeds in agriculture include reduced crop quality by contaminating the commodity, interference with harvesting. Also serve as hosts for crop disease causing or providing shelter for insects to hibernate, limit the choice of crop rotation sequences and cultural practices. Perennial deep-rooted weeds may cause blockage of water channels. Other weeds produce chemical substances which are toxic to crop plants (allelopathy), animals, or humans. Generally, weeds increase crop production costs.

Despite their negative impacts, some weeds are beneficial as they enhance soil stabilization, provide habitat and feed for wildlife and nectar for bees. Weeds can also be used for aesthetic qualities, thatching materials in construction, medicinal purposes, addition of soil organic matter as well as provision of genetic reservoir. Some weeds are used as food for humans and livestock. Weeds also provide employment opportunities in different fields including weed management, research, and herbicide production.

Identification of common weeds

The term identification in relation to weed science refers to a process of assigning names to individual plants that are already placed in a given taxon. Weed names can either be in common or scientific names. Vernacular (local) names are also given to weeds in some places. Common names are usually in English and give some clue of the physical appearance or usefulness and or place of origin of the weed. Examples are American fox tail, Mexican poppy, goat weed, pig weed, devil's horse whip, sodom apple, thorn apple, and many others. Examples of Swahili names given to weeds are 'mashona nguo', 'mtanda mbu', 'majani ya sungura', 'magugu maji', and others. Common names are user-friendly but can bring confusion as one weed can have several common names depending on the place. To avoid such ambiguities, scientific names are used to refer to a similar weed worldwide. Scientific names contain genus and species name. Table 5.1 and Figure 5.1 shows some common weeds in Tanzania.

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Table 5.1: Some common names and scientific names of common weeds in Tanzania

Common name	Scientific name
Wild oat	*Avena fatua*
Wild rice	*Echinochloa colonum*
Goat weed	*Ageratum conzoydes*
Pig weed	*Amaranthus spinosus*
Devil's horse whip	*Achyranthes aspera*
Wandering jew	*Commelina bengalensis*
Gallant soldier	*Galinsoga parviflora*

Wild oat (*Avena fatua)*

Wild rice (*Echinochloa colonum)*

Goat weed (*Ageratum conzoydes*)

Pig weed (*Amaranthus spinosus)*

Devil's horse whip (*Achyranthes aspera*)

Sodom apple (*Solanum incanum)*

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Wandering jew (*Commelina bengalensis)*

Gallant soldier (*Galinsoga parviflora)*

Figure 5.1: Pictures of some common weeds in Tanzania

Correct weed identification can be done by using several methods including; the direct comparison method, the use of a dichotomous key, and the use of an interactive key. These methods help to reach the correct name of a weed specimen, that has been already specified in a guidebook. Weed identification is the first step toward their effective control, as two weed species can look very similar at certain growth stages but yet they have different life cycles, modes of reproduction, effects on crops, and responses to control tactics.

Proper weed identification is done with the help of a good field guide manual, or taxonomic key to the agricultural weeds of a given region. Such manuals can be accessed from various sources including online. Usually, several collected weed specimens are examined closely, by observing their physical characteristics which, remain relatively the same among all individuals within species. These include foliage, stem, flowers, roots, and other below ground parts. The botanical knowledge regarding identifying plants is useful in identifying weed plants.

Biology and ecology of weeds

Biology of weeds

The interaction or relationship between weeds and their environment is called weed ecology. It deals with growth characteristics and adaptations that enable weeds to survive the changes in the environment. The study of the establishment, growth, reproduction and life cycles of weed species is called weed biology. Generally, weed biology and ecology knowledge aim at minimizing the negative effects and pointing out possible beneficial advantages of weeds. Based on reproductive strategy, weeds reproduce by both seed and vegetative parts as described hereunder:

(a) Reproduction by seed

Reproduction by seed is called sexual reproduction. It requires the fertilization of an ovule by pollen. Pollination of the ovule in a flower result into a seed that is capable of producing a new plant. Through sexual reproduction, abundant

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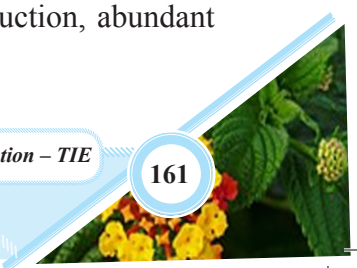

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and small seeds are produced. For example, while Canada thistle has been observed to produce as few as 680 seeds per plant, curly dock often produces more than 30 000 seeds per plant. Seed production varies greatly among and within weed species in part due to environmental variability between years, competition from neighbouring plants, and genetic variability (Table 5.2).

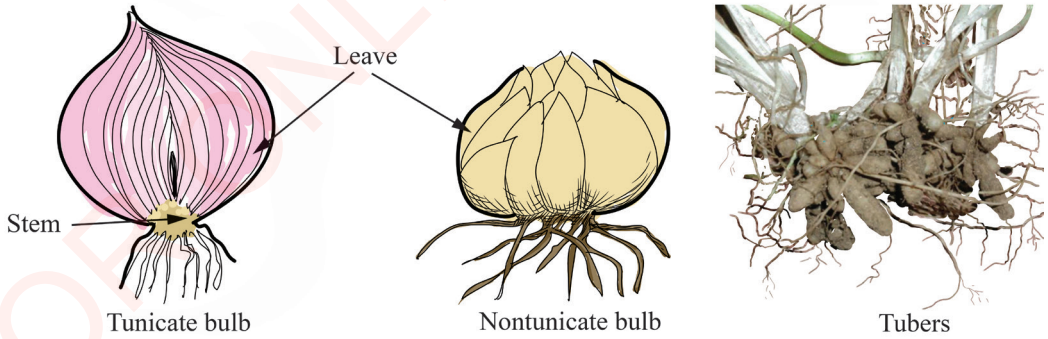
Annual and biennial weeds depend on seed production as the sole means of propagation and survival. Perennial weeds are less dependent on this mechanism. A few weeds may produce seed through apomixis (without fertilization). For example, ferns reproduce by spores.

Table 5.2: Average weed seeds produced per plant per life cycle of some weeds

Weed plant species	Number of seeds per plant
Amaranthus retroflexus	196 405
Solanum nigrum	178 000
Chenopodium album	72 000
Wild wheat and rice	90-100

(b) Vegetative reproduction

In vegetative (asexual) reproduction, a new plant develops from a vegetative organ such as stem, root, or leaf. Several modifications of these organs are common in perennial weeds, such as underground stems (rhizomes), above-ground stems (stolon), bulbs, corms, and tubers (Figure 5.2). Although vegetative structures generally do not survive in the soil for long time like seeds, very small structures can result in a new plant. Vegetative reproduction can be as prolific as seed reproduction.



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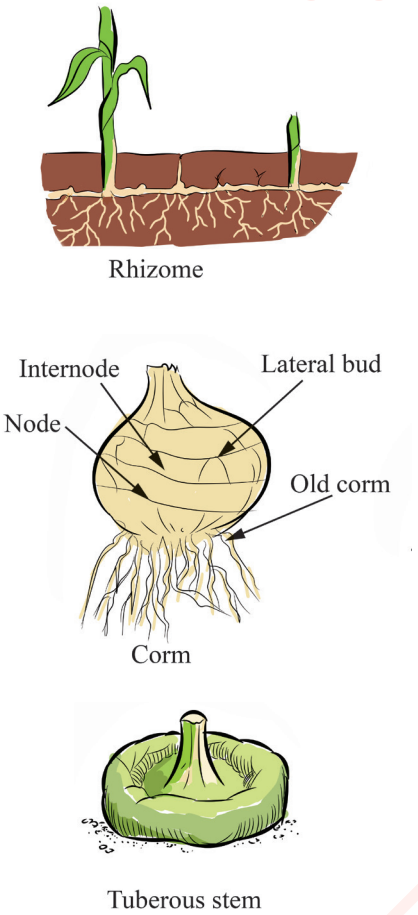

Figure 5.2: Vegetative propagation structures of weed plants

Weed ecology

Weed-crop ecology is the study of how weeds interact with a crop, humans, and their physical surroundings. Weeds typically invade bare, open areas where more desirable plants tend not to grow. Annual grass weeds typically invade first into the land while, annual broadleaf weeds invade later. Perennial grass weeds, perennial broadleaf weeds, brambles and vines are established after annual weeds. Trees are the last species to invade an area. Understanding these ecological attributes of the weed helps in the choice of most effective and economically sound strategy of weed management. The following are characteristic features of weeds which make them to be more competent than other plants. They include viable reserve potentials (weed seed bank), seed dormancy, and weed persistence as described hereunder:

(a) Weed seed bank

The weed seed bank is the reserve of viable weed seeds present on the soil surface and scattered throughout the soil profile. Once in the soil, weed seed can remain viable for many years. In any given location, the weed seedbank contains a vast library of weed species and ecotypes that are adapted to a great range of environmental conditions and are ready to germinate given the proper signal. It is estimated that a square foot of soil, 15 cm deep, contain from 98 to 3 068 viable weed seeds. This represents between 4.3 and 133 million viable seeds per acre. The amount of time that a seed is capable of producing a seedling, or its viability, varies with weed species. In the extreme, lotus (*Nelumbo nucifera*) seeds remained viable after 1 000 years. More commonly, the annual plant jimsonweed (*Datura stramonium*) has over a 90 % germination rate after 40 years in the soil.

(b) Seed dormancy

Dormancy is the resting stage of seeds and it is the primary method of weed seed dispersal in time. Many weed seeds

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have long term dormancy because their seed coats are impermeable to water and/or oxygen or are mechanically resistant. Other seeds have immature embryos or have a waiting period (called after-ripening) that must be completed before the seed will be able to germinate. Seed dormancy is affected by environmental conditions, such as temperature, light, oxygen, and the presence of chemical inhibitors. Weed seeds have a variety of special germination mechanisms adapted to changes in temperature, moisture, aeration, exposure to light, and depth of burial of seeds. When conditions are unfavourable for germination, they can remain dormant or delay germination. Conditions favourable for weeds seed germination are:

(i) Seeds of many weeds require an exposure to light for germination. This is regulated by bluish-green protein pigment called phytochrome. Soil turnover during ploughing and other operations exposes the seeds to light and induces germination and shading can be means of weed management.

(ii) Many weed seeds germinate under aerobic conditions while some require anaerobic condition. This is a reason why weed management in rice production is through flooding to create anaerobic condition.

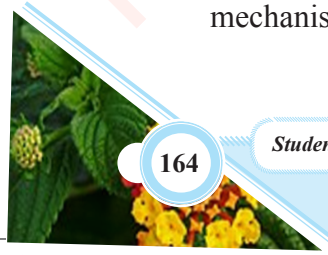
(iii) Periodicity of germination is another specialised germination mechanism. *Amaranths spp* have a definite pattern of peaks of germination at regular intervals.

(iv) Dry season annuals are adapted to higher temperature while those germinating during cold season are adapted to lower temperatures. But some weeds germinate freely throughout the year.

(c) Weed persistence

Weeds are known to be highly persistent group of plants as they have existed even before the first seed of any crop was planted on earth and probably in larger numbers and with greater vigour. Normally, if weeds are left to grow with crops, soon there will be weeds all over, with no trace of the crop plants. High persistence nature of weeds is ascribed to various adaptation mechanisms, as described further hereunder:

(i) **Prolific seed production:** Most weeds are prolific seed producers. For instance, the per plant seed production capacity of *Cuscuta spp.* is around 16 000; *Conyza spp.* 33 992; *Chenopodium album*, 72 000; and *Amaranthus*, 196 000. Furthermore, the immediate viability of weed seeds varies from 6 to 78 %. Therefore, it can be anticipated that even a few weedy plants that escaped control measures in the field, can be sufficient to produce enough seeds to continue their progency for years to come. One more interesting note is that they can set viable seeds even when they are harvested before full maturity. For example, perennial sow thistle (*Sonchus arvensis*) can



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set viable seeds even when it is cut during its flowering stage and kept in shade. Chickweed (*Stellaria media*) and purslane (*Portulaca oleracea*) have also been found well adapted to premature flowering and seed setting under adverse environmental conditions. Ability to produce some seeds before they perish when subjected to stresses of nature such as drought, disease or insect pest gives them a chance to leave seed progenies before life cycle is completed.

(ii) **Dormancy of weed seeds and other propagules in soil:** As stated above, the majority of weed seeds lying below about 5 cm soil depth remain dormant, and act as source for future flushes of weeds. Depending on the species, weeds seeds laid out in the soil for up to 10 decades and can retain its viability for 2 to 100 years. Therefore, both agricultural and non-agricultural soils act as 'reserve banks' for the weed seeds and their other propagules. If all weed seeds present in the soil were to germinate at one time, a single tillage operation could wipe them out of the farm. Contrary to it, only a fraction of weed seeds present in any soil germinate at any time, leaving others to germinate later. Also, a few weedy plants which escaped attention in a field are often sufficient to recoup the seed banks in the soil.

(iii) **Vegetative propagation:** The majority of weeds are highly persistent because of their ability to propagate by vegetative methods. This is important because, when the above ground parts of such weeds are destroyed during weed management, their deeply placed vegetative propagules re-sprout to produce new shoots as soon as the external stresses are removed and favourable conditions resume. Therefore, even if deep tillage is employed in an attempt to destroy these weeds it will be a futile activity. This is because the fragments of the weed propagules remaining in the soil will easily be dispersed to new areas where they initiate fresh colonies.

(iv) **Rapid dispersal mechanisation** Dispersal is an extremely important means of weed survival and persistence. Dispersal exposes weeds to different environments so that each weed species can choose its most favourable environment and struggles for existence in nature. Dispersal plays a key role in developing a persistent weed population for every possible niche in the environment. Dispersal helps persistence of weeds in proportion to the dispersal agents and adaptations available to them (Figure 5.3).

(v) **Inherent hardiness:** Weeds seem to have some kind of inbuilt mechanism to survive against the

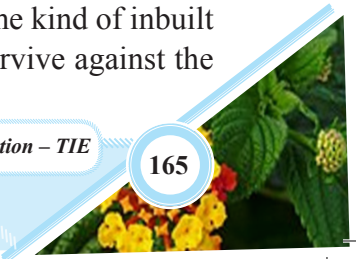

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Figure 5.3: Light weight weed seeds that can be dispersed via air

vagaries of nature, like extreme cold, heat, drought, biotic stress, and soil abnormalities. The mechanism is the inherent hardiness of weeds, enabling to resist damage due to severe stress conditions such as frost, or be destroyed by attacks of insect pests. It is a rare phenomenon to find weeds that are either developing chlorosis or any other mineral deficiency or toxicity symptoms, even though the soil may actually be abnormal in its mineral composition. Even, poor quality water declared unfit for irrigating crops, fails to cause injury to weeds. In fact, in crop fields all abnormal features of soil and water help weeds to grow vigorously in spaces vacated by the stunted growth (or death) of the crop plants. In short, weeds are naturally hard and adaptive.

(vi) **Evasiveness:** Many weeds are capable of evading or escaping destruction by animals and humans because of their bitter taste, unpleasant odour, spiny nature, and mimicry.

(vii) **Self-regeneration:** Weeds are self-sown plants. They don't require any artificial, friable seedbeds for their germination. Detached from the mother plants, weed seeds and other propagules germinate profusely on undisturbed soils whenever the environment is favourable for the purpose (Figure 5.4).

Figure 5.4: Weed seed rhizomes which can self-regenerate after removal of above ground parts

(viii) **Selective invasion:** Weed species differ widely in their ecological requirements. In invading new ecologies, entry of a weed species in a particular location depends upon the chance a particular weed had to reach that particular site. Thereafter, nature makes a critical selection out of the population and allows only the adapted surviving weed seeds to germinate. The native weed seeds wait in soil till the outside environment changes. At this stage, suddenly another

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set of weed species takes over the ground. The major environmental factors which determine the weed species composition are soil moisture, soil pH, temperature, photoperiod, and solar energy. To cite some examples, *Tribulus terrestris, Argemone mexicana, Eragrostis cilianesis, Euphorbia hirta, Celosia argenta,* and *Heliotropium eichwaldi* are successful invasive species in different agroecologies around the globe. Kongwa weed is a typical example in Tanzania range land of Dodoma region (Figure 5.5).

Figure 5.5. Kongwa weed in Kongwa ranch Dodoma, Tanzania

Source: *www.sua.ac.tz/news/kongwa-weed-research-project-launched*

Classification of common weeds

Weeds can be classified based on their, morphology and ecology, life cycles, and ecological affinities as described hereunder.

Based on morphology and ecology

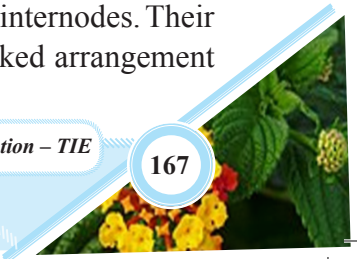
According to their morphological features weeds can be classified into three major categories namely; grasses and sedges, herbaceous weeds, and woody weeds. When ecological features are considered, weeds are classified as wetland and dryland weeds. Weed biology and ecology help to understand weed characteristics to inform the adoption of appropriate control strategies for different weeds. For example, control strategies for annual weeds might not be effective for perennial weeds, or control strategies for broadleaves cannot be similar to that of narrow leaves likewise managing aquatic weeds might require a different approach as compared to that of dry land weeds.

(a) Grasses (Poaceae) or narrow-leaf weeds

These are monocotyledons, having only one seed leaf when seedlings emerge from the soil. They have leaves that are long and narrow with a parallel venation pattern. Their stems produce tillers. Leaves arise in an alternate pattern on each side of a hollow stem or culm. Each leaf has two parts: the lower portion called the sheath, which is wrapped around the culm, and the upper portion called the blade. Most have fibrous root systems. Examples of grass weeds include star grass, couch grass, thatch grass, wild finger millet, sword grass, and kikuyu grass.

(b) Sedges weeds

These are also monocotyledons, but not true grasses, though they exhibit a lot of the same characteristics as grasses. They are different from grasses, because their stems are solid, triangular, and have no clear marked nodes and internodes. Their leaves have a three-ranked arrangement



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(instead of an alternate arrangement). The basal portion of each leaf forms a tube around the stem with no clear division between sheath and blade. Examples of sedges that are found in Tanzania include Cyperus species, such as nut grasses (*Cyperus rotundus*) and creeping sedge (*Kyllinga erecta*)

(c) Broadleaf / herbaceous weeds

Herbaceous weeds are different from grasses and sedges as their leaf blades are expanded. Their leaves have netted venation as they are dicotyledons. Their stems branch as the plant grows, and they often have flowers. When broadleaf weed seedlings emerge from the soil, they have two seed leaves. They often have tap roots or coarsely branched roots. Most of them have succulent shoots. Some common broadleaf weeds in Tanzania include chick weed, spindle pod, wandering jew, goat weed, black night shade, thistle and many others.

(d) Woody weeds

These are wild shrubs and tree weeds. They have strong lignified stems, and the majority are perennial with broad leaves. They include lantana and cactus.

Based on their life cycle

Under this category weeds are considered as annual, biennial, and perennial weeds

(a) Annual weeds

Annual weeds complete their life cycle in one year or less. During that time, they germinate, complete their growth cycle by flowering, producing seeds, and die. Some develop prostrate stems or adventitious roots. If the stems are cut, they may develop into new plants. Annual weeds include black jack and goat weeds.

(b) Biennial weeds

Have life cycles that span two years (i.e., two growing seasons). During the first year, biennials germinate, and the plant focuses on growth. The plant overwinters, and then during the second year or growing season, it flowers, produces seeds, and dies. Biennial weeds include common burdock and musk thistle.

(c) Perennial weeds

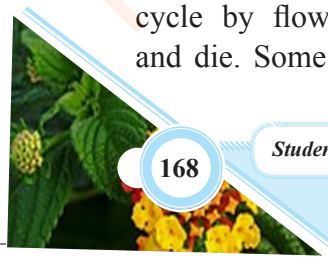
Have life cycles that span more than two years. They reproduce from seeds or vegetative parts of the plant like rhizomes, bulbs, tubers, and stolons. Like annuals, perennial weeds can be classified into cool-season perennial weeds and warm-season perennials based on the time of year when they grow. Seedlings are the easiest to destroy whether they are annuals, biennials, or perennials. and generally harder to control. Once perennials are fully established, they are generally hard to manage. Perennial weeds include star grass and coach grass.

Based on ecological (physical surroundings) affinities

Under this aspect, weeds are classified as wetland and dry land weeds.

(a) Wetland weeds

Wetland weeds can either be those requiring a large amount of water or



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those which require moderate amount of water like those common under irrigated lands. They are tender annuals with semi-aquatic habits and can thrive well under waterlogged conditions. Propagation is chiefly by seed e.g., *Eclipta alba*, and water hyacinths. Irrigated land weeds, neither require large quantities of water like wetland weeds nor can successfully withstand extreme drought as dryland weeds. Examples are *Trianthema portulacastrum*, and *Digera arvensis.*

(b) Dry land weeds

Dry land weeds are usually hardy plants with a deep root system. They are adapted to withstand drought conditions. Their stems are gelatinous and hairy for example, *Tribulus terrestris, Argemone mexicana*, and many others.

Noxious and non-noxious weeds

A noxious weed is a weed that has been designated by an agricultural or other governing authority as a plant that is injurious to crops, ecosystems, humans, and livestock. Depending on the extent of their effects, noxious weeds can further be categorised as weeds designated for: eradication, stopping the continued spread of their species, a subject on additional education, research, and biological control, and as a potential threat to agricultural productivity and environmental values of the land in a given country. The later, are normally kept on a watch list.

A watch list is intended to serve for advisory and educational purposes only. Its purpose is to encourage the identification and reporting of these species to the respective authority to facilitate the collection of information to assist the extension and research officers in determining which species should be designated as noxious weeds. Examples of noxious weeds in Tanzania include *Striga spp*, water hyacinth, Kongwa weed, and marijuana. Knowledge about weedy species should not be limited to herbaceous plants only, woody weed plants also pose significant limitations.

One of the differences between noxious and non-noxious weeds is that, non-noxious weeds can be easily controlled by employing good agronomic practices while noxious weeds are difficult to control because of various characteristics that make them persistent.

Activity 5.1

Use your school or nearby environment to carry out simple weed identification by performing the following tasks:

(a) Use a garden folk or a small hoe to dig up some emerging weeds

(b) Check if the roots are still attached to the seed or if there are remains of the seed coat;

(c) Observe the ease with which the weed is pulled from the soil;

(d) Check if the weeds are attached to larger roots, rhizomes, or tubers;

(e) Categorize the weed based on whether emerge from seeds or tuber, narrow or broaden leaves, perennial or annual and aquatic or dryland;

(f) Suggest the appropriate

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management strategies for each identified weed; then

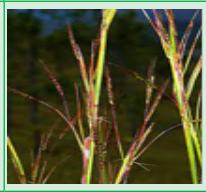
(g) In a tabular form give the local, common and scientific names for each collected weed (internet sources may be used to supplement some useful information);

(h) Collect and prepare a weed album (herbarium) for common weeds found around your school environment; then,

(i) Make a summary of the lesson gained from this activity.

Activity 5.2

1. Use library and internet sources to find out a list of 20 common weeds and classify them as shown in the following example:

S/N	Common names	Scientific name	Family name	Life span	Ecology	Botanical feature	Weed picture
1.	Nut grass	*Cyperus rotundus*	Cypera-ceae	Perennial	Moist/we tland	Sedges	
2.	Thorn apple	*Datura stramoni-um*	Sapota-ceae	Annual	Dry land	Herbaceo us	
3.	Thatch grass	*Hyparrhe-nia rufa*	Poaceae	Perennial	Dry land	Grass	
4.	Blacken fern	*Pteridium aquilinum*	Denns-taedtiaceae	Perennial	Moist land	Woody	

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Exercise 5.1

1. Explain the concept of weed.
2. Explain the economic importance of weeds.
3. Describe how you can make common weed identification correctly.
4. Distinguish between noxious weeds and non-noxious weeds.
5. Give a brief explanation of how to classify weeds based on morphological and ecological features.

Principles of weed control

These are general propositions that have numerous special applications across wide fields. The principles guide how to manage weeds using various methods. In a broader sense, weed management is better than weed control. Weed control deals with weeds that are already present, while weed management is a systematic approach that intends to minimize weed invasion in aggressive forms. The principles adhered to in weed management, include eradication, control, and prevention as described hereunder:

(a) Prevention

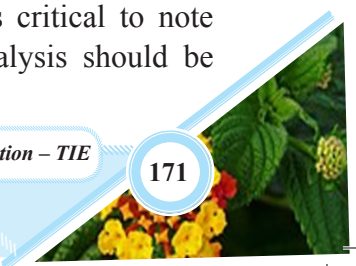
Preventive approaches involve limiting new weeds to invade an area, or limiting weed seed multiplication. This can be achieved by employing cultural methods like the use of weed-free planting materials, repeated weeding, and early weeding before weed flowering. Repeated weeding helps to minimize the seed bank already in the soil, while early weeding prevents the production of new seeds which could otherwise bulk the seed bank. Other cultural preventive measures include the use of well-decomposed farmyard manure or compost, avoiding grazing animals in crop fields, cleaning of farm equipment, and many others.

(b) Eradication

Eradication intends to perform a complete removal of weed plants, seeds, or weed propagules such as corms, rhizomes, runners, and others. Although it is not possible to do complete eradication, the application of chemicals in form of fumigants or other forms can serve the purpose to a greater extent. The application of high dosages of chemicals has detrimental impacts on the environment, animals, and users. Hand pulling, deep cultivation, and controlled burning approaches can also be useful.

(c) Control

Weed control methods should be employed before the crop begin to suffer from weed competition. This helps to increase crop productivity. because understanding weed biology and ecology is a key step toward effective control. Control methods to be adopted varies with weed type and characteristics. Various control methods like cultural, physical, chemical, and biological are effective in controlling weeds. They can be used in combination to ensure maximum results. It is critical to note that, a cost-benefit analysis should be



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considered to make a rational decision on whether to control or not to control weeds.

Methods of weeds control

(a) Cultural methods.

Many cultural practices are useful for weed control. They may include, choosing the right type of planting method or cropping system, use of weed-resistant cultivars, timely planting, proper spacing, proper land cultivation, mulching, and soil management.

(b) Mechanical Methods

Hand pulling, hand hoeing, and other related practices can be effective ways for weed control. However, these practices are time-consuming, costly, and tiresome (Figure 5.6 (a), (c) and (d)).

(c) Biological Methods

Biological weed control is the utilization of living organisms to manage weeds (Figure 6.5 (e), (f) and (g)). These living organisms (natural enemies of targeted weed) can include arthropods like insects and mites, pathogens such as viruses, bacteria, fungi, and nematodes, and predators like birds, fish, and other animals. They help to reduce weed density to an acceptable level. However, these methods are not typically used by farmers. They are still under research and have few demonstration plots.

(d) Chemical Method

Herbicides are specific chemicals for weed control. They help to control germinated and non-germinated weeds (Figure 5.6. (b)). They can be selective or not selective, contact or systemic. Contact herbicides kill weeds that come into contact with herbicide while systemic herbicides are absorbed and translocated to different plant parts where they disturb the physiological functioning of weeds and hence kill them. They are quick to react, effective, and efficient for large-scale farmers. However, they are toxic both to humans, animals, and the environment when not used properly. Thus, it is advised to make critical thinking and relate cost-effectiveness and other rationales before opting for the use of herbicides.

Figure 5.6 (a): Hand hoeing

Figure 5.6 (b): Chemical weed control

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Figure 5.6 (c): Hand uprooting

Figure 5.6 (d): Mechnical weeding

Figure 5.6 (e): Ducks feeding on weeds

Figure 5.6 (f): Weeding suppression by inter cropping

Figure 5.6 (g): Insect feeding on weeds

Activity 5.3

1. In a group, manage three plots using three different methods then, compare effectiveness of the methods in three plots in terms of:
   (a) Time taken for visible impacts to be realised;
   (b) Cost-effectiveness;
   (c) Sustainability; and
   (d) Applicability.
2. Write a summary of what you have learned in this chapter in your portfolio.
3. Share your observations in class.

Revision exercise 5

1. Outline important principles of weed control.
2. Explain the advantages and challenges of each method of weed control.

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3. Discuss any six advantages and disadvantages of weeds in agriculture.

4. Explain the following concept:
   (a) weed;
   (b) weed management;
   (c) weed control; and
   (d) weeding.

5. Explain any five control practices that help to minimize weeds.

6. Describe:
   (a) five steps to be followed in classifying weeds based on their emergency.
   (b) five characteristics features of weeds.

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Chapter Six

Plant diseases

Introduction

Plants, like all other living organisms, are made up of cells which when harmed or diseased, the cells and organs are also affected. This in turn, reduces their performance. In this chapter you will be exposed to the concepts of plant diseases, their causes, and how to control them. The competencies developed will enable you to recognize different types of plant diseases, their causes, and how to apply appropriate management measures in agricultural production.

The concept of plant diseases

Plant pathology or phytopathology is the science that deals with plant diseases. The term Phytopathology is derived from Greek word 'Phyto' meaning 'plant', 'pathos' meaning 'disease or ailments', and 'logos' meaning 'discourse or knowledge'. It is the branch of agricultural, botanical or biological science that deals with the causes and management of plant diseases. It is concerned with health and productivity of plants. The determination of the cause of diseases is known as aetiology. When micro-organisms attack plants, they affect and change the physical appearance and productivity of that crop hence showing symptoms of abnormality. This abnormality is referred to as a disease. It infers a state of not being in good health, and hence a plant is said to be diseased. A plant or plant part is only considered healthy if it continues to perform all of its regular physiological functions and produces the expected yield based on its genetic potential. The following are some characteristics of a normal healthy plant:

(i) Undergoing normal cell division, differentiation, and development;

(ii) Absorbing of water and minerals from the soil and translocation;

(iii) Undergoing normal photosynthesis and translocation of photosynthates;

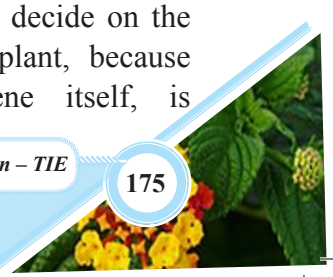
(iv) Utilization and storage of photosynthates;

(v) Metabolism of metabolites and photosynthates;

(vi) Performing normal reproduction processes (flowering, pollination, fruit set, and maturation; and

(vii) Storing of reserves for over-seasoning or reproduction.

Though, it is difficult to decide on the genetic potential of a plant, because the expression of gene itself, is



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influenced by environmental factors, the negative deviation from normal plant performance or plant diseases, can either be a pathological (caused by pathogenic agent or non-pathological (caused by an environmental element) that causes long-lasting irritation. Figure 6.1 show (a) a healthy avocado plant leaves, (b) diseased avocado plant leaves, (c) healthy avocado fruit and (d) diseased avocado fruit.

Figure 6.1 (a): Healthy avocado leaves

Figure 6.1 (b): Health avocado fruit

Figure 6.1 (c): Diseased avocado leaves

Figure 6.1 (d): Diseased avocado fruit (Anthracnose)

Importance of plant diseases

Globally, millions of people have died as a result of hunger and malnutrition, induced by crop failures caused by many factors including plant diseases. Examples of such diseases include the potato late blight caused by *Phytophthora infestans* and the rice brown spot disease by *Polaris oryzae*. Plant diseas of are associated with huge crop losses for over 50 %, resulting into significant economic loss to farmers. This is because they damage plants and plant products on which humans depend for food, clothing, furniture and environmental use. Plant diseases do not only reduce crop yields but also deteriorate product qualities (Figure 6.2) hence result into increased price due to reduced supplies.

In Tanzania and other countries in tropical regions for example, tomato crop become highly vulnerable to fungal diseases during wet season resulting in crop failure and hence escalation of tomato prices. Apart from reduction in the quality, some pathogens also produce toxic compounds which contaminate

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crop products, posing a food safety problem due to food poisoning. For example, some fungal pathogens especially species of the genera Fusarium, Aspergillus and Penicillium infect crops such as maize and produce mycotoxins like fumonisins, aflatoxin and ochratoxins respectively. All these mycotoxins are associated with various illnesses to consumers. Plant diseases also make farmers incur additional costs associates with plant disease management such as buying seeds of disease resistant varieties, pesticides for disease control and expensive storage systems such as cold storage, to prevent deterioration on storage or shipment. Under severe cases, plant diseases can limit the kinds of plants to be grown in an area.

Figure 6.2: Maize grains infected with grey-green moulds

Activity 6.1

1. Conduct a field study to the nearby farm or garden and:
   (a) Observe diseased and healthy plants or plant parts;
   (b) Observe differences between pathological and non-pathological diseases;
   (c) Determine quality and quantity losses of crops due to plant diseases; then
2. Write a report in your portfolio and share in class.

Types of plant abnormalities

Depending on the cause, plant abnormalities are categorized as pathological and non-pathological. Plant abnormalities that are caused by pathogens are referred to as pathological diseases while those caused by non-living agents or conditions are called disorders. The two categories are described hereunder:

(a) Plant disorders

Plant abnormalities caused by the non-pathological agents are referred to as a disorder and are usually caused by sub-optimal or extreme environmental (abiotic) factors. Disorders of the plants can be caused by plant exposure to excessive light intensity (sun scorch), low soil fertility (nutritional deficiencies), chilling (injury), low soil moisture (wilting), excess soil moisture (lodging), temperature extremes (heat injury), or salt damage. Other examples of abnormalities caused by non-pathological agents include damping-off, blossom end rot, chilling, sunscald, or sunburn.

(b) Plant diseases

Plant diseases are normally caused by pathogenic organisms such as fungi,

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bacteria, viruses, protozoa, nematodes as well as parasitic plants. These pathogenic agents have many ways in which they can affect plants. These include utilizing host cell contents, pathogens inflicting disease conditions by killing the host or interfering with its metabolic processes through their enzymes, and toxins. They can also affect plants by weakening the host due to continuous loss of nutrients. Likewise, pathogens cause plant diseases by interfering with the translocation of the food, minerals and water. Figure 6.3 summarizes the causes of plant abnormalities.

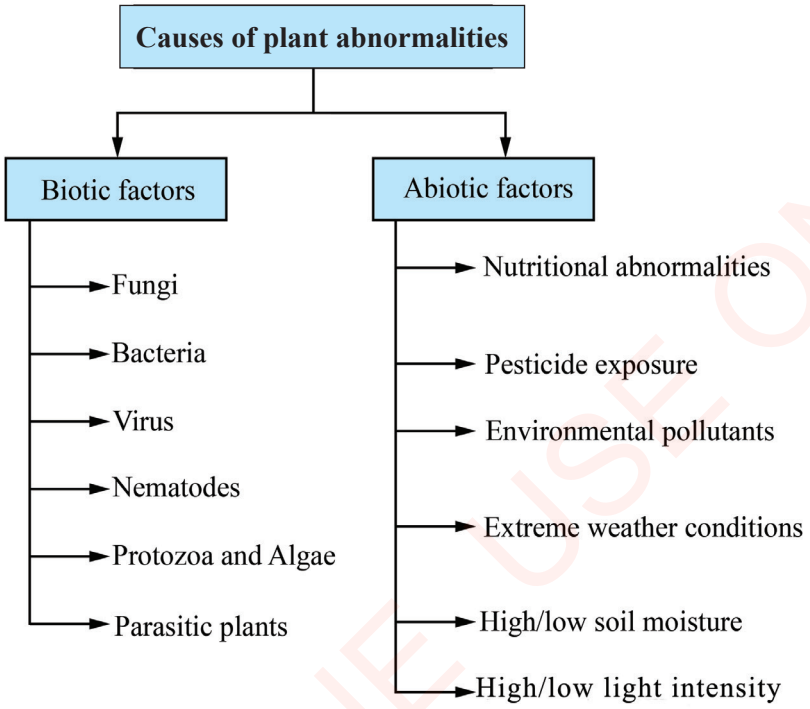

Figure 6.3: Pathological (biotic) and non-pathological (abiotic) causes of plant abnormalities

Signs and symptoms of plant diseases

Traditionally, symptoms are useful in the process of identifying plant diseases through visual examination. However, visual observation is often possible only after major damage has already occurred to the crop and possibly at a stage where treatment will be of limited value. Therefore, to save plants from irreparable damage by pathogens, farmers should be able to identify an infection even before it becomes visible. This can be made possible by using very sensitive methods for early diagnosis of disease. Plant disease diagnosis is the process of identifying the disease's nature so as to determine the causal agent whether living or non-living. Diagnosis using visual observation is normally based on symptoms and signs of plant diseases as described in the following sections:

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(a) Signs

A sign is a piece of physical evidence of the presence of a pathogen on a crop plant (Figure 6.4 (a) and (b)). Fungal fruiting structures for example, is a sign of infection. When powdery mildew is observed on a cucurbit leaf, it infers parasitic fungal pathogen. Bacterial canker of stone fruits causes gummosis, a bacterial liquid exudate emerging from the cankers. The thick, liquid exudate is mostly made up of bacteria and is a marker or sign of the disease.

Figure 6.4 (a): Mycelia as signs of fungal infection in cucurbit

Figure 6.4 (b): Mucilage as sign of Bacterial infection in banana plant

(b) Symptoms

The visible effects of disease on plants are called symptoms. It is any detectable changes in colour, shape, and/or functions of the plant in response to a pathogen or disease-causing agent. The disease agent can cause local or extensive necrosis. It can also inhibit normal growth (hypotrophy) or induce excessive abnormal growth (hypertrophy or hyperplasia) in a portion of or throughout an entire plant. Symptoms associated with necrosis include leaf spots, blight, scab, rots, damping-off, anthracnose, dieback, and canker. Symptoms associated with hyperplasia include clubfoot, galls, warts, and leaf curls. These symptoms can be classified as either local or systemic, primary or secondary and microscopic or macroscopic symptoms as outlined hereunder:

(i) **Local or systemic symptoms:** It is local if the physiological or structural changes are within a limited area of host tissue, such as leaf spots, galls, and cankers or, systematic if reaction involves a greater part or the whole plant, such as wilting, yellowing, and dwarfing.

(ii) **Primary or secondary symptoms:** It is considered as primary if the symptoms are the direct result of pathogen activity on invaded tissues, for example, swollen 'clubs' in the club root of cabbage and 'galls' formed by feeding of the root-knot nematode. It is considered secondary if symptoms result

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from the physiological effects of disease on distant tissues and uninvaded organs e.g., wilting and drooping of cabbage leaves in hot weather resulting from club-root or root-knot.

(iii) **Microscopic or macroscopic symptoms:** When expressions of disease in cell structure or cell arrangement are only seen under a microscope. Or it can be macroscopic symptoms when expressions of disease are seen with unaided eye.

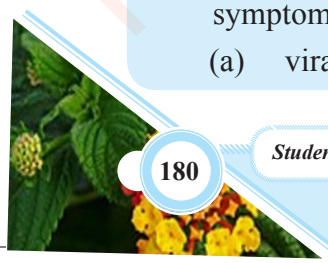
Similarities are normally common in terms of symptoms for the plant diseases caused by different pathogens. This is the reason why one cannot embark on diseases management without an accurate diagnosis. Table 6.1 presents examples of signs and symptoms of different pathogens.

Table 6.1: Symptoms and signs of bacteria, virus and fungal pathogens

Pathogen	Symptoms	Signs
Virus	Mosaic leaf pattern Crinkled leaves Yellowed leaves Plant stunting	No sign
Bacteria	Leaf spot with a yellow halo Fruit spot Canker Crown gall Shepherd's crook stem ends on woody plants.	Bacterial ooze. Water-soaked lesions. Bacterial streaming in water from a cut stem.
Fungi	Black and sunken lesions Damping-off of seedlings (Phytophthora) Leaf spot (Septoria brown spot) Chlorosis (yellowing of leaves).	Leaf rust (Common leaf rust in corn) Stem rust (Wheat stem rust) Sclerotinia (white mold) Powdery mildew

Exercise 6.1

1. Explain the meaning of:
   (a) Symptoms; and
   (b) Pathology.
2. With examples, describe the symptoms of plant:
   (a) viral diseases;
   (b) bacterial diseases; and
   (c) fungal diseases.
3. Differentiate between pathological and non-pathological plant abnormalities.
4. Outline importance of plant diseases in agricultural production.



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Conditions for a diseases to develop

For a disease condition to develop, two components, the vulnerable host and a virulent pathogen must be present and must interact. This is because a plant becomes diseased usually when it is attacked by a pathogen. However, if at the time a pathogen comes into contact with a plant, environmental conditions are too cold, too hot, too dry, or some other extremes, the pathogen may be unable to attack or the plant may be able to resist the attack. Therefore, despite the two being in contact, no disease develops. In this case then, a third component, namely environmental conditions within a favourable range, must also prevail for the disease to develop. The three components however, have varying degree of influencing a disease severity within an individual plant and within a plant population. For example, the host plant may be resistant to the pathogen, it may be too young or too old for what the pathogen prefers, or plants over a large area may show genetic uniformity, all of which can either reduce or increase the rate of disease development by a particular pathogen. Similarly, a disease will not develop if the pathogen is less virulent, or in a dormant state, or in absence of a film of water or a specific vector in which it can develop.

Finally, the disease might also fail to develop if the environment affects both the growth and the resistance of the host plant and the rate of growth or multiplication. Other factors are the degree of virulence of the pathogen, as well as its dispersal mechanism (wind, water, vector, and so on). Such interactions of the three components of disease have often been visualized as a triangle, generally referred to as the "disease triangle (Figure 6.5).

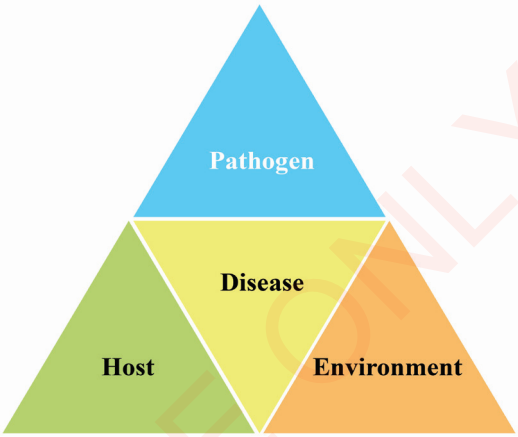

Figure 6.5: Disease triangle indicating the important conditions for disease to occur

Abiotic agents of plant disorders

Environmental circumstances can occasionally combine with the host plant to cause disorder. For instance, injury due to cold, fruit scorch due to high light intensity, or growth stunting because of pollution are all types of diseases with no causal organism. Essentially, not all three elements of the disease triangle (Figure 6.5) are compulsory for disorders to happen. However disorders may predispose plants to diseases caused by infectious agents.

Pathological (biotic) agents

Pathological agents are living organisms that cause plant diseases. They include fungi, viruses, bacteria, viroid, mycoplasmas, and parasitic plants. Pathological agents are also called

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infectious because they can spread from one diseased plant to another through propagules or inoculum that can infect other plants. The term inoculum refers to the pathogens or their parts that can cause infection. Inoculum is a portion that is brought into contact with the host plant and causes harm. Examples of inoculum include fungal spores, bacterial cells, mycelium and nematodes. On the other hand, the term propagule refers to the part of the organism or pathogen that may be disseminated and can reproduce the same organism; e.g., bacterial cell viruses, fungal spore and nematode eggs.

The common disease-causing organisms, are referred to as pathological agents i.e., they are responsible for causing diseases (pathological-being diseased). Pathogens are categorized into five main groups which are viruses, fungi, bacteria, protozoa, and nematodes. Their associated diseases are discussed in the following subsections:

Viruses

Viruses are minute organisms that are frequently referred to as particles because of their size. Like other microbes, virus can spread from one location to another via mechanical means or through pollen grains, fungus, insects, seeds, and humans. They can also spread through the soil and vegetative reproduction. Vectors are biological organisms that carry pathogens or their particles from one plant to another. When insects or nematodes eat infected plants, they ingest the virus as well. They spread the virus to other plants when they leave infected plants and go to feed on un infected ones. Examples of viral diseases include the following: cucumber mosaic disease, maize streak disease, papaya lethal yellowing disease, papaya yellow spot disease, cassava mosaic disease, tobacco mosaic disease, and beet curly top. Figure 6.7 show symptoms of (a) viral diseases of cassava and (b) sweet potato. Symptom and mode of transmission of viral plant diseases are outlined herein:

(a) Symptoms of viral plant diseases

The symptoms of plant disease caused by viruses include the following:

(i) Discoloration for example, vein clearing and yellowing;

(ii) Dwarfism, growth retardation of both individual parts and the whole plant;

(iii) Necrosis, wilting, and the appearance of annular stripes and spots;

(iv) Malformation (distortion) of plant parts such as the growth of shoots, distortion of leaves and flowers;

(v) Leaf chlorosis;

(vi) Leaf curling;

(vii) Mosaic (light green or yellow patches); and

(viii) Rosettes; development of the abnormally short internode.

(b) Transmission

This is done through the use of infected vegetative materials and insect vectors like aphids, mealybugs, and leafhoppers.

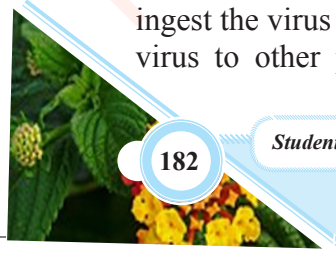

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Figure 6.7 (a): Cassava brown streak virus disease

Figure 6.7 (b): Sweet potato feather mottle virus disease

Fungi

Fungi are non-green organisms that cause infection in crop plants. Fungi that cause plant diseases dwell on the host plant as parasites. These fungi produce reproductive structures which are called spores. Spores are multiplication structures that spread by water and air from one location to another. They can also be dispersed via the surface of farm implements, machinery, the bodies of insects, farm animals, and even humans. These spores may proliferate on the crop plant's surface if they fall on it. The plant on which the spores germinate becomes infected with the disease. This is how fungus-related plant diseases spread. There are many different species of fungi, each with its body shape, colour, and generative structure. Some fungal diseases are described in the following sections:

(a) **The damping-off disease:** Damping-off is a fungal disease that affects seedlings of plants including solanaceous vegetables, such as tomato, eggplant, and pepper. The disease is popular in crops that are first sown in nursery beds to raise their seedlings and then transplanted. It is caused by several fungi species including the *Colletotrichum spp, Fusarium spp, Phytophthora spp, Rhizoctonia spp,* and *Pythium spp.* Figure 6.8 (a) and (b) show dumping off-disease in beans and cabbage respectively.

Figure 6.8 (a): Damping-off disease in beans

Figure 6.8 (b): Damping-off disease in cabbage

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(b) **Downy mildew:** This is a disease caused by *Pseudoperonospora spp*. It is an extremely destructive disease of members of Cucurbitaceae including the cucumber, sweet melon, and watermelon. It also attacks cereals such as maize, sorghum, pearl millet, bulrush millet as well as other crops such as tobacco, mango, and grapes (Figure 6.9).

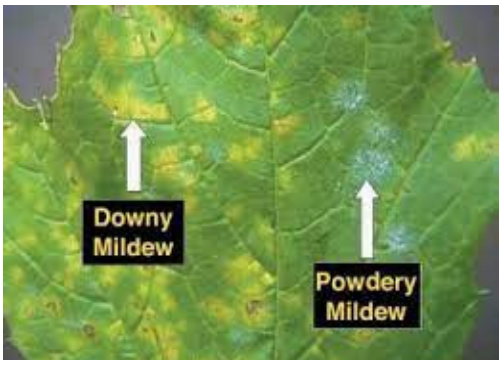

Figure 6.9: Downy and Powdery mildew

(c) **Powdery mildew:** Powdery mildew is caused by *Uncinula necator*. It is a fungal disease common in grapes, cashewnuts and most of vegetables.

(d) **Early blight:** Refers to any of various plant diseases whose symptoms include sudden and severe yellowing, browning, spotting, withering, or dying of leaves, flowers, fruit, stems, or the entire plant. It is characterised by rapid discoloration followed by the death of plant organ, entire leaf, or shoot which gives a burnt appearance (Figure 6.10).

Figure 6.10: Symptoms of southern leaf blight of maize

(e) **Late blight**: Leaf symptoms of late blight first appear as small, water-soaked areas that rapidly enlarge to form purple-brown, oily-appearing blotches. On the lower side of leaves, rings of greyish white mycelium and spore-forming structures may appear around the blotches. Entire leaves die and infections quickly spread to petioles and young stems. Infected fruit turn brown but remain firm unless infected by secondary decay organisms; symptoms usually begin on the shoulders of the fruit because spores land on fruit from above.

Late blight occurs when humid conditions coincide with mild temperatures for prolonged periods. When humidity is above 90% and the average temperature is within the range of 18° to 25°C, infection occurs in about 10 hours. If conditions are ideal, disease development can be rapid and losses be severe. The fungus hibernate in potatoes, tomatoes, hairy nightshade, and possibly in the soil. Spores of the fungus are easily spread by wind to other

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plants. Figure 6.11 shows effects of late blight caused by *Phytophthora infestans* in round potatoes.

Figure 6.11 (a): Late blight disease in potato plant

Figure 6.11 (a): Late blight disease in potato tuber

(f) **Coffee berry disease** (CBD): The disease is caused by a fungus (*Colletotrichum kahawae, Colletotricum coffeanum*). The fungus invades the berry during the green stage (4–14 weeks after flowering) producing dark brown spots that end up covering the cherry and affecting bean development and quality (Figure 6.12).

Figure 6.12: CBD disease symptoms

(g) **Banana leaf spot or Sigatoka**: Black Sigatoka is a leaf spot disease of bananas (Figure 6.13). It is a significant banana disease in many countries around the world. Severely infected leaves can die, significantly reducing fruit yield, and causing mixed and premature ripening of fruit bunches. The disease is caused by *Mycosphaerella musicola.*

Figure 6.13: Banana leaf spot (Black sigatoka)

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(h) **Rust:** A plant disease caused by more than 7 000 species of fungi of the phylum Basidiomycota. Rust affects many economically important plant species and usually appears as yellow, orange, red, rust, brown or black powdery pustules on leaves, (Figure 6.14 (a) and (b)). In cereals, rust is caused by *Puccinia graminis*.

Figure 6.14 (a): Leaf rust in bean plant

Figure 6.14 (a): Leaf rust in maize plant

(i) **Smut**: This is a fungal disease caused by *Ustilago spp.* It is a plant disease primarily affecting plants of Graminae family, including maize, wheat, sugarcane, and sorghum (Figure 6.15 (a), (b) and (c)). Smut is characterized by fungal spores that accumulate in soot-like masses called sori, which are formed within blisters in seeds, leaves, stems, flower parts, and bulbs.

Figure 6.15 (a): Smut disease in maize plant

Figure 6.15 (b): Smut disease in wheat plant

Figure 6.15 (c): Smut disease in sorghum plant

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(j) **Phyllody:** Phyllody is the abnormal development of floral parts into leafy structures. It is generally caused by phytoplasma or virus infections, though it may also be because of environmental factors that result in an imbalance in plant hormones. It occurs on the flowers of crops such as bulrush millet, sorghum, and maize.

(k) **Spot:** A leaf spot is a limited, discoloured, diseased area of a leaf that is caused by fungal, bacterial or viral plant diseases, or by injuries from nematodes, insects, environmental factors, toxicity or herbicides. These discoloured spots or lesions often have a centre of necrosis or cell death (Figure 6.16). The spots will vary in size and colour depending on the plant affected, the specific organism involved, and the stage of development. Spots are most often brownish, but may be tan or black. Concentric rings or dark margins are often present.

Figure 6.16: Early and late leaf spot disease of groundnuts (Fungal pathogen)

(l) **Anthracnose:** Anthracnose is the name given to a group of fungal diseases that infect a wide variety of herbaceous and woody plants. The infections of anthracnose diseases are distinctive and appear as limited lesions on the leaves, stem and or fruit (Figure 6.17 (a) and (b)). In leaves and in some fruit, the lesions are often angular and follow the vein pattern. Secondary pathogens that then invade the dead tissue typically cause some stem dieback, premature leaf fall and or fruit rot. Multiple infections in small areas where the lesions coalesce may result in stem and leaf blight**.** It is a common fungal disease of shade trees that results in leaf spots, cupping or curling of leaves and early leaf drop.

Figure 6. 17 (a): Anthracnose disease symptoms in bean

Figure 6. 17: Anthracnose disease symptoms in mango

Bacteria

Bacteria are single-celled microscopic organisms that reproduce through binary

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fission. They are prokaryotic organisms as they lack the nuclear membrane that encloses the nuclear material i.e., they have no defined nucleus. Plant pathogenic bacteria cause many different kinds of symptoms that include galls and overgrowths, wilts, leaf spots, specks and blights, soft rots, as well as scabs and cankers. In contrast to viruses, which are inside host cells, walled bacteria grow in the spaces between cells and do not invade them. Table 6.2, shows some plant bacterial diseases, causes, symptoms and the mostly affected crops while, Figure 6.18 (a), (b), (c) and (d) show symptoms of bacterial spot in tomato, bacterial streak in wheat, bacterial wilt in banana and cabbage black rot.

Transmission

Bacteria are transmitted through different means which include irrigation water, seeds, fertilisers, manures, wind, raindrop splash, insects, soil and mechanical means.

Symptoms of bacterial diseases

The common symptoms shown by plants with bacterial diseases include wilting, cankers, rots, blights, and gall formation of the infected tissue.

Table 6.2: Plant bacterial diseases, causes, symptoms and the mostly affected crops

Disease	Causes	Symptoms	Crops affected
Gall (e.g., Crown gall) or root proliferation	*Agrobacterium tumefasciens*	**hypertrophies** (cell enlargement)	Tomato, roses, grapes, peach, cocoa
Bacterial wilts, canker leaf spots,	*Clavibacter michiganensis*	Gummosis (production of gummy substances), wilts, leaf spots	Tomato, potato pepper
Blights, wilts, soft rots	*Erwinia spp*	Blights, wilts, soft rots	Cabbage
Necrosis, blight, cabbage black rots, citrus canker	*Xanthomonas spp*	Necrosis, blight Rots, canker	Cabbage, citrus
Blight, Rots (e.g. soft rot of potato, onion bulb rot, and soft rot in pepper), canker, wilts leaf spots (leaf spots of hibiscus)	*Pseudomonas spp*	Angular brown leaf spots, chlorotic surrounding tissue, vascular wilts, rots	Chilli pepper, potato (*Ipomea batatus*), Hibiscus, onion bulb, apples, common lima

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Bean blight (e.g., soil rot of sweet potato scab of Irish potato, beet, carrots, and radish	*Streptomyces spp* *(Streptomyces scabies)*	Localized scabby	Bean, sweet potato beet, carrot, radish, apple, irish potato (*Ipomea toberosum*) The taproot of radish and carrots
Maize streak disease (e.g., phone peach disease, alfalfa dwarf plum leaf scald	*Xylella spp* (*Xylella fastidiosa*) which is transmitted by xylem feeding insect hence, the name xylella	Marginal necrosis, stunting and a general decline, internal discoloration of the stalk and stem, reduced yields	Maize, peaches, sugarcane, wheat plum, alfalfa

Figure 6.18 (a): Bacterial spot in tomato

Figure 6.18 (b): Bacterial streak in wheat

Figure 6.18 (c): Bacterial wilt in banana

Figure 6.18 (d): Cabbage black rot (*Xanthomonas canpestris*)

(a) **Cankers**: are spreading sunken lesions in the stem or fruits surrounded by a raised margin. A canker is really a symptom of an injury often associated with open wound infected by a fungal or bacterial pathogen (Figure 6.19). Canker disease frequently kills the branches or structurally weakens a plant until the infected area

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breaks free, often due to wind or other external factors.

Figure 6.19: Citrus canker symptoms on fruit

(b) **Galls**: are abnormal fleshy or woody outgrowths known as warts when small and knots when large. Galls are abnormal growths that occur on leaves, twigs, roots or flowers of many plants (Figure 6.20). Most galls are caused by irritation and or stimulation of plant cells due to feeding or egg-laying by insect such as aphids, wasps, mites, and nematodes.

Figure 6.20: Leaf galls as a response to bacterial irritation

(c) **Rots**: the affected tissues (root, stem, or fruits) die and decompose to a great extent. Based on the type of decomposition, different common types of rots include soft rot, dry rot, wet rot and black rot. Rot refers to any of several plant diseases, caused by any of hundreds of species of soil-borne bacteria, fungi, and fungus-like organisms (Oomycetes). Rot diseases are characterized by plant decomposition and putrefaction. The decay may be hard, dry, spongy, watery, mushy, or slimy and may affect any plant part. Figure 6.21 (a), (b) and (d) show bacterial soft rot of carrot, banana plant and potato tuber.

Figure.6. 21 (a): Bacterial soft rot of carrot

Figure.6. 21 (b): Bacterial soft rot of banana

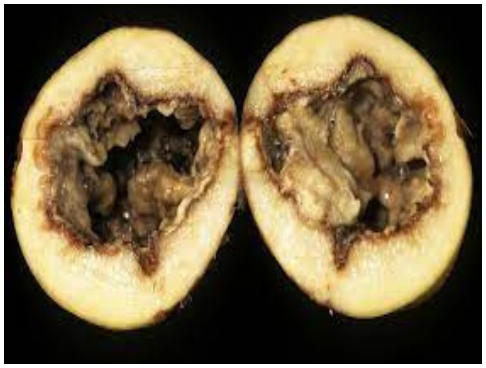

Figure.6. 21 (c): Bacterial soft rot of potato tuber

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(d) **Blight**: A plant bacterial disease characterised with rapid discolouration giving a burnt appearance (Figure 6.22 (a) and (b)). Similar blight related characteristics, have been described earlier on page 184 and illustrated in Figure 6.10.

Figure 6.22 (a): Symptoms of Bacterial blight disease on leaf

Figure 6.22 (b): Symptoms of Bacterial blight disease on pods

(e) **Spots**: These are minute circular lesions of various colours that include brown, white, dark, red, and orange (Figure 6.23 (a), (b) and (c)).

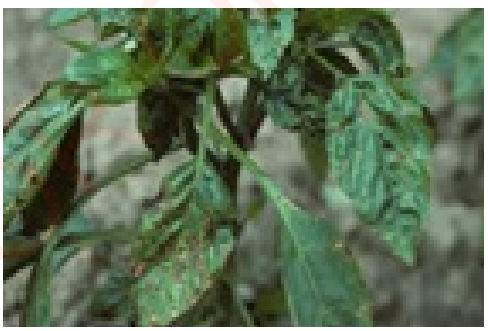

Figure 6.23 (a): Bacterial leaf spot of pepper plant

Figure 6.23 (b): Bacterial fruit spot of pepper

Figure 6.23 (c): Bacterial leaf spot of pumpkin plant

(f) **Die back**: is a common symptom or name of disease, especially of woody plants, characterized by progressive death of twigs, branches, shoots, or roots, starting at the tips (Figure 6.24 (a), (b) and (c)). For instance, die back in mango is very destructive disease caused by *Lasiodiplodia theobromae* which is alarming among mango growers worldwide. Characteristic symptoms of the disease are discolouration and darkening of twigs from tip downward, withering, drying and defoliation.

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Figure 6.24 (a): Tree die back disease on mango

Figure 6.24 (b): Tree die back disease on citrus

Figure 6.24 (c): Tree die back disease on avocado

Nematodes

Nematodes are parasitic roundworms that live in the soil and hence they mainly affect roots, tubers, and bulbs (Figure 6.25 (a), (b) and (c)). Disease symptoms due to nematodes include:

(a) Fusiform thickening of the stems

This is triggered by stem worms. It deforms leaves, petioles swelling, and the presence of dark spots on tubers.

(b) Blemishes on top of the leaves and back of the grains

This is the disease in paddy caused by nematodes called *Aphelenchoides besseyi.* It marks blemishes on the top of the leaves and back of the grains.

(c) Gradual death of leaves and branches (e.g., in citrus trees)

Nematodes such as *Tylenchuslus semipenetrans* cause serious citrus disease. The disease is characterized by the gradual death of leaves and branches.

Figure 6.25 (a): Root-knot nematode

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Figure 6.25 (b): Nematode galls

Figure 6.25 (c): impact of nematode on tomato plants

Control measures of nematode diseases

Although nematodes need a long period to cause significant damage to plants, they spread rapidly. Therefore, timely identification of crop diseases in the field is crucial to save the affected plants and prevent the disease from spreading. Parasite control involves a wide range of activities such as crop rotation, improving crop disease resistance and treatment of the soil using proper nematicides.

Activity 6.2

In a group under the teacher's supervision, conduct a field visit to find some fungal, bacterial, and viral diseased plants then:

(a) Observe and point out the responsible disease-causing agent;

(b) Describe the distinguishing characteristics of the collected diseased plants with respect to their causative agents; and

(c) With reasons, comment on whether the disease is pathological or non-pathological.

Causes of plant disorders

Disorders are caused by environmental conditions, cultural practices, or chemical exposure. They are caused by extremes environmental conditions such as temperature, moisture, nutrient supply and light. Pollution is another environmental factor linked to plant disorders. These environmental factors are described in the following sub sections.

(a) Temperature extremes

Temperature stress in plants, is classified into three types depending on the stressor which may be higher, chilly, or freezing temperature. Temperature stressed plants show low germination rates, growth retardation, reduced photosynthesis and often dies. Figure 6.26 (a) and (b) show the effect of extreme temperature in plants.

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Figure.6.26 (a): Effect of high temperature (heat injury)

Figure.6.26 (b): Effect of very low temperature (cold injury)

(b) Moisture extremes

Plants can be harmed by both too much and too little moisture and due to low oxygen levels in the root zone, extreme waterlogging causes root death. More often, excess soil moisture is a factor in root disease (edema) which shows as multiple swollen pimples on the lower side of leaves, is another illness that can emerge in high moisture conditions. Insufficient moisture, on the other hand, can cause scorch signs on leaves, stunting, leaf yellowing, leaf drop, and flower and fruit abortion.

(c) Nutrient imbalance

Extreme fertilizing can cause root burn and plant damage due to high soluble salt concentrations. Based on the nutrients involved, lower-than-optimal levels of nutrients usually result in reduced growth and a variety of foliar symptoms. Even though nutrients are present in the soil, if the pH is not within the proper range, they may be unusable. Blossom end rot of water melon (Figure 6.27 (c)) and sunscald in peppers (Figure 6.27 (d)) are common nutritional problems that can be mistaken for a disease. Around the area where the blossom was attached, flattened, tan-coloured dead spots emerge on the fruit. This frequently occurs on the first cluster produced by a tomato plant. Damage to peppers can also emerge on other parts of the fruit.

Figure 6.27 (a): Nitrogen-deficient maize plants

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Figure 6.27 (b): Nitrogen treated maize plants

Figure 6.27 (c): Blossom end rot in watermelon

Figure 6.27 (d): Sunscald in pepper

(d) Light

Crop plants require light for proper growth. However, some plants require shade as they show sunscald on their leaves when exposed to the direct sunlight. Examples of such crops that can show sunscald on fruit include fleshy vegetables e.g., peppers and tomatoes. Other plants require sunlight if grown in shade they grow thin until they reach adequate light or show some color changes a process called etiolation. Etiolation is defined as the yellowing of normally green tissues caused by inadequate sunlight.

(e) Wind

Dry winds can draw moisture from plant leaves, leading to a scorched apearence. Strong wind may cause destructive effects to crop plants. The wind force can tear leaves or strip them from the plant. Dense plant canopies may suffer abrasion through intermittent or constant rubbing. Soil particles carried by wind, have the potential to abrade and damage plant tissues. Hail can punch holes in leaves or even knock the whole plant down (Figure 6.28). Furthermore, lightning strikes can damage or kill plants.

(f) Pollution

Human activities such as tillage, chemical weeding, chemical disease management may cause soil, water, and air pollution and consequently, negatively affect crop growth. Generally, apart from their direct negative impact on crop growth, these abiotic injuries may attract insect and parasite to attack crop plants.

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Figure 6.28 (a): Chilling injury in cucumber

Figure 6.28 (b): Tomato split

Figure 6.28 (c): Drought-stressed bean plant

Figure 6.28 (d): Hail effects on salad leaves

Activity 6.3

In a group, collect diseased plants/plant parts, then:

(a) Identify disorders due to non-pathological agents;

(b) Critically explain the cause of those disorders; then,

(c) Summarise your responses and share it in class.

Exercise 6.2

1. Briefly write short notes on:
   (a) Pathological diseases
   (b) Non-pathological agents
2. Giving examples in each case, explain the causes of pathological diseases.

Plant diseases management

Man's attempts to manage plant disease date back at least to 700 B.C., when olive oil sediments (specks of dust) were sprinkled on plants to avoid blight disease outbreaks. During World War I, the information on plant diseases, including prevalence, geographical distribution, and severity, was readily available to those who were involved in disease control. The purpose of plant diseases control was to defend the country's food, feed, fibre, and oil supplies by assuring the early discovery of enemy crops and challenges or their causing damage. Plant diseases are not new; they have been recognized since before the earliest writings. Humans

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have struggled to control many diseases that have troubled vital crops using techniques such as growing resistant cultivars.

Principles of plant diseases management

Plant diseases are the result of extensive interactions between plants, pathogens, and the environment. Human beings have evolved a variety of approaches to promote interactions that favour host plant growth and development. These approaches are unfavourable for pathogen establishment, reproduction, and transmission. Controlling a plant disease entail lowering the amount of harm it causes to the crop. Plant disease if not controlled reduces the expected profit of the agricultural produce.

In plant disease control, the following principles are considered. These include exclusion, protection, eradication, resistance, and avoidance of inoculums. The principles are discussed hereunder:

(a) Exclusion

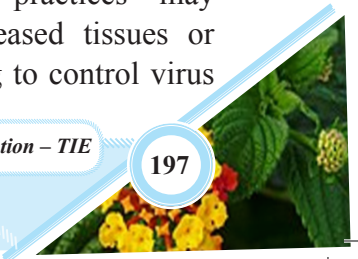
Refers to preventing pathogens/ inoculums from entering and establishing in the field, states, or country where it does not exist or with uninfected plants. Seed certification, crop inspection, and eradication of inoculums and/or insect vectors are some of the means for preventing the spread of pathogens**.** It also includes, avoiding use of diseased planting materials from the dealer or nurseryman. An exclusion involves quarantines and legal prohibitions from states.

(b) Protection

Protection is the establishing of a defensive barrier between the susceptible section of the host plant and the pathogen. For defending host plants against invading inoculums, precautions must be taken. This can be achieved by establishing a poison laced barrier between the plant surface and the inoculums. Methods such as chemical sprays, specks of dust, environmental change, and host nutrition modification can be used. The principles of avoidance, exclusion and eradication may not be adequate to prevent the host from coming into touch with the pathogen, resulting in disease development. So, applying a defensive spray or dust to the plant before the arrival of the fungus spore, and killing insects and other infecting agents as well as erecting a physical barrier are important common practices.

(c) Eradication

Eradication is the process of decreasing, inactivating, removing, or destroying inoculums at their source, be it from a region or a single plant where they have already been established. It refers to the destruction of a pathogen that has been established on a plant in a farm or garden. Eradication can be done by destruction of substitute or collateral hosts, crop rotations, field hygiene practices, heat or chemical treatments of plant materials or soil, biological control, and other methods to minimize inoculums. Hygiene practices may include removing diseased tissues or parts, such as rogueing to control virus



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diseases or cutting off cankered tree limbs. One of the examples of eradication includes getting rid of the citrus canker (*Xanthomonas axonopodis*) in which the citrus trees are cut and burnt to eradicate the pathogen. Cultivation helps to keep weed hosts down and deep tilling buries diseased plant remains. Rotating susceptible and non-susceptible crops starves out the pathogens in diseased plant debris. The other technique of eradication is through disinfection, which is normally done with chemicals. Also, heating the soil kills or eradicates the nematodes and fungi in it.

(d) The use of resistant variants

Resistant variants have existed from the ancient time; nature has always sorted out the unfit. Man has been speeding up this process by selective breeding and propagating disease-resistant plants. The generation of disease-resistant cultivars is used to control some infections by pathogens. It makes use of built-in mechanisms to fend off pathogen attacks and the genetic pathogen's infection or subsequent harm can be rendered useless. When a host can exclude, hinder, or overcome the effects of a virus, pathogen, or other harmful cause, it is said to be resistant. A plant may be resistant to one pathogen or condition, but not others. When a plant is not resistant it is said to be susceptible, susceptibility is the opposite of resistance (Figure 6.29 (a) and (b)).

Figure 6.29 (a): Blight susceptible and resistant maize

Figure 6.29 (b): Resistant and susceptible cowpea

Biotic and abiotic variables can also be used to generate host resistance. Tolerance refers to the ability of a crop plant to survive when colonized by a pathogen or exposed to an abiotic factor without dying or showing symptoms of the disease. This is an excellent technique for crop growers and home gardeners to control plant diseases. The production of crop varieties resistant to specific infections or groups of pathogens has been aided by the discovery of Mendelian rules of heredity and advances in plant breeding techniques. Selection, mutation and hybridisation are examples of breeding procedures. To generate resistant cultivars of many economically important crops, biotechnologies such

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as tissue culture, genetic engineering, and protoplast fusion are being applied.

(e) Avoidance

The main goal is to prevent the host from coming into contact with the pathogen or to ensure that the plant's sensitive stage does not coincide with favourable pathogen circumstances. The key techniques to avoid include geographical area selection, site selection, sowing time selection, seed and planting material selection, short-duration disease escape crop varieties, and agricultural agronomy modification.

Exercise 6.3

1. With examples of specific practices describe the four principles of plant disease management.
2. With vivid examples describe cultural disease control strategy.
3. State four advantages and disadvantages of using chemical disease management.
4. Describe the integrated disease management approach.
5. What are the advantages of cultural management over chemical disease management?

For effective execution of the discussed disease control principles, the following approaches or methods can be employed: agronomic (e.g., field hygiene and crop rotation), regulatory (e.g., eradication and quarantine), genetic (e.g., disease resistance and tolerance), physical cultural (e.g., solarisation and soil treatment), and chemical disease management (e.g., pesticides application). These concepts can be applied separately or in combination. When applied in combination to suppress the causal pathogen, boost host immunity, or change the biotic and abiotic ecosystem where host-pathogen interact it is referred to as Integrated Disease Management (IDM) In short, plant disease control encompasses cultural, biological, host resistance gene, chemical control, and IDM.

Cultural methods for disease management

What we do to prevent disease is more worth than dealing with a disease after its establishment. The daily actions performed as part of the process of producing crops as disease and pest preventive measures are referred to as cultural practices. Cultural control management practices include host eradication, crop rotation, field sanitation, improving plant growing conditions. Others are creating conditions unfavorable to pathogens, use of mulching, reduced tillage, fallow and trickle irrigation. These are further described hereunder:

(a) Crop rotation

These include practices such as rotating the place in the field where crops are grown from one year to the next to try to interrupt the disease cycle. In the same field or garden plot, crops from the same

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family such as cabbage and broccoli, should not be alternated.

(b) Sanitation

Removal of diseased plants (roguing) or plant parts can help to limit the number of pathogens in the area. The removal of infected tomato leaves, for example, can help to break the development of Septoria leaf spots. Some fungal foliar and fruit diseases hibernate in the dead leaf litter. Remove roots in a field or garden that has been afflicted with nematodes or root rot pathogens. Additionally, the fungus that causes tomato black spots can over season on fallen leaves. During the offseason, prune and remove cankers from the field, this is because certain fruit diseases pathogens hibernate in cankers. Avoid any unnecessary harm, as most infections enter the host through wounds.

(c) Improving plant growing conditions

Plant soil-borne diseases can be reduced by improving the soil. Proper soil drainage, pH, and fertility, promote healthier plants that are more resistant to insects, diseases, and environmental conditions. Soil testing can uncover pH and nutrient issues that might suppress growth. Planting in raised beds for water-logged soil, will significantly reduce *Phytophthora* root rot problems. Most nematodes, fungi, bacteria, and some viruses are soil inhabitants, therefore, avoid moving soil between landscapes. Early weeding is important because other weeds can harbour disease and arthropod vectors.

(d) Creating conditions unfavorable to pathogens

Try to plant and harvest particular crops at the specified periods to offer the plant the best chance of success. For instance, late-planted pumpkins and squash are more susceptible to powdery mildew, whereas sunflowers in high-rainfall locations should not be planted until the middle of the rain season for the same reason. If compost is used as manure on the farm, turn the pile thoroughly during the composting process to ensure that pathogenic fungi, bacteria, and nematodes are killed by temperature. Never put infected plant materials in a pile even if the temperature in a compost pile is high enough to destroy the pathogen.

(e) Reduced tillage farming

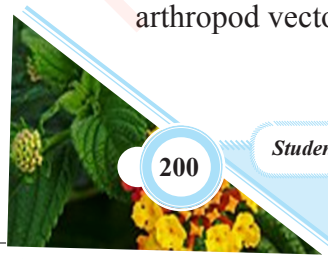
To expose soil pathogens, insects, and disease organisms to desiccation, freezing temperatures, and predation, cultivate the field or gardens early so that weeds that might carry pests have time to die before you plant.

(f) Mulching

Mulches serve as a barrier between the soil and the plant, preventing inoculum-infested soil from splashing onto the plants during irrigation or heavy rain. Mulching benefits the health and life of most plants as well. The mulch usually covers fungal structures, preventing spores from being released into the air.

Biological control

Biological control (biocontrol) has been used in plant pathology. The concept refers to both the use of microbial opponents to suppress diseases pathogen and the use of host-specific pathogens to



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decrease weed populations in plant pathology. The organism that suppresses the pathogen is referred to as a Biological Control Agent (BCA). Biocontrol is the suppression of one organism's harmful actions by one or more organisms, commonly referred to as natural enemies (Figure 6.30). It is the intentional use of introduced or resident living organisms, more than disease-resistant host plants, to decrease one or more plant diseases' activities and populations. Suppression of plant diseases can be achieved in a variety of methods, including cultural measures such as crop rotation and the cultivation of disease-resistant cultivars. This could also entail using microbial inoculants to combat a specific type of plant disease.

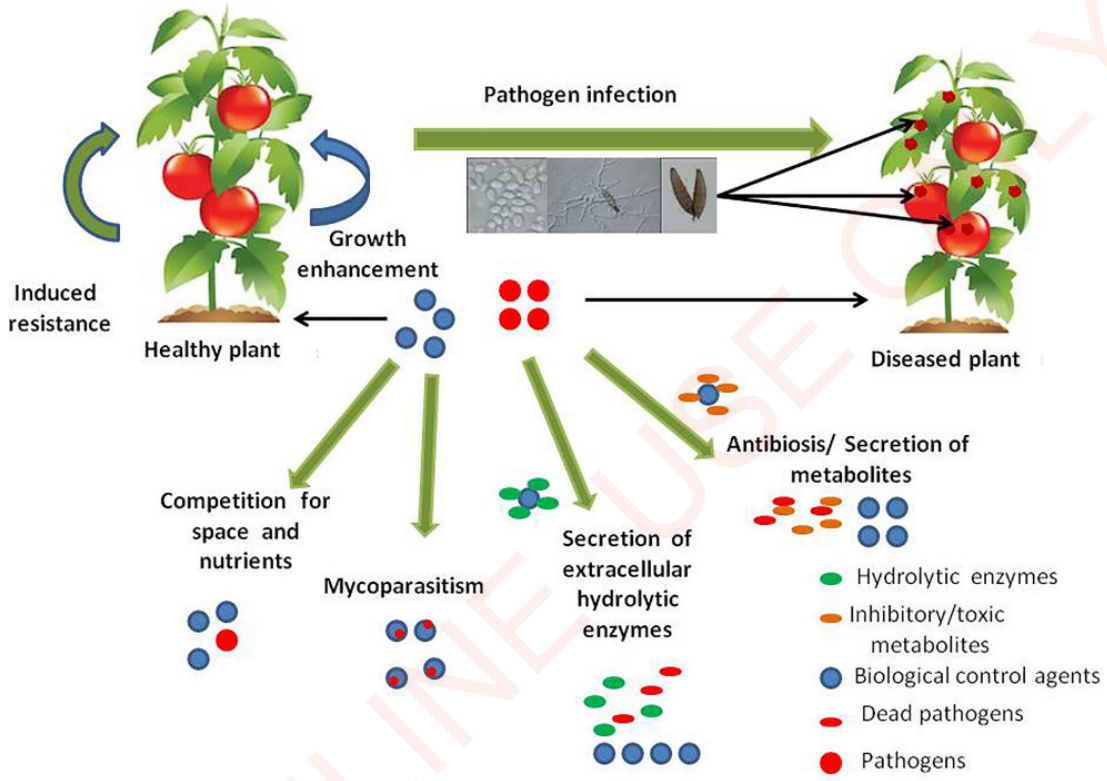

Figure 6. 30: Visual representation of key mechanisms involved in biological control of plant fungal diseases by fungal antagonists

Host plant genetic resistance

Plant disease pathogen is among the components of the environment in which a plant is produced. Other components include carbon dioxide supply, temperature, moisture supply, soil fertility, and sunlight. The disease component differs from others because it involves the genetic system. With the knowledge of the existence of the disease resistance and the demonstration that this resistance was inherited in the simple Mendelian manner, plant breeders needed to select and use host resistance types for agricultural production. Pathologists and plant breeders have embarked on a management system for resistance genes that lead to developing varieties/cultivars of crops with profound resistance to some pathological disease-causing agents.

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Disease-resistant plants with sufficient quality, adaptability to the growing location and with acceptable levels of durable resistance are available. Using them to manage plant diseases is the best option. A resistant plant can avoid an attack of a pathogen (Figure 6.31 (a)). A susceptible plant can be easily attacked by pathogen and become diseased (Figure 6.31 (b)), and a tolerant plant is the one that can be attacked but does not become diseased and it produces normally (Figure 6.31 (c)). Unless other infections are present, using disease-resistant plants reduces the need for additional measures to prevent disease losses. Breeding practices of selection or hybridisation are frequently used to create resistant plants. Hybridisation is a technique in which a plant with favourable agronomic or horticultural properties but susceptible to disease is crossed with a plant that is disease resistant but may or may not have other desirable characteristics such as size, yield, flavour, aesthetics, and others. In these techniques, plants are subjected to high levels of disease pressure and the surviving plants are used as sources of disease resistance in the selection of resistant plants. Plants that survive this stress are more likely to have genetic resistance, which can be used directly in propagation or as a source of resistance in the development of resistant plants with the necessary traits for that crop.

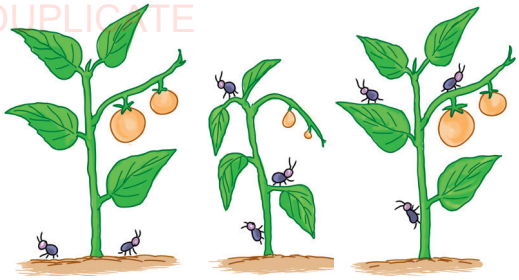

Figure 6.31: Disease resistancy (a) resistant (b) susceptible and (c) tolerant

Plant cultivars with resistance to some pathogens have recently been developed conventionally. Examples are potato cultivar with resistance to Potato Virus A, late blight tuber infection, and the wheat cultivar with resistance to stripe rust (*Puccinia striiformis*). The genetic engineering of disease-resistant plants has gained interest, and some progress has been made with several virus infections, the best example is papaya ringspot (*Papaya ringspot virus)*. Improvement of resistance has been most effective against the host specific pathogens such as rust fungi, smut fungi, powdery mildew fungi, and viruses. However, less so against non host specific pathogens such as many blights, canker, root rot, and leaf spot pathogens.

The insertion of genes from other creatures into plants to impart some feature is a new and controversial strategy in generating disease-resistant plants. This has been possible through biotechnology which has contributed to the successful management of plant diseases. Genes from the *Bacillus thuringiensis* bacterium, for example, have been introduced into plants to

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defend them from insect attacks. The bacterium produces proteins that are toxic to some insects when eaten, but not others. Plants containing these inserted genes of bacteria are known as Genetically Modified Organisms (GMOs), and they have raised concerns that unintended and potentially harmful features, such as unsuspected allergies, could be passed on to the new plants. However, traditional plant breeding procedures can sometimes pass on unintended and unwanted traits as well.

Chemical control

Chemical control is essential in the management of plant diseases. Today, a wide range of compounds have been formulated and designed to prevent plant diseases by blocking or eliminating the disease-causing microorganisms or vectors that carry pathogens (Figure 6.32 (d)). Chemicals that control bacteria are called bactericides, fungus (fungicides), insects (insecticides) nematodes (nematicides) are among the many types of chemicals available. For plant disease control, these pesticides should be applied correctly. Protective dust and sprays are used to keep crop foliage and fruit free of infection. Chemical dust and sprays come in a variety of forms of which for the case of field disease pathogens and vectors, the sprays apply mostly (Figure 6.32 (a)), which may be applied by using knapsack sprayer in small scale farming (Figure 6.32 (b)) or by using drones in large scale farming (Figure 6.32 (c)) in the case of dust, it is mainly meant for the storage of grains. They are not absorbed or translocated by the plant thus, they only protect the sections of the plant that have been treated before the pathogen's invasion. Because the initial coating may be swept away by the wind, rain, or irrigation water, a second spray is always suggested and required. However, the use of chemicals control method has advantages and disadvantages as explained hereunder:

(a) Advantages of chemical plant disease management

(i) It is comparatively the most effective method;

(ii) Chemical are stable and easily available in the market;

(iii) Are also, fast-acting and result in less damage to the crops; and

(b) Disadvantages of chemical plant disease control

(i) They are harmful not only to the target organisms but to other organisms as well;

(ii) Non-selective chemicals are the most harmful to other organisms of the ecosystem;

(iii) Selective chemicals have a limited range;

(iv) They may get into the food chain;

(v) Normally it leads to environment degradation hence, decrease biodiversity.

(vi) Is a relatively low cost; and

(vii) Continuous application of chemicals may develop host resistance.

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Figure 6.32 (a): Chemicals for disease control

Figure 6.32 (b): Knapsack sprayer for pest control

Figure 6.32 (c): A drone spraying pesticide on farm

Figure 6.32 (d): Disease pathogen insect vectors

Integrated Disease Management

Integrated Disease Management (IDM), is a pathologist-developed concept that combines all plant management approaches or principles. These may include the use of resistant cultivars, changing planting procedures, adjusting the environment through draining, irrigating, pruning, thinning, shading, and, if necessary, pesticide use. Monitoring environmental parameters such as temperature, moisture, soil pH, nutrients, disease forecasting, and determining economic thresholds are all significant components of the management plan. To maximize the benefits of each component, these actions should be implemented in a coordinated, integrated, and harmonized way (Figure 6.33). Whatever interventions are taken they must be compatible with the cultural techniques that are required to manage a particular crop. The main components of an IDM programme are as follows:

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(a) **Prevention:** Restrict entry of pathogens into fields through planting materials, irrigation water, workers and tools.

(b) **Monitoring:** Engage in regular field scouting to identify disease symptoms and plant disease vectors. Constantly review pest alerts from diagnostic clinics, state and government agencies, grower magazines and bulletins.

(c) **Accurate disease diagnosis:** Consult extension agents and diagnostic clinics. Identifying the causal organism for a disease is relevant as most biological and chemical control options available are pathogen specific.

(d) **Development of acceptable disease thresholds:** Understand the effect of a disease and yield loss. For example, 10% disease incidence because of a specific pathogen may not cause a significant yield loss in a vegetable crop, in which case chemical control may be an unnecessary expense.

(e) **Optimal selection of management tools:** Identify an integrated management plan depending upon the disease, crop, and field history. The field history of disease outbreaks is highly relevant in assessing the risk involved in the production. Cultural, host-plant resistance, biological, and chemical control options should be based on the conditions in that specific location.

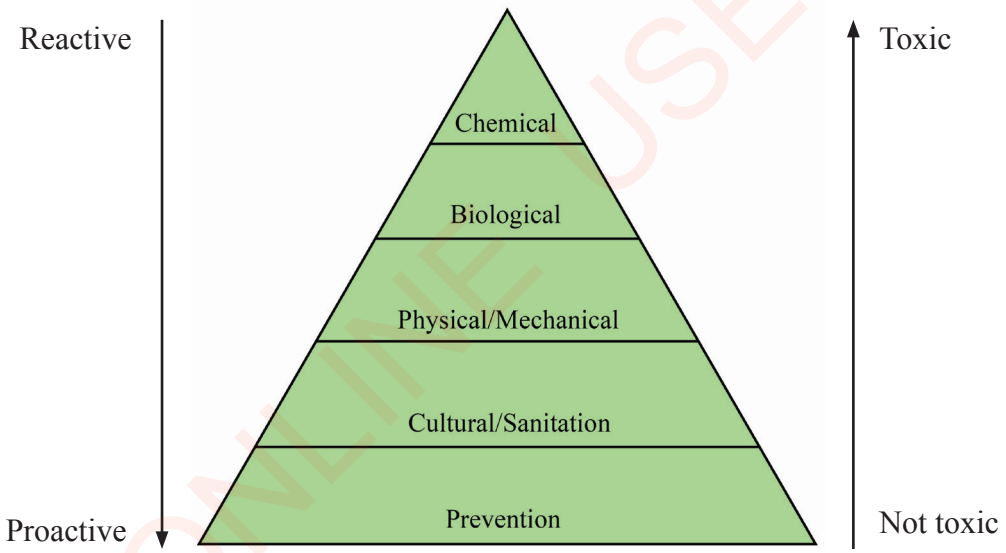


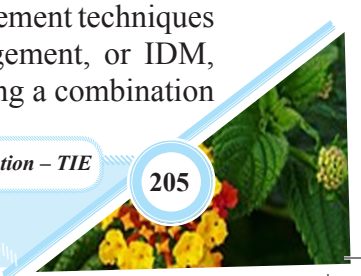
Figure 6.33 Integrated disease management pyramid

Activity 6.4

Using the school field/farm, prepare a plot for growing annual or perennial crop and practice the cultural agronomic practices on controlling crop diseases.

Selection of the appropriate plant disease control techniques

When control measures are required, you must decide which management techniques are most appropriate in your context. An integrated pest management, or IDM, strategy is most prudent and effective because it involves employing a combination



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of management techniques. Cultural practices and plant selection are the first line of defence. Pesticides may be required and can be a part of an IDM program, but should be viewed as a last resort. Pesticides are often overused, particularly when one simply wants to solve a pest problem quickly rather than understand why it occurred. When pesticides are needed, select the least toxic product that is designed for that specific plant and disease.

When pesticides are necessary, follow the recommended application methods and rates described on the pesticide label. A little extra is definitely not better when it comes to the application rate. Repeated use of some pesticides can cause the target organisms to develop resistance, which could make future applications less effective. In some cases, pesticides can also harm human health, the environment, or non-target organisms, including birds and beneficial insects that might help keep other plant problems in check.

Activity 6.5

1. Under the guidance of your teacher perform the following task:
   (a) Manage at least 3 diseased plots using different disease control techniques (one group may use chemical control, another group biological control and cultural control in another group);
   (b) After about two weeks, observe the progress in three plots and write a report;
   (c) Presents your findings in class for discussion (the discussion should base on:
      (i) Effectiveness and efficiency of each of the three approaches;
      (ii) Advantages and disadvantages of each approach.
2. Prepare a comprehensive summary for what you have covered in this chapter.

Revision Exercise 6

1. Explain how non-pathological agents cause plant diseases.
2. How can biotechnology contribute to the successful management of plant diseases?
3. Describe any two ways in which plant disease spread between plants and between plant fields.
4. How can a farmer prevent or reduce the spread of diseases from one plant to another during agronomic practices in the field or garden?
5. Explain any five cultural management practices that help to reduce plant disease in crops.
6. Give any five non-pathological disease-causing agents.
7. Explain seven importance of plant diseases.
8. Outline any five types of crop diseases based on cause and symptoms

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Chapter Seven

Animal nutrition

Introduction

Animal nutrition deals with the nature of feeds in terms of their origin, state and classification. In addition, it describes the nutrient contents in feeds, utilisation of feeds by the animals and estimation of nutrients requirements of the animals. In this chapter, you will learn on aspects of feed components and how they are estimated. Furthermore, you will be introduced to the aspects of nutrients utilization by the animal body, measurements of feed utilisation, factors limiting feed utilisation, including ways of improving feed utilisation. The concepts of ration formulation for different animal species at various physiological statuses will also be illustrated. The competencies developed in this chapter will enable you to prepare feed rations for various farm animals and hence increase farm production and household incomes.

Concepts of feeds and feed utilisation

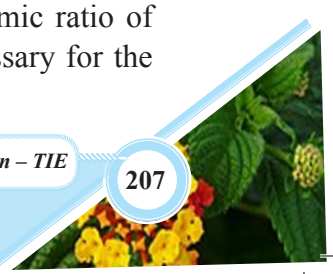
Animals depend on feeds for their maintenance and various production functions, including growth and reproduction. Feed is any material with nutritional value which can be ingested, digested, absorbed and utilised by animal's body. The quality and quantity of nutrients in feed with balanced rations enhance their utilization and effective animal performance and farm enterprises. In this subsection, the components of feeds with their respective functions in the body are described. Furthermore, the digestive systems of farm animals and digestion processes are also discussed due to their paramount importance for the efficient utilization of feedstuffs.

Components of feeds and their roles

Feeds contain nutrients of different types and quantities. Nutrients are chemical compounds or essential compounds capable of being utilised by animals for the chemical metabolism. Such nutrients are also known as feed components. The major components of feeds are normally classified into six groups, which are water, carbohydrates, protein, fats, vitamins and minerals. The nature and roles of each component of the feed in the body of animal is described in the subsequent subsections.

Water

Water is composed of hydrogen and oxygen elements at the atomic ratio of 2:1, respectively. It is necessary for the



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survival of animals. An animal can live longer without feed than without water. Water makes up about 75% of the weight of a mature animal and as much as 90% of a new born animal. Water is the most common molecule in the body, making up about 98% of the body molecules. Water plays the following biological roles in the body.

(a) **Cell rigidity and elasticity:** The body is able to change its shape by conforming to some extent, on the force applied on it at a particular point. This is made possible by the liquid contents of the cells.

(b) **Solvent action:** Water saves as an ideal solvent for a wide variety of compounds. It serves as a universal medium in which intracellular and extracellular chemical reactions take place.

(c) **Hydrolytic reactions**: Hydrolysis is an important chemical process involved in digestion and metabolism.

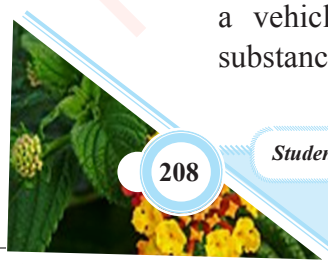
(d) **Ionic and other reactions:** The process of living depends upon a continuous series of chemical reactions and many of these reactions require a medium in which to act. Water is therefore a medium of such reactions.

(e) **Lubrication**: Water acts as a lubricant to prevent friction and drying in joints, pleura and conjunctiva.

(f) **Transportation**: Water acts as a vehicle for transportation of substances into the body and as the extracellular fluid moves nutrients to and wastes out from the tissues. In the alimentary canal, water serves as the medium for transportation of food materials from the intestine and excretion of metabolic wastes.

(g) **Regulation of body temperature**: Water has high specific heat, thus more heat is required to raise the temperature of 1g of water to 1^0C than most known liquids and solids. This property makes water capable of regulating body temperature. Water helps heat loss through the urine and faeces and by evaporation from the skin and lungs.

The amount of water needed by an animal is related to the activity of the animal, stage of growth, and type and levels of production. The exact specifications of water requirements for a given class of animal are difficult to establish because several factors are known to have direct or indirect effects on the overall daily water intake. One of such variables is the environmental temperature, whereby ambient temperature has a marked effect on the water demand. The intake of water is higher in hot than cool seasons. For example, a cow weighing 450kg with daily intake of 10kg dry matter, water intakes are 28, 41, and 66 litres when temperatures are 4°C, 21°C and 32°C, respectively. The amount of water intake is also influenced by the level of feed intake. In sheep, it is estimated that 2 litres of water are required for each 1kg



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of feed dry matter intake. Other factors are related to amounts of the nutrients in feed. Feeds of high protein or mineral contents lead into increase in urinary water, hence more demands of water by the animal. The level of production also has effect on water intake, whereby high level of production requires more water than low level. Pregnant cows require more water than dry cows.

Carbohydrates

The carbohydrates are composed of carbon, hydrogen and oxygen at different atomic ratios. They contribute about 75% of the diet of animals. Carbohydrates are categorized into simple and complex compounds. Simple carbohydrates can easily be digested. Sugars and starches are simple carbohydrates found mainly in feeds including maize, wheat, cassava, barley and sorghum. Complex carbohydrates are more difficult to digest than simple carbohydrates. Cellulose and hemicelluloses are complex carbohydrates and in mature roughages are bound with lignin, which make them less available in animal body. There are five important functions of carbohydrates as outlined hereunder:

(a) Carbohydrates provide a great part of the energy in most animal diets. They are metabolised in the body to produce energy, liberating carbon dioxide and metabolic water.

(b) Body movements and internal communication systems are facilitated by glucose, a component of carbohydrates.

(c) They are also used as storage of energy. Animals store excess food energy in the form of glycogen and body fats. Glycogen may be stored in the liver or in the muscles, while fat is stored mainly in subcutaneous and around the abdominal organs.

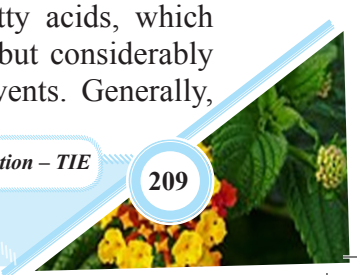
(d) The end products of carbohydrate metabolism act as organic catalysts for oxidation reactions, hence assisting in the breakdown of other feed components. For example, some glucose obtained from carbohydrates metabolism is converted to deoxyribose and ribose, which are important in building the vital macromolecules in the body.

(e) Carbohydrate metabolites are used as starting material for the synthesis of various biological components such as fatty acids.

(f) Carbohydrates serve as structural component of important organic compounds, such as glycoproteins and glycolipids. Major structural materials in the body such as muscles, bone and skin constitute some form of carbohydrates. The body immune system and other chemical reactions needed in the body are derived from the carbohydrates.

Lipids

Lipids are organic compounds made up of glycerol and fatty acids, which are insoluble in water but considerably soluble in organic solvents. Generally,



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lipids are composed of carbon, hydrogen and oxygen but with different atomic ratios when compared to carbohydrates. Fats and oils are also known as lipids. Fats are solid and oils are liquid at room temperature. Fats or lipids play role in the following biological functions:

(a) Fats form the highly concentrated source of energy for animals when are metabolised. Fats have more than twice the energy contained in carbohydrates. Being a compact fuel, fat is efficiently stored in the body for later use when carbohydrates are in short supply.

(b) Fats form the important food reserves in both plants and animals. In plants, lipids are stored in seeds, for example groundnut, mustard, coconut and castor. In animals, fats are mainly stored in subcutaneous and visceral adipose tissues in the body.

(c) Fats are also used for protection and insulation. Some fats deposited beneath the skin and around the internal organs prevent the loss of body heat. They act as shock-absorbing cushions around the eyeball, kidney, and gonads.

(d) Fats play role as structural components of cell membranes, for example glycolipids found in a myelin sheath in the brain.

(e) Fats are source of hormones, vitamins and some digestive juices. Cholesterol is used in the synthesis of steroid hormones, vitamin D, and bile salts. Prostaglandins are hormone-like compounds derived from fatty acids, such as arachidonic acid.

(f) They are medium and carrier for fat soluble vitamins A, D, E and K. These vitamins are transported into cells of the small intestine in association with fat molecules.

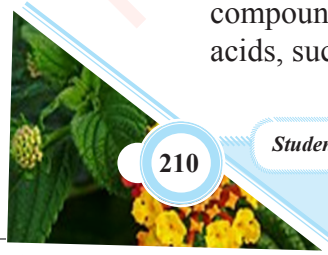
Proteins

Proteins are macromolecular compounds made up of amino acids as basic units. The amino acids are composed of carbon (50-55%), hydrogen (6-8%), oxygen (20-23%), nitrogen (15-18%) and sulphur (0-4%). The amino acids can be divided into essential and non-essential. The essential amino acids are those which cannot be synthesized in the animal body at an adequate rate to meet metabolic requirements and must be supplied in the diet. These include: arginine, histidine, isoleucine, lysine, leucine, methionine, phenylalanine, threonine, tryptophan, and valine. The non-essential amino acids are those that can be synthesized in the animal body from nitrogen-containing substances. Some of these include: alanine, aspartic acids, citrulline, cystine, glutamic acid, glycine, hydroxyproline, proline, serine, and tyrosine. The roles of proteins are outlined herein:

(a) Proteins build body tissue and structural constituent of cell membranes. They are involved in the repair of worn-out cells and tissues like skin, hair and muscle.

(b) Proteins act as biological catalysts. Enzymes which are made of protein catalyse nearly all reactions of organic bio-molecules in the cell.

(c) Proteins are involved in transportation and storage of molecules. Haemoglobin is a



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good example of a transport protein that is involved in the transportation of oxygen in erythrocytes while myoglobin transports oxygen in the muscles.

(d) Proteins are also necessary for nutrient storage. Iron is stored in ferritin, casein stored in milk and albumin in egg white.

(e) Some proteins including, actins and myosin found in skeletal muscles, enable cells and organisms to contract to facilitate movement.

(f) Antibodies (immunoglobulin) that protect animals against infections, as well as fibrinogen and thrombin, which help in blood clotting, are all proteins in nature.

(g) Proteins help to regulate cellular or physiological activities of the body. Proteins are the main component of hormones, such as insulin, growth hormones and parathyroid hormones, which are involved in different regulatory activities of the animal body.

(h) Protein is used as source of energy whenever there is insufficient energy from carbohydrate sources.

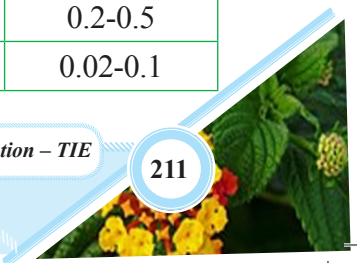
Minerals

Minerals are essential inorganic nutrients, required in small amounts for health, maintenance and production. Essential minerals are elements, which are proved to have a metabolic role in the body. They must be present in the diet to meet requirement and when deficient causes symptoms which are repeatable. About 40 mineral elements are regarded to be essential.

Minerals are divided into two groups. The first group is major or macro elements, which are minerals needed in the body in large amounts. The second group is the trace or micro elements, those minerals needed in relatively small amounts. The grouping of the important essential minerals and their average concentration in the animal diets are shown in Table 7.1.

Table 7.1: The important major and trace mineral elements and their average concentration in the diets of animals.

Major/macro elements	g/kg	Trace/micro elements	mg/kg
Calcium (Ca)	15	Iron (Fe)	20-80
Phosphorus (P)	10	Zinc (Zn)	10-50
Potassium (K)	2	Copper (Cu)	1-5
Sodium (Na)	1.6	Molybdenum (Mo)	1-4
Chlorine (Cl)	1.1	Selenium (Se)	1-2
Sulphur (S)	1.5	Iodine (I)	0.3-0.6
Magnesium (Mg)	0.4	Manganese (Mn)	0.2-0.5
		Cobalt (Co)	0.02-0.1



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The important aspect to consider in supplying minerals to animals is their availability or how well a mineral is utilised within the animal body. Some minerals may be present in the animal diet; however, the proportions of the minerals that are absorbed from the diet and used for normal body functions may generally be limited. Some of the factors affecting the availability of minerals are coarseness of the feed, contents of other minerals in the feed, season of the year and location or area.

Too coarse feed makes difficult for minerals to be released to the animal body. The extent of feed processing, mastication, enzyme and microbial digestion have influence on the availability of minerals. The contents of other minerals in the feed, for example, high levels of Zn in the diet forms complex compounds with dietary Ca and P and hence make them unavailable. Tropical forages contain fewer minerals during dry season. During maturation minerals in plants accumulate in the roots, thus mineral deficiencies are more likely to develop during dry season. Mineral contents of the soil influence mineral contents in feedstuffs. Some plants accumulate minerals which are toxic in high concentrations, for example selenium (Se). Fertilisation influences both the quantity and quality of minerals in feedstuffs. The important roles of minerals in the body of an animal are summarised as follows:

(a) Minerals are naturally found throughout the animal body, in the bones, muscles, teeth, blood and nerve cells.

(b) Minerals help to maintain a normal water balance within the body and regulating the breakdown of carbohydrates.

(c) They also take part in such processes as enzymatic actions.

(d) Minerals are also necessary for the contraction of muscles, nerve reactions and clotting of blood.

Vitamins

Vitamins are organic compounds, which are required in small amounts. They are compounds of natural foods that are distinct from carbohydrates, fats and proteins. They are essential for the development of animal tissue, for normal health, maintenance and production in animal life. When absent from the diet or not properly absorbed or utilised, result in specific deficiency symptoms. Some compounds function as vitamins only after undergoing a chemical change and such compounds are described as pro-vitamins or vitamins precursors. Vitamins are classified into two groups, the fat-soluble and water-soluble vitamins. Fat-soluble vitamins are those vitamins soluble in fat, including vitamins A, D, E and K. These vitamins are absorbed together with fats and the factors affecting absorption of fats also affect absorption of these vitamins. They are normally stored in tissues and the excess are excreted by the liver and discarded by the bile and in faeces. The general sources, functions and deficiency symptoms of the fat-soluble vitamins are presented in Table 7.2.

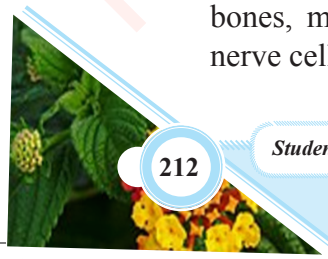

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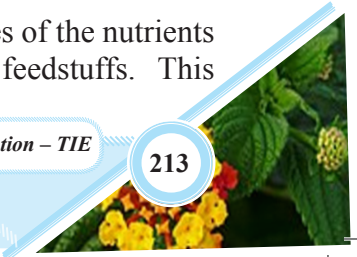
Table 7.2: General functions, sources and deficiency symptoms of fat-soluble vitamins

Vitamin	General Functions	Main Sources	Deficiency symptoms
A	Promote vision, immune system, growth and reproduction.	Dairy products, liver, fish, eggs, orange, coloured fruits and vegetables.	Loss of vision, poor growth and reproduction.
D	Promote bone growth and strength, support immune system.	Sunlight (ultra – violet), oily fish, liver, eggs dairy products.	Rickets, osteoporosis.
E	Prevent blood clotting in veins and arteries, boost immunity and act as anti- oxidant.	Sunflower seeds and oil; wheat germ, oil, peanuts, spinach.	Poor vision, muscle coordination and low immunity.
K	Speed up blood clotting to minimize bleeding, enhance bone strength and prevents calcification of blood vessels.	Egg yolk; liver, spinach, butter.	Delayed clotting on wounds, bone weakness, high blood pressure.

The water-soluble vitamins, which are found in feed and derived from both animals and plants, include vitamin C and the B-vitamin complex. These are absorbed in the intestine and their availability depends on the amount of water. Vitamins B are synthesised by the gut microorganisms; thus, it is not necessary to supplement ruminants with these vitamins except under special conditions. In non-ruminants, these vitamins are necessary to be supplemented. Vitamin B plays a role as a co-factor in the intermediary metabolism. Deficiency symptoms of B-vitamin are very diffuse and they are most often caused by accumulation of metabolites in the body. In farm animals, Vitamin C is only considered in pigs as other animals can synthesize it from other nutrients.

Quantification of feed components or nutrients

Rationing require values of the nutrients available in various feedstuffs. This



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implies that the quantities of different nutrients contained in feedstuffs should be known. These nutrients are normally estimated by conducting feed analysis procedure in laboratory. There are a number of techniques used for such analyses. However, the routinely used procedure in animal nutrition is the Weende scheme of analysis or proximate analysis. This method is based on the separation of a sample of feedstuff into nutritive components through a series of chemical determinations. It reflects the nutritive value of the material. The feed sample is fractionated into six components, which are;

(a) **Dry matter (DM):** This is the dried feed sample obtained by drying it in an oven to remove the water. The portion which disappears represents the amount of water or moisture content of the feed;

(b) **Crude protein (CP):** This is an estimates of the protein content of the feed by estimating the nitrogen content of a sample using a series of chemical determinations. The amount of nitrogen is multiplied by a factor of 6.25 to obtain the crude protein content of the feed material;

(c) **Ether extract (EE):** The amount of fat or lipid present in a dry weighed sample is extracted using ethyl ether. The difference in weight between the sample and residual gives the fat/lipid content in the feed. This component is referred to as ether extract (EE) representing the amount of crude fat/lipid in the feed;

(d) **Crude fibre (CF):** The amount of fibre in the feed is estimated using a series of chemical extractions. This component represents the less available carbohydrates of the feed;

(e) **Ash:** This is determined by burning a weighed dried sample. This procedure burns out the organic matter of the feed. The remaining component represents the mineral matter and termed as ash;

(f) **Nitrogen free extract (NFE):** This component is obtained by computing the difference that is the cumulative proportions of the moisture, ash, crude protein, crude fibre and ether extract are subtracted from 100%. It represents the highly available carbohydrates in a feed, such as sugars and starches.

(% NFE = 100% - (% moisture + % ash + % CP + % CF + % EE)

Feed utilisation

Feed utilisation simply refers to the absorption and assimilation of the feed nutrients by the animal. It starts with the animal consuming the feed. When an animal eats feed, the nutrients in that feed are gradually broken down from insoluble to soluble substances. The action of breaking down feed nutrients is known as digestion. The process of digestion take place in the digestive tract of the animal. After being digested, the nutrients are absorbed to the body system where they are metabolised for various body functions.

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Digestive systems of farm animals

This section highlights some aspects of the digestive tract and feed digestion process in different parts of the guts of farm animals. The digestive systems of pig, poultry, cattle, and rabbit are presented in Figure 7.1 (a), (b), (c) and (d) respectively. The system consists of the alimentary canal and other organs, such as liver, gall bladder, and pancreas, which play role in the secretion of various digestive juices and enzymes.

The alimentary canal is a hollow tube-like structure that extends from the mouth to the anus, lined with a mucus membrane. It includes the mouth, oesophagus, stomach or compartments in ruminant, small intestine, caecum, large int

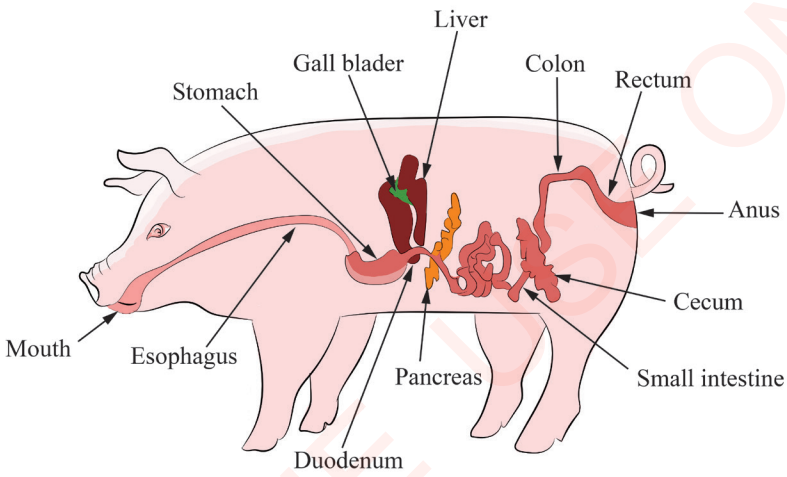

Figure 7.1 (a): Digestive system of pig

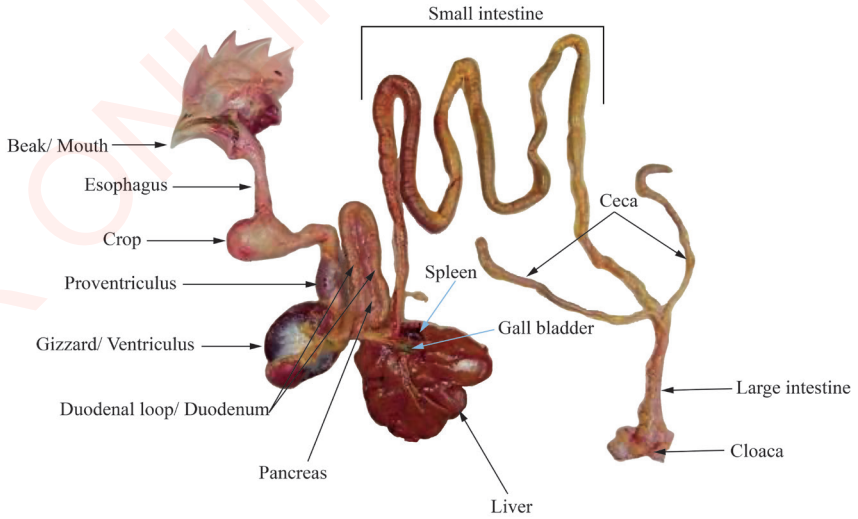

Figure 7.1 (b): Digestive system of chicken

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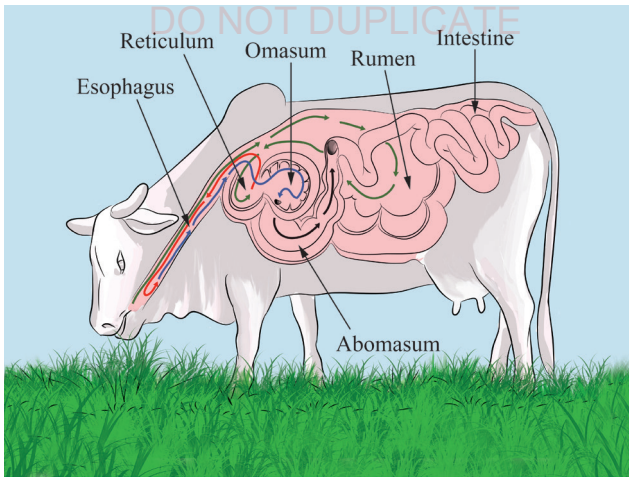

Figure 7.1 (c): Digestive system of cattle

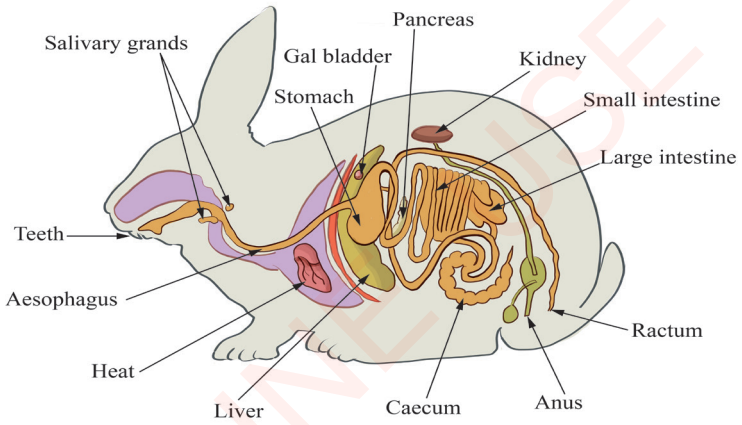

Figure 7.1 (d): Digestive system of rabbit

Animals, such as pigs and poultry have simple stomach and they feed largely on concentrated feeds. These are known as monogastric or omnivores animals. Other animals for example cattle, sheep, and goats have stomach with four compartments and they feed mainly on fibrous feeds and are known as ruminants or herbivores. Animals such as rabbits, horses and donkeys have simple stomach and relatively large caecum and are able to feed on and utilise both fibrous and concentrate diets. These may be grouped as hind gut fermenters or herbivores non-ruminants.

Activity 7.1

Visit a nearby slaughter house for either cattle, goat or sheep. Make another visit to a slaughter place for either pigs, chickens or rabbits then:

1. Observe, draw and label representative digestive system of:

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(a) Ruminant;

(b) Either a pig, chicken or rabbit;

(c) Herbivore non-ruminant (hind gut fermenters).

2. Differentiate the digestive systems of ruminants and non-ruminant herbivores; then

3. Write a report and present in the class for discussion.

Digestion in different parts of the digestive systems

The processes of digestion may be described as physical, chemical and microbial. The physical processes entail chewing, ruminating and movement of the gut or peristalsis. The chemical digestion involves the breakdown of the feed particles by the enzymes produced by the animal body. The microbial digestion is performed by the enzymes produced by microbes in the body.

Digestion in monogastric animals

The digestive system of monogastric animals contain the following parts.

(a) Mouth

The digestion of feed begins in the mouth by mechanical and some chemical actions. In the mouth, there are three salivary glands. These are the parotid glands, which are situated around the ear region, the mandibular or submaxillary gland situated around the lower jaw and the sublingual gland, which lies under the tongue. The major function of the salivary gland is the secretion of saliva. Saliva contains biological catalysts that accelerate chemical reactions. These catalysts are called enzymes. The enzymes present in saliva are amylase and ptyalin. These enzymes break down starch into simple sugars. The digestive systems and processes in pigs and poultry are similar although they differ anatomically. In poultry, the lips are modified to beak. The beak picks up feed into the mouth. The mouth of poultry does not have teeth but has glands that secret saliva.

(b) Oesophagus

The oesophagus is a tube-like structure that connects the mouth and stomach. After being swallowed, the chewed and softened feed goes through the oesophagus. Peristalsis is a one-way sequence of wave-like movements that drive feed toward the stomach through the smooth muscles of the oesophagus. It transfers feed from the mouth to the stomach. In poultry, it takes feed from the mouth to the crop and from the crop to the proventriculus.

(c) Stomach

The stomach of pigs (Figure 7.1 (a) acts as the place of digestion and feed storage. The wall of the stomach secretes hydrochloric acid which activates pepsin enzymes. Pepsin breaks down protein into polypeptides under acidic conditions. In early stages of life, the stomach wall secretes gastric juice, which contains enzyme called rennin. Rennin breaks down milk protein particles and converts them into polypeptides. Partially digested feed with enzymes in the stomach is known as chyme.

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(d) Crop, proventriculus and ventriculus

In poultry, the crop is an out-pocketing of the oesophagus in the neck area of poultry, just outside the body cavity (Figure 8.1(b). The crop stores ingested grain and water until it is transferred to the rest of the digestive tract. When the crop is nearly empty, it transmits hunger signals to the chicken's brain, causing it to eat more. Even though the digestive enzymes released in the mouth started the digesting process, the crop just serves as a temporary storage pouch. The proventriculus is the true stomach of the avian digestive system. It is the site where digestion primarily begins. Hydrochloric acid and digestive enzymes are secreted and act upon the digester. Figure 8.1a (ii), shows the proventricular and ventriculus of poultry. The ventriculus, commonly known as gizzard, is referred to as the mechanical stomach. It is made up of two sets of strong muscles that act as the teeth of birds. Gizzard collects digester and digestive juices from the salivary glands and proventriculus for grinding, mixing, and mashing.

(e) Small intestine

The digestion processes in the small intestine for pigs and poultry are similar. The chyme leaves the stomach and enters the small intestine. In the small intestine, the chyme is mixed with different secretions from the liver and pancreas. The small intestine acts by mixing digester and alkaline secretion. The function of alkaline is to protect the intestine wall from hydrochloric acid entering from the stomach. The liver secretes bile and transport it into the small intestine through the bile duct.

The pancreas secretes pancreatic juice which contains enzymes that act on proteins into amino acids, starch and glycogen into simple sugar as well as lipids into glycerol and fatty acids.

(f) Large intestine

The large intestine does not secrete any enzymes. In pigs, the large intestine is composed of caecum, colon and rectum. In birds, caecum is two shade bags located where small and large intestines join and the colon is connected to an organ called the cloaca. The feed travels slowly through the caecum to colon and rectum or cloaca in birds. Large intestine helps to reabsorb water remaining in the digester and there is existence of the microorganisms, which ferment any remaining rough materials. During this fermentation, there is production of volatile fatty acids and vitamins B, which are partly absorbed and available to the animal. The colon is where faeces is formed and later expelled through the anus.

Digestion in ruminant animals

The digestive system of ruminant animals involves the following parts.

(a) Mouth

In the mouth of ruminants, mechanical digestion, such as chewing and grinding takes place. Ruminants have no upper incisors, they have dental pad, which provide a surface against which the lower incisors can put pressure to bite off and pull fibrous feeds. Chewing is mainly through grinding of the feeds

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to increase the surface area and make it more available to the chemical and microbial processes. In the mouth there is secretion of saliva which coats the feed for swallowing. Saliva functions as smearing agent of the feed material. It has a buffering effect and contains nitrogen from the rumen microbes.

(b) Oesophagus

The ruminant oesophagus has strong muscles that propel the feed downwards into the rumen during regurgitation. Regurgitation is the action by which the digester is taken back from the rumen to the mouth for re-grinding, reforming the bolus and re-swallowing. The process is cyclic where regurgitation is followed by swallowing.

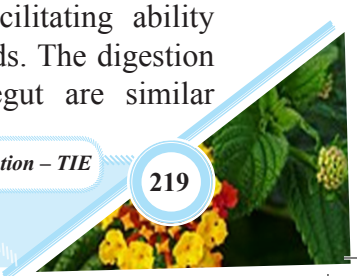
(c) Stomach

The stomach of ruminant animals is divided into four compartments; these are rumen, reticulum, omasum and abomasum (Figure 8.1b (i). The rumen is the first part of the stomach followed by reticulum. Sometime the two are referred to as reticulo-rumen. The rumen acts as a storage area for ruminant feed and supports the breakdown of large feed particles. The reticulum retains foreign materials that could harm the digestive system and also categorises feed particles by detecting large particles that need to be brought back to the mouth for re-grinding.

In the reticulo-rumen there are symbiotic microorganisms, such as bacteria, protozoa and fungi, whose function is to help in the breakdown and fermentation of the feedstuffs. Through fermentation, the feed (carbohydrates) are broken down by the microbial enzymes to produce volatile fatty acids (VFAs), carbon dioxide (CO_2) and methane (CH_4). The VFAs are absorbed and used as source of energy to the animal. The CO_2 and CH_4 are released out of the body through the process called eructation. The proteins are broken down to produce simple nitrogenous compounds, which are taken up by the microbe to produce microbial protein. These are then, digested by the animal body enzymes to supply amino acids to the animal. The fats are also hydrolysed by the microbes. In newly born calves, milk passes through an esophageal groove directly to the omasum and abomasum. The rumen and reticulum develop gradually when calves consume solid feed, especially grass. The omasum is the third part of the stomach, which contains folds or layers of muscles that act as a filter by squeezing the liquid material away from the feed particles and breaks down the feed particles into a smaller size. The abomasum or fourth compartment is a true stomach. It contains acids and digestive enzymes for further digestion of feed and passes digester to the small and large intestines. The digestion processes which take place in these parts are similar to those described under the monogatric animals.

Digestion in pseudo-ruminant animals (hind-gut fermenters)

The hindgut fermenters include rabbits, donkeys, and horses. These animals have simple stomach, long small intestine and large caecum, facilitating ability of utilising fibrous feeds. The digestion processes in the foregut are similar



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to those of monogastric animals. They have large caecum, which is populated by micro-organisms, and function similar to those present in the reticulo-rumen of ruminant animals. They are also adapted to have fast rate of digestive passage in the alimentary canal, and facilitates high absorption rate of soluble components of the feed. Other animals in this group, for example rabbits recycle the digester, and hence get access to the products of microbial digestion in the caecum.

Estimation of feed utilization

Digestibility of a feed refers to the potential amount of feed nutrient or energy that can be digested, absorbed and processed by animal's body. It is the proportion of feed or nutrient consumed which is not excreted in the faeces and is therefore, assumed to be absorbed by the animal. The extent of utilisation of feeds by animals can be measured by the amount of nutrients absorbed or performance of the fed animal. The digestibility of a feed is commonly expressed in terms of dry matter as a coefficient or a percentage.

$$\text{Digestibility (\%)} = \frac{\text{Nutrient consumed} - \text{Nutrient (faeces) excreted}}{\text{Nutrient consumed}} \times 100$$

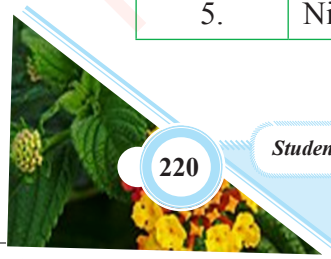
Estimating digestibility involves feeding animals a known quantity of the feed under investigation and collection of total faeces excreted. The digestibility of nutrients is obtained by analysing the proximate components, that are dry matter (DM), crude protein (CP), crude fibre (CF), ether extract (EE) and nitrogen free extract (NFE) of both feed and faeces. The digestibility coefficients of the different feed components or nutrients are then estimated. A feed with high value of digestibility implies that it is well utilised and has relatively high nutritional value.

Worked example 1

A goat ate 1kg of fresh guinea grass (*Panicum maximum*) and excreted 0.5 kg of faeces. The chemical composition of the grass and the faeces excreted by the goat is given in Table 7.3. Calculate the digestibility coefficients of dry matter and for the individual components of the guinea grass.

Table 7.3: Data on chemical composition of guinea grass

S/N	Component (%)	Guinea grass	Faeces
1.	Dry matter (DM)	40	30
2.	Crude protein (CP)	8	6
3.	Crude fibre (CF)	35	40
4.	Ether extract (EE)	7	6
5.	Nitrogen free extract	40	36



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Solution 1

Dry matter digestibility (%) of the grass

Fresh grass intake = 1 kg

DM content of grass = 40 %

$$\text{Dry grass intake} = \frac{1\text{ kg} \times 40}{100} = 0.40\text{ kg}$$

Fresh faeces excreted = 0.5

DM content of faeces = 30 %

$$\text{Dry faeces excreted} = 0.5\text{ kg} \times \frac{30}{100} = 0.15\text{ kg}$$

$$\text{Dry matter digestibility} = \frac{\text{Dry grass intake} - \text{Dry faeces excreted}}{\text{Dry grass intake}} \times 100$$

$$\text{Dry matter digestibility} = \frac{0.40\text{ kg} - 0.15\text{ kg}}{0.40\text{ kg}} \times 100 = 62.5\%$$

$$= 62.5\ \%$$

The digestibility of the feed components or nutrients of the grass can similarly be calculated as shown in solution 2

Solution 2

Digestibility (%) of crude protein (CP)

Dry grass intake = 0.40 kg

Dry faeces excreted = 0.15 kg

CP content of grass = 8%

CP content in faeces = 6%

CP intake = 8/100 x 0.4 kg = 0.032 kg

CP faeces = 6/100 x 0.15 kg = 0.009 kg

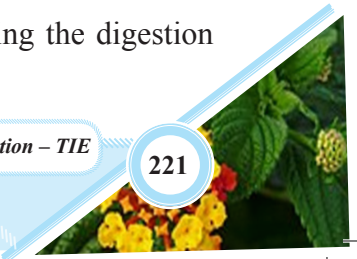
$$\text{Digestibility coefficient of CP} = \frac{\text{CP intake} - \text{CP faeces}}{\text{CP intake}} \times 100$$

$$= \frac{0.032\text{ kg} - 0.009\text{ kg}}{0.032\text{ kg}} \times 100 = 71.875\%$$

Digestibility coefficient of crude protein (CP) = 71.87%

Feed factors limiting feed utilisation

The feed factors limiting feed utilisation are mainly those affecting the digestion



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rates or digestibility of the feed. The factors include methods of feed preparation chemical composition of the feed, presence of anti-nutrition factors/ poisons, level of feed consumption and level of feed intake as described hereunder.

(a) Processing methods

Feed processing is the practice of modifying feed before it is fed to the animals. It includes physical, chemical and biological methods. Physical treatments, such as grinding, chopping, chafing, crushing and cooking have great effects on the utilisation of nutrients in feeds. For example, fine grinding of roughage increases the rate of digester passage in the reticulo-rumen. This allows less time for microbial fermentation, hence lower the digestibility. Such feed will be poorly utilised by the animals. Chemical treatments such as, treatment of straws with NaOH tend to increase the digestibility of straw, hence improve its utilisation. Biological treatments of some feeds, for example use of enzymes, such as lignase breaks down lignin in roughages and improve their utilisation by ruminants.

(b) Chemical composition of feed

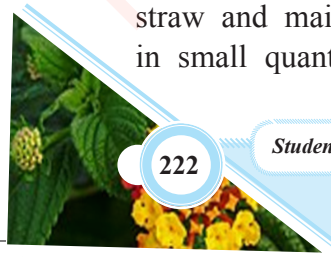
Feed with high crude fibre (CF) content generally have lower digestibility than that with low CF content. Crude fibre content in forages increases with stage of growth, making mature forages to have poor utilisation by animals. Feeds with low digestibility, for example rice straw and maize straw are consumed in small quantities due to their slow rate of passage through the gut. Hence have low rate of utilization while legume-grass mixtures are consumed in greater quantities with high nutrients being utilised in ruminant animals. Digestibility of a feed increases with increasing protein content of the feed.

(c) Anti-nutritional factors and poisons

Anti-nutritional factors are substances, which themselves or through their metabolic products interfere with feed utilisation, hence affecting animal performance. The effect of anti-nutritional factors in feeds results in poor palatability and feed intake. Some of the anti-nutritional or toxic factors present in the feed are described hereunder.

(i) **Gossypol:** This is a toxic compound found mostly in cotton seeds. Gossypol content depends on species, cultivars, fertiliser rates, growing conditions, and insect pressure. The micro-organisms in ruminant's digestive system, detoxify gossypol in cotton seeds. Young ruminants with immature rumen as well as monogastric animals do not benefit from this protection and are thus sensitive to gossypol. The use of unprocessed cotton seeds in these species is not recommended. However, addition of iron salts to the diet binds gossypol and alleviates gossypol toxicity.

(ii) **Trypsin inhibitors:** These are anti-nutritional factors found in soybean seeds. Trypsin inhibitors bind with trypsin, a



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protein digesting enzyme in the small intestine to form inactive complex substance that prevents the enzyme from digesting feed proteins. Trypsin inhibitors are heat-labile, hence are destroyed by heating. Heat treatment is required before feeding soybean products to animals.

(iii) **Hydrogen cyanide (HCN):** This is a toxic compound present in both leaves and tubers of cassava in amounts ranging from 80 to 2000 mg/kg DM, depending on the variety, maturity, fertiliser application, and post-harvest processing. Detoxification of HCN can be done using different methods, such as sun-drying, wilting or ensiling.

(iv) **Tannins:** These are other toxic substance found in sorghum. Tannins bind with proteins, precipitate them and make them unavailable during digestion. Hence, the digestibility of feeds containing tannins is consequently reduced. There are a number of ways of inactivity tannins; examples are reconstitution followed by anaerobic storage, formaldehyde and acid treatments.

(v) **Mimosine** This is a poisonous amino acid abundant in leucaena that is harmful to non-ruminants (horses, donkeys, rabbits, pigs, and poultry). Leucaena is hazardous to cattle if provided in significant doses (greater than 30% of the diet) for lengthy periods. It decreases live-weight gain and reproductive performance of animals by decreasing feed intake, alopecia, increased salivation, and enlarged thyroid glands. Leucaena toxicity can be reduced by supplementing with zinc sulphate or iron salts. The amount of mimosine in a product can also be lowered by soaking it in water and drying it.

(d) **Level of feed supplementation**

Improper levels of supplementation lead to poor utilisation of basal feeds. In ruminant animals, a higher level of concentrate supplementation, inhibit digestion of forages by rumen microorganisms as a result of lowered rumen pH. The utilisation of the forage by the animal will be low. In monogastric animals, increased levels of mineral and vitamin mixtures in the feed lowers feed intake and overall feed utilisation.

(e) **Level of feed intake**

High levels of feed intake increase the rate of passage of digester and reduces the time for microbes to break down fibrous feeds. This leads into low digestibility especially that of crude fibre and hence poor feed utilisation.

Activity 7.2

In a group under guidance of the teacher, perform the following tasks:

(a) Collect different animal feed samples

(b) Based on your knowledge, outline the poisons/anti-nutritional factors of each feed sample;

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(c) Describe appropriate ways of dealing with each anti-nutritional factors on each identified feedstuff; then

(d) Write a summary and present it in class for discussion.

Exercise 7.1

1. Differentiate macro elements from microelements.
2. Describe the main roles of the important feed components.
3. With the aid of a diagram, describe the digestive systems of poultry and rabbit.
4. Outline the enzymes found in the small intestine and their functions.
5. Describe the four compartments of the stomach of ruminant animals.
6. Using the data given in previous Worked example 1 calculate the:
   (a) Digestibility coefficients of crude fibre; and
   (b) Nitrogen free extract.

Feed formulation

Feed formulation is a technique of combining feed ingredients to give a composite feed that will meet the nutrient requirements of a particular farm animal. It involves simple calculations, measurements and art. The main objective of formulating a diet or ration is to meet animal requirements at different levels of production, growth stage and reasonable cost. Feeds are formulated either as complete feeds or as supplementary feeds. Complete feed supplies all the required nutrients and can be fed as an individual ration without any supplement except water. These are fed either on free access (ad-libitum) or on a restricted basis, mostly in monogastric animals. Supplementary feeds for herbivores such as ruminants are fed over the power of the animal feeds to supply specific nutrient (s) for example energy, protein or vitamins. The following are factors to be considered before formulating a ration.

(a) List of feedstuffs, their availability, suitability as well as their composition on a dry matter basis;

(b) Nutrient requirements of an animal for a desired level of performance and stage of growth;

(c) Chemical composition of feed: the necessary nutrients and the potential available to the animal body;

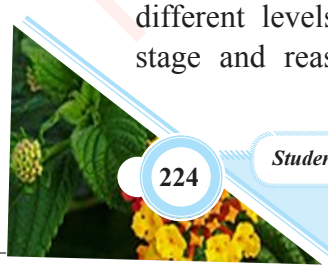
(d) Costs of feeds must be reasonable with low price fluctuation between, on and off-seasons;

(e) Physical composition of feeds to indicate the necessity of processing;

(f) Presence of anti-nutritional factors or toxic factors that can impair performance;

(g) Type of rations that is either complete ration or a supplement ration; and

(h) Expected level of feed intake.



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List of feedstuffs

The feedstuffs commonly used in animal rations can be classified into roughages, concentrates, supplements and feed additives. These are further described hereunder:

Roughages

Roughages are fibrous materials that can be categorised as dried, green and fermented roughages. The characteristic of each category is discussed in the following sections:

(a) Dried roughages: Dried roughages are grass or legume where the moisture content is very low and normally less than 15% and have high crude fibre normally more than 18%. Characteristically, they have low nutritive value in terms of crude protein, minerals, and vitamins. Roughages have low digestibility in monogastric animals, thus suitable for ruminant animals. Examples include grass hay, straws, maize cobs, stover and haulms. Figure 7.2 shows staked baled hay.

Figure 7.2: Baled hay

(b) Green roughages: Green roughages are greenish fibrous materials that are high in moisture content, easily digestible, and are commonly used for feeding dairy and other high productive animals. Green roughages include: fodders, forages, range grasses, sugarcane tops, and special tree leaves. They contain relatively higher levels of protein as compared to other types of roughages. Green roughages grown naturally are called forages and cultivated ones are called fodder. Moisture content of green roughages varies with age and agronomic practices. They have high crude fibre, but lower than in dry roughages. Availability of crude protein and digestibility depends on age, species, and agronomic practices. Have variable amounts of minerals and vitamins, particularly vitamin A. Figure 7.3 shows an example of fodder species (*Leucaena leucosephala)*.

Figure 7.3: Part of *Leucaena leucosephala***.**

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(c) **Fermented roughages:** Fermented roughages are types of roughages made from different crops which have been preserved and fermented to the point of acidification. Feed conservation through fermentation process is called ensiling. The commonest example is silage, which can be made from maize, sorghum, and some leguminous plants. The nutritive value of silage depends on the age of cutting and method of preparation. Figure 7.4 shows silage fermented and storage in a silo.

Figure 7.4: Silage storage in a silo

Concentrate feeds

Concentrate feed is the one used either as a complete feed or supplement to improve the nutritive balance of the ration. Concentrates can be categorized based on nutrient source, as energy and protein sources.

(a) Energy sources

Energy sources have high-energy contents due to high contents of readily available carbohydrates including starch and sugars. They have low crude protein varying from 8 to 12% and this protein is of low biological value because they are deficient in some of the essential amino acids, especially lysine and methionine. They are also deficient in vitamins A and D, but have adequate amounts of vitamin B1 (Thiamine). Energy sources have low calcium but relatively high phosphorus content. They contain fat levels ranging from 2 to 5%, mainly unsaturated type, which tend to become rancid with prolonged storage. Examples of energy feedstuffs include maize, sorghum, wheat, barley, rice, molasses, cassava and potatoes. They also include cereal by-products including bran, pollard and hominy meal. Figure 7.5 shows maize grains as one of the energy sources

Figure7.5: maize grains as one of the energy source

(b) Protein sources

Protein sources are types of feeds of plant origin that have high levels of protein relative to energy contents. Protein sources are classified into plant and animal origins and non-protein nitrogenous compounds.

(i) **Plant protein Sources:** Plant protein sources is a class of feed of plant origin containing various crude proteins ranging between 20% and 50%. They have variable crude fibre content depending on the sources and

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methods of processing, for example decorticated and un-decorticated materials. Some of these proteins are deficient in essential amino acids, especially cysteine, methionine, and lysine. They also have low calcium and phosphorus contents. They are associated with anti-nutritional factors, however, can be rendered harmless by heating. Examples of plant protein sources are oil seedcakes/meals, such as cotton and sunflower seedcake, sesame, copra and soybean meal. Legume seeds include beans, cowpeas, peas, pigeon peas, bambara nuts, and chickpeas. Examples of protein leaf meals are leucaena, glaricidia, moringa and cassava leaf meals. Figure 7.6 shows soya bean as one of the plant protein sources.

Figure 7.6: Soybean as one of plant protein

(ii) Animal and marine protein sources: These are feed proteins based on animal and fisheries products. These sources contain relatively higher level of protein (above 50%) than other protein sources. They generally have high digestibility and high biological value because they contain balanced essential amino acids. They are good sources of vitamins and minerals especially calcium and vitamins B. They have high-fat contents ranging between (0-15%). Examples of feedstuffs of animal and marine protein sources are sardines, fish, meat, bone and blood meals. Figure 7.7 (a) and (b) show marine and animal protein sources.

Figure 7.7 (a): Sardines

Figure 7.7 (b): Dried blood

(c) Non-protein nitrogen compounds

Non-protein nitrogen compounds (NPN) are materials which contain nitrogen, but are not protein. Ruminant animals are adapted to utilise NPN through microbial degradation in the reticulo-

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rumen to produce simple nitrogenous compounds. The rumen microbes use these simple nitrogenous compounds to synthesize microbial proteins, which later become available to the ruminant body. Examples of NPN materials, which are used in feeding ruminants, include urea, ammonia and poultry manure. The NPN materials are normally mixed with readily available energy sources, such as molasses and starch to balance energy. Care should be taken when such compounds are used in animals because overdosing can be fatal to the animals. To avoid poisonous urea inclusion must not exceed one percent of total dry matter. Furthermore, NPN materials should be used for fully developed mature ruminant animals ration and not for non-ruminants as they are not able to utilise NPN. Poultry manure is rich in uric acid and contains about 5% N which is equivalent to 31% CP (i.e., 5 × 6.25). Table 7.4 presents the chemical composition of different protein sources.

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Table 7.4: Chemical composition and digestible energy (DE) of different protein sources (% as fed basis)

Plant sources	Dry matter	Crude protein		Fat	Fibre	DE (Mcal/ kg)	Minerals			
		Total	Digestible				Ash	Ca	P	Mg
Plant sources										
Beans, cull navy	89	21.0	18.5*	1.4	4.5	3.26*	4.0	0.15	0.45	0.17
Brewers' dried grains	92	26.0	20.5	6.5	13.0	1,89	3.8	0.25	0.50	0.14
Wheat germ meal	89	24.0	21.6	8.5	3.5	3.77	4.5	0.05	0.25	
Brewers' dried yeast	93	45.0	39.6	1.0	3.0	3.08	6.5	0.11	1.40	0.23
Cottonseed meal, 41% solvent	94	41.0	34.9	1.0	13.0	2.95	6.5	0.15	1.20	0.47
Soybean meal, solvent	90	44.0	40.0	0.5	6.5	3.30	6.0	0.25	0.60	0.27
Sunflower meal, solvent	93	46.0	41.4	2.9	11.0	3.03	7.0	0.40	1.00	-----
Animal sources										
Blood meal	92	81.0	63.2	1.5	1.0	2.68	6.0	0.30	0.20	0.21
Feather meal (hydrolysed)	92	85.0	56.0	2.5	1.8	3.00	4.0	0.20	0.70	0.20
Meat meal	92	54.0	48.0	7.2	2.5	3.01	28.0	7.4	3.80	0.27
Meat/bone meal	92	50.0	44.5	8.7	2.8	2.86	30.0	9.20	4.70	1.10
Marine sources										
Fish meal	92	70.0	65.7	9.0	1.0	3.65	15.0	3.0	2.0	0.15
Fish soluble, condensed	50	31.0	18.3	5.0	0.5	1.92	10.0	0.1	0.5	0.02
Milk sources										
Buttermilk, dried	94	32.0	29.8	5.5	0.2	3.39	9.5	1.40	1.00	0.48
Skim milk, dried	94	33.0	32.3	1.0	0.1	3.78	8.0	1.25	1.00	0.12

Source: Church (1984)

* Values which are on ruminants; otherwise, they are swine data.

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(d) Mineral supplements

Balancing animal rations require some mineral supplements. Supplementation will depend on the species of animal, type of production and feed source. Mineral supplementations are either macro or micro-elements. Macro elements, such as Ca, P, Mg, and S must be supplemented because are required in large quantities and often are in low levels in feeds. Microelements to be supplemented include Cu, Fe, Se, Mn, Zn, Co, and I. Common mineral supplements used in animal feeding include limestone, which contains 36-38% Ca; oyster shell meal containing $CaCO_3$; rock phosphate containing 17% P; eggshell containing Ca; Di-calcium Phosphate (DCP) containing Ca and P; and bone meal containing 34% Ca, 17% P and 1% Mg. The microelements are normally supplemented as mineral premixes and mineral licks. Figures 7.8 shows (a) egg shells and (b) Dicalcium phosphate.

Figures 7.8 (a): Egg shells

Figures 7.8 (b): A sample of Dicalcium phosphate (DCP)

(e) Feed additives

Feed additives are compounds, added to a ration to improve growth, production and disease control. Feed additives are non-nutritive components including, antibiotics, enzymes, hormones, anabolic, anthelminthic, sweeteners, binders, antioxidants, anti-fungal, and coccidiostats.

Activity 7.3

Visit some nearby farms, markets or farm input shops and collect various feedstuff samples then:

(a) Identify the different types of feeds that are locally available based on the following categories: green roughages, dry roughages, fermented roughages, energy sources, plant and animal and marine protein sources, mineral supplements including premixes and feed additives;

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(b) Record the prices of each feedstuff and supplements available in different farm or input shops; then

(c) Write a summary of results and present in class for discussion.

Feedstuff and feeding standards tables

Feed formulation requires the knowledge of nutritive value of the ingredients to be used together with the requirements of the animal type and class. This information is obtained from Feedstuff tables and Feeding Standard tables, respectively. Feedstuff tables summarise the nutritive values of different ingredients to be used in the formulation, whereas Feeding standards tables give quantitative description of the amounts of one or more nutrients needed by animals. The amounts are expressed as dietary nutrient concentrations or daily requirements. Feeding standards are available for various animal species and for each species, there are tables for various categories, such as age, sex and production levels.

Various organisation or boards publish both Feedstuff tables and Feeding standards tables. Examples of such organisations are the Tanzania Bureau of Standards (TBS), the National Research Council (NRC) in the USA, and the Ministry of Agriculture, Food and Forests (MAFF) in the UK. Tables 7.5 give the nutrient requirements for (a) pigs and (b) poultry as extracted from different feeding standards tables.

Table 7.5 (a): Nutrient requirements for different classes of pigs

Nutrients	Starter	Grower	Finisher	Lactating	Pregnant
Metabolizable Energy (kcal/ kg)	3300	3000	2900	2900	3000
Crude protein (%)	20	17	15	14	16
Lysine (%)	1.20	0.95	0.65	0.61	0.70
Methionine + Cystine (%)	0.80	0.57	0.43	0.40	0.45
Calcium (%)	1.00	0.80	0.80	1.00	1.00
Phosphorus (%)	0.80	0.70	0.70	0.80	0.80

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Table 7.5 (b): Nutrient requirements for different groups of chicken

Nutrient	Broilers		Layers			
			weeks			Layers/ breeders
	Starter	Finisher	0-6	6-14	14-20	
Metabolizable energy (kcal/kg)	3000	3000	2900	2600	2600	2650
Crude protein (%)	23	19	20	16	13	17
Lysine (%)	1.20	1.00	1.10	0.80	0.66	0.75
Methionine (%)	0.50	0.38	0.32	0.36	0.28	0.35
Methionine + Cystine (%)	0.93	0.80	0.75	0.67	0.45	0.55
Calcium (%)	1.00	1.00	1.00	1.00	1.00	1.00
Phosphorus (%)	0.70	0.70	0.70	0.70	0.70	0.70

Source: (Tran *et al*., 2020)

Methods of formulating balanced rations

There are several methods of formulating balanced rations. In this section, simple Pearson square, algebraic and simultaneous methods are elaborated.

Simple Pearson square method

Pearson square is a method used to determine the proper mixture of feed in order to meet a particular nutritional requirement of a livestock or other animal. The method is most effective for simple ration with only few feed ingredients.

(a) Simple Pearson square for a ration with two ingredients

This is a method used for balancing animal ration using two ingredients. This process is done by using an art known as the *person's square.* Hereunder is the procedure for Pearson Square Methods:

(i) Draw a simple square with diagonals;

(ii) Put the percent desired level of animal requirement at the centre of the diagonals;

(iii) Place the percent of nutrients of a feedstuff with the highest content at the upper left of the square;

(iv) Place the percent of nutrients of a feedstuff with the lowest content at the lower left of the square;

(v) Subtract along the diagonals to get the parts of each ingredient;

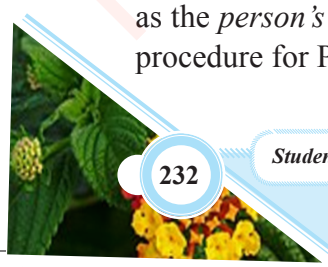
(vi) Add the parts to get the total parts of the ration;

(vii) Calculate and add the percent of each ingredient; and

(viii) Check the nutrient content of the mixture.

Worked example 2

Formulate a feed mixture containing 15% CP for a dairy cow using maize bran having 10% CP and cottonseed cake with 40% CP.



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Procedure

(i) Draw a square with diagonals.

(ii) Place the desired level of animal requirement at the centre of the square.

(iii) Place the percent of nutrient of a feedstuff with the highest content at the upper left hand of the square.

Cotton seed cake 40

(iv) Place the percent of nutrient of a feedstuff with the lowest content at the lower left hand of the square.

Cotton seed cake 40

Maize bran 10

(v) Subtract along the diagonals i.e., the larger value to the smaller value (15 - 10 = 5) parts of cottonseed cake and (40 - 15 = 25) parts of maize bran.

Cotton seed cake 40 — 5 Parts

Maize bran 10 — 25 Parts

(vi) Add the parts to get the total parts of the ratio.

Cotton seed cake 40 — 5 Parts

Maize bran 10 — 25 Parts

30

(vii) Calculate the percent of each ingredient

Item		**% In the ration**
Cottonseed cake	= 05/30 × 100=	16.67 %
Maize bran	= 25/30 × 100=	+ 83.33 %
Total		**100.00 %**

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(viii) Check the CP content of the mixture

Ingredient	Percent mixture	CP contribution (%)	
Cottonseed cake	16.67	16.67 × 40/100	= 6.67
Maize bran	83.33	83.33 ×10/100	= + 8.33
Total	**100.00**		**15.00**

Exercise 7.2

1. A pig producer wants to know what combination of soybean meal containing 45% CP and sorghum with 12% CP is suitable for feeding weaner pigs requiring 16% CP in a daily ration. Calculate the amount of each ingredient to be used.
2. A dairy cattle producer wants to formulate a dairy meal containing 18% CP using sunflower cake containing 30% CP and a maize meal with 8% CP. Calculate the amounts of each ingredient to be used.
3. A poultry keeper wants to formulate a chick and duck mash containing 20% CP using oats having 10% CP and cowpeas meal with 25% CP. Calculate the amounts of each ingredient to be used.
4. Formulate a ration containing 14% CP using wheat pollard with 12% CP and fish meal containing 60% CP. Calculate the amounts of each ingredient to be used.

(b) Simple Pearson square for a ration with more than three ingredients

Worked example 3

Formulate animal ration containing 14% CP using maize meal containing 8.8% CP, hominy meal 11.7% CP mixed at a ratio of 1:2, and soybean meal containing 40% CP.

Solution

(i) Draw a square with diagonals.

(ii) Place the percent desired level of animal requirement at the centre of the square.

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(iii) Calculate the weighted average for energy and protein feedstuffs by multiplying the ratio by the percent to get proportion contribution and add them. Calculate the percent energy contribution by dividing the percent contribution by the total parts.

Energy (maize meal + hominy meal) at a ratio of 1:2

Maize meal	= 1 × 8.8%=	8.8%
hominy meal	= 2 ×11.7%=	+23.4%
Total	3 parts =	32.20%
Average for Energy content 32.20/3 =		**10.73%**

Average for protein will remain the same because only one is used

Soybean meal = 40.00%

(iv) Place the percent of nutrient of a feedstuff with the highest content at the upper left hand of the square.

Soybean meal 40

(v) Place the percent of nutrient of a feedstuff with the lowest content at the lower left hand of the square.

Soybean meal 40

Energy feeds 10.73

(vi) Subtract along the diagonals, that is the larger value to the smaller value (14 – 10.73 = 3.27) parts of soybean meal and (40 – 14 = 26) parts of maize meal.

Soybean meal 40 3.27 Parts

Energy feeds 10.73

(vii) Add the parts to get the total parts of the ration

Soybean meal 40 3.27 Parts

Energy feeds 10.73 26 Parts

29.27

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(viii) Calculate the percent of each ingredient

Energy feeds	26/29.27 × 100 =	88.83
Soybean meal	3.27/29.27 × 100 =	11.17
Total		**100.00**

(ix) But energy is composed of maize meal and hominy meal at the ratio of 1:2 Therefore percent contribution:

Maize meal 1/3 × 88.83 =	29.61
Hominy meal 2/3 × 88.83 =	59.22
Soybean meal as above =	+ 11.17
Total	**100.00**

(x) Check for CP content of the mixture

Ingredient	Percent mixture	CP contribution (%)
Soybean meal	11.17	11.17/100 × 40 = 4.47
Maize meal	29.61	29.61/100 × 8.8 = 2.60
Hominy meal	59.22	11.7/100 × 59.22 = 6.93
Total	**100.00**	**14.00%**

Exercise 7.3

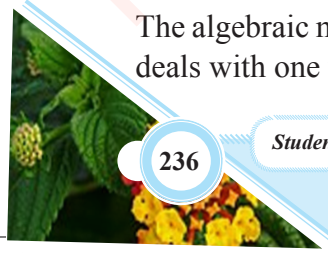
1. Formulate a layer's mash containing 20% CP using maize meal 9% CP, sorghum meal 12% CP mixed at a ratio of 2:1, fish meal 60% CP, bean meal 25% mixed at a ratio of 1:2.

2. Formulate a ration containing 21% CP using maize meal containing 8.8% CP, hominy meal 11.7% CP mixed at a ratio of 1:2 and fish meal containing 60% CP.

3. Formulate a dairy meal containing 16% CP using sorghum meal 12% CP, wheat pollard 10% CP, rice polishing 13% CP mixed at a ratio of 1:1:2, fish meal 60% CP, blood meal 80% CP, and chickpeas 25% CP mixed at a ratio of 1:1:2.

Algebraic methods

The algebraic method is similar to the Pearson square method, however, this method deals with one unknown variable to balance the ration.



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Worked example 4

Formulate a mixture with a combination of maize meal (8.8% CP) and legume meal (40% CP) for pigs with a daily nutrient requirement of (16% CP) by using the algebraic method.

Solution

Complete mixture = 100% = maize meal (0.088) + legume meal (0.40) [in fraction]

Let X = legume meal

Then Y=maize meal = 100 – X

Therefore 0.40 X + 0.088(100 – X) = 16

= 0.40 X + 8.8 – 0.088 X = 16

= 0.40 X - 0.088 X + 8.8 = 16

= 0.40 X – 0.088 X = 16 – 8.8

= 0.312 X = 7.2

X = Legume meal = 7.2 / 0.312 = 23.077%

Y= Maize meal = 100 – 23.077 =76.923%

Worked example 5

Formulate chick and duck mash with a combination of maize meal 9% CP and soybean meal 56% CP with a daily nutrient requirement of 20% CP%. Use the algebraic simple equation method.

Solution

Complete mixture = 100% = maize meal (0.9) + soybean meal (0.56) [in fraction]

Let X = maize meal

Then soybean meal = 100 – X

Therefore 0.09 X + 0.56(100 – X) = 20

= 0.09X + 56 – 0.56 X = 20

= 0.09 X – 0.56X + 56 = 20

= 0.09 X – 0.56 X = 20 – 56

= –0.47 X = –36

X = Maize meal = -36 / -0.47

= 76.60%

Soybean meal 100 – x (maize meal) = 100 –76.60 = 23.40%

76.60 + 23.40 =100.00%

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Exercise 7.4

1. A pig producer wants to know what combination of soybean meal containing 48% CP and sorghum with 11% CP is suitable for feeding weaner pigs requiring 17% CP in a daily ration. By using algebraic methods calculate the amount of each ingredient to be used

2. A dairy cattle producer wants to formulate a dairy meal containing 19% CP using sunflower cake containing 25% CP and a maize meal with 9% CP. By using algebraic methods calculate the amounts of each ingredient to be used.

Simultaneous method

The method deals with two unknown variables with simultaneous questions to balance nutrients.

Worked example 6

Formulate a 1 000kg feed mixture with a combination of maize meal 8.8% CP and legume meal 40% CP for pigs with a daily nutrient requirement of 16% CP.

Solution

Change feed ingredient values from percent to proportions or decimal points.

Let:

X = maize meal containing 8.8 % CP = 0.088

Y = Legume meal containing 40% CP = 0.40.

Given animal requirement = 16% CP.

Formulate equations;

Then x + y = 100…… (1)

0.08 x + 0.40 y = 16…… (2)

Use the above two equations to balance the nutrient.

0.088 X+Y = 100

1 0.088 X + 0.40 Y = 16

0.088x +0.088y =8.8

-0.088x + 0.4y =16

0 - 0.312y=-7.2

y=7.2/0.312

y=23.08%

x=100-23.08=76.93%

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Amount of feed mixture on weight basis i.e. 1000 kg will be as follows:

Maize meal (x) = 79.92/100 × 1000 = 769.23 kg

Legume meal (y) = 23.07/100 × 1000 = 230.77 kg

Activity 7.4

In a group under supervision of the teacher:

(a) Use feedstuff tables, feeding standard tables or any other appropriate method to formulate any livestock rations of your choice;

(b) Summarise and share your group work present in class; and

(c) Write a summary of what you have learned from this chapter in your portfolio.

Exercise 7.5

1. Formulate a 1000 kg ration containing 16% CP using soybean 35% and sorghum 8%.

2. A pig producer wants to know what combination of soybean meal containing 45% CP and sorghum with 11% CP is suitable for feeding weaner pigs requiring 17% CP in a daily ration. Calculate the amount of each ingredient to be used.

3. A dairy cattle producer wants to formulate a dairy meal containing 18% CP using sunflower cake containing 28% CP and a maize meal with 8% CP. Calculate the amounts of each ingredient to be used.

Revision exercise 7

1. Giving examples in each case, write short notes on the following:
   (a) plant origin protein concentrates.
   (b) energy concentrates.
   (c) common feedstuff.

2. Explain the following terms:

   Chyme, nutrients, digestion, concentrate, feed additive, balanced ration, feed additive

3. Explain:
   (a) the main feed components and their role.
   (b) feed factors that limit feed utilization.
   (c) factors to be considered before making a ration.

4. Describe characteristics of:
   (a) energy concentrates.
   (b) dry roughages.

5. With the aid of a diagram differentiate between the ruminant and monogastric digestive systems.

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Chapter Eight

Pasture agronomy

Introduction

Animal production goes hand in hand with feeding. Animals may be grazed on natural open places or may be supplied with feeds while confined in their house structures. Natural places for grazing animals may run out of adequate pasture supply or may not have a good mixture of required animal feeds. Thus, it is important to have assurance by either establishing pasture fields or improving naturally occurring ones. Knowledge on the important pasture species and how they are produced is important. In this chapter you will learn about the concept of pasture and pasture agronomy, types of pasture and pasture improvement. The competencies developed will enable you make proper choice of pasture species, distinguish desirable and undesirable ones as well as managing pasture fields.

Concept of pasture and pasture agronomy

Pasture may be defined as a grassy field or land covered with grass or other low plants suitable for grazing ruminant animals. These can be naturally or artificially established. The term pasture can also be used to refer to grass or other growing plants used as a feed for grazing animals. They can be harvested, processed and stored as hay or silage. Hay and silage are used to feed animals contained in a specific area rather than the grazing ones. The term pasture agronomy simply means pasture production. It is concerned with all important aspects to be considered for successful production/cultivation of pasture for animals

Importance of pasture and fodder crops

It is important to recognise the importance of pastures and other fodder crops in tropical agriculture. In the tropical areas, there is a large area where grazing animals have access and which provide the main feed sources for their sustenance. These extensive areas are called rangelands. The overall contribution of these grasslands is to sustain the domestic ruminant animals, such as cattle, goats and sheep. Other herbivores and wildlife animals similarly depend on these range lands. The importance of pasture and fodder crops are described hereunder:

(a) **Basis of food:** Pastures and fodder crops form the cheapest

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and the major source of feed for livestock and wild ungulates. Good quality pastures and fodder crops provide about 60% of the total nutrients required by dairy animals and almost the total nutrient requirement of range animals.

(b) **Soil conservation:** Plants protect the soil from mechanical damage caused by the grazing animals, raindrops, runoff and wind. Their root system binds soil particles together and their foliage provides a surface cover.

(c) **Water conservation:** Plant cover reduces the speed of runoff, hence improving water infiltration and percolation. It also reduces water loss through evaporation.

(d) **Improvement of soil fertility:** Decomposition of dead plant materials forms humus which improves soil texture, water holding capacity and return nutrients back to the soil. Leguminous plants and some grasses have microbial association (symbiosis) in which the atmospheric nitrogen is converted through the process of nitrogen fixation to nitrogenous compounds readily available to plants.

(e) **Indicators of healthy status of the soil:** Plants are useful indicators of the environment in terms of soil fertility, acidity, groundwater, past use and soil pH. For example, Guinea grass is commonly found in fertile and productive areas whereas Aristida species is dominant in arid and unproductive areas.

Types of pastures

Generally, pastures are categorised into two groups based on their mode of establishment. These types are natural pastures and established pastures as they are described hereunder:

Natural pastures

Natural pastures, also referred to as natural grassland is composed of native plants growing in a given land. These plants are adapted to their place of origin and tend to survive in harsh environments. They support both domestic and wild animals. Its potential plant community may consist of valuable grasses, forbs and shrubs in sufficient quantities to justify grazing use. These have been established through natural selection hence there is an absence of sown or planted species. Most tropical grazing lands used by pastoralists, ranches, and game reserves fall under this category. Figure 8.1 shows livestock and wildlife animals grazing on natural pasture.

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Figure 8:1: Wild animals and Livestock grazing on natural pastures

Source: https://www.reseachgate.net/figure/Livestock-and-wildlife-grazing-together-There-is-increased-competition-for-pastures-due_fig10_38111984

Important grazing lands in Tanzania and their respective pasture species

In Tanzania, there are five main types of grazing lands based on the country agro-ecological zones. These zones have been categorised by considering altitude, rainfall and soil characteristics. Within these agro-ecological grazing lands, there are specific dominant pasture species as described hereunder:

(a) Semiarid to sub-humid grazing land

These grazing areas are mainly found in the central plains including the pastoral systems of Arusha, Dodoma, Shinyanga, and Singida. It covers nearly 30% of the total grazing land. About 40% of the cattle in the country is found here. The commonest grasses found in these areas include *Chloris gayana, Cenchrus ciliaris, Brachiaria brizantha, Cynodon spp,* and *Andropogon gayanus* and *Sporoboluss pp*. These species dominate the overgrazed areas.

(b) Humid plateau lands

These represent the agropastoral zones of Mwanza, Mara and Mbeya. The area occupies 30% of the grazing area and support nearly 50% of the national livestock population. The most common species of legumes found in this zone are *Desmodium spp., Clitoria ternatea, Macroptilium atropurpureum., Neonotonia wightii* and *Stylosanthes guianensis.* Dominant grasses are *Chloris gayana, Pennisetum purpureum* and *Setaria sphacelata.*

(c) Humid lowland

This zone covers mainly of Mtwara and Lindi region. It represents 20% of the grazing area, even though it is only about 2% of the livestock that graze in the area. Pasture species commonly found in this zone include *Hyparrhenia spp.* and *Cynodon spp*.

(d) Very humid highlands

These areas cover 9 % of the grazing area and support 5 % of the national livestock herds herd. Very humid highlands in Tanzania comprise parts of Kilimanjaro, Mbeya, Ruvuma, and Kagera regions. Most of the exotic and crossbred cattle are found in these areas. The potential of the area is for forestry or intensive agriculture. The natural grassland responds to intensive management and can support one stock unit on less than one hectare. Grasses found in this zone are *Cenchrus ciliaris,* and *Setaria sphacelata* var. *Splendida, Panicum spp.,* and *Pennisetum purpureum.* Legumes species found in this zone include *Centrosema pubescens*, *Desmodium intortum, Neonotonia wightii* and *Medicago sativa*.

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(e) Very humid lowlands

This is a limited area restricted to Tanga region, where improved livestock, dominated by crossbred dairy stock keeping is practised. Grass species commonly found in this area include *Panicum spp., Pennisetum purpureum, and Chloris gayana.* Legumes species include *Neonotonia wightii* and *Centrosema pubescens*.

Challenges facing natural pasture in Tanzania

There are some challenges facing natural pastures. They include:

(a) Most natural grassland species have minimal response to additional fertiliser and have low productivity.

(b) Bush encroachment which reduces the accessibility of forages to animals and suppresses the growth of nutritious herbages.

(c) The majority of natural grassland species specifically in humid and sub-humid areas have low nutritive value due to high growth rate coupled with high lignifications.

(d) Natural grasslands have a low proportion of natural fast-spreading legumes. This contributes to rapid decline of nutritive value, especially during the dry season.

(e) Pest and disease infestation is another challenge to natural grasslands. About 60% of natural grazing land in Tanzania is infested by tsetse fly, a vector of Trypanosome which causes Trypanosomiasis.

(f) Invasive weeds tend to replace pasture species by filling in gas or voids thus, reducing yield and overall quality of pasture and foliage. They also reduce yield by competing with the crops on water, light space and soil nutrients.

Factors leading to deterioration of natural pastures

The factors attributed to deterioration resulting into loss of natural pastures include human influences, climate and diseases.

(a) Human influences include:

(i) Cultural values, specifically ownership of big herds of animals leading to higher stocking rates than the carrying capacity of the pastures land.

(ii) The land tenure system, which demarcate communal land ownership, hence no incentive to conserve the grazing land.

(iii) The existing competition between crops and animals resulting into animals being moved to marginal land.

(iv) Poor animal marketing facilities in some areas hinder destocking due to low animal prices.

(v) Frequent or uncontrolled fires destroy grasslands

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(b) Climate, particularly low rainfall causes a shortage of water hence low productivity of pastures and ultimately deterioration of pastures

(c) Diseases particularly tick-borne diseases and Trypanosomiasis are a great barrier to natural grassland.

Activity 8.1

Go around your school environment or nearby farm and perform the following tasks:

(a) Identify and collect samples of the important pasture species found in the locality.

(b) Classify the collected pasture species in terms of grasses and legumes.

(c) Prepare a herbarium with ten species of each group of pasture grass and legumes.

(d) Write a report and present to the class for discussion.

Exercise 8.1

1. Discuss the human activities which degrade natural pastures

2. Wafugaji village is experiencing a shortage of natural pasture. Given an opportunity as agricultural expert, prepare a brief speech on how you would advise the livestock keepers in the village on the best way of addressing this challenge.

Established Pasture

The established pasture is composed of intentionally grown forage plants. Established grasses and legumes differ in their level of productivity depending on the kind of input used by each producer. Successful pasture establishment through proper land preparation like ploughing and harrowing is recommended. Well managed pastures provide more nutritious livestock feeds and hence improving the health of animals. Pasture establishment and management ensure timely availability of basic forage and supply all year round especially during an extremely long period of drought. Thus, with a full supply of good quality pastures in the forms of succulent, hay or silage, the nutritional status of animals is improved. This ensures availability of high-quality livestock and their products, which fetches premium prices in livestock markets. In recent years the business of foliage materials or pastures in the forms of succulent, hay, and silage has been increasing thus, creating employment among communities that are engaged in the livestock industry. This is more profound in dairy cattle keeping areas, such as Kilimanjaro, Arusha, Njombe, Iringa, Mbeya, Kagera, Morogoro, Coast, Dar es Salaam and Tanga regions. Figure 8.2 (a), (b), (c) and (d) show examples of established pasture with improved pasture species.

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Figure 8.2 (a): Bana grass

Figure 8.2 (b): Dairy cattle grazing on improved pasture

Figure 8.2 (c): Gap filling in a pasture field

Figure 8.2 (d): Boar goat feeding on established pasture field

Commonly established pasture plant species

Established pastures are grown and maintained as either pure stand or mixed species. They are further sub-divided into five sub-types as follows:

(a) **Long-term pastures:** These consist of perennial pastures which can stay up to 10 years before being replaced by the same species or another perennial species. Such pastures have high nutritive value and carrying capacity. They include species such as *Cenchrus ciliaris*.

(b) **Short-term or rotational pastures:** These are related with arable crops. They can stay up to four years in the field. Most species of these pastures are adapted to intensive mixed agriculture which is associated with good soil and crop management. They have a very high carrying capacity

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as they are fast-growing. Examples are species such as *Chloris gayana*, Guatemala grass, *Seteria spp*.

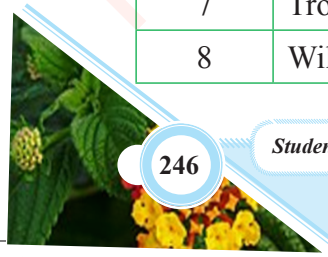
(c) **Annual or temporary pastures:** These consist of annual species such as maize and sorghum. They are commonly used to make hay or silage. They require intensive management in establishing, weeding and harvesting.

(d) **Complementary or supplementary pastures:** These form a subsidiary source of animal feeds. They include mainly leguminous plant species such as *Medicago sativa*, stylo, *Calopogonium muconoides* and *Tropical* kudzu (*Pueraria phaseoloides*). They can be cut and fed as supplements, sometimes they can be used as cover crops to suppress weeds.

(e) **Plantation pastures:** These pastures include species such as *Panicum maximum*, and *Brachiaria brizantha*. They do not need much light hence they can grow well under the trees. Pasture species such as bana grass have been improved by crossing Pennisetum purpureum and *Pennisetum americium.*

Table 8.1: Commonly cultivated pasture species in Tanzania

S/No.	Common names	Scientific names
Grass species		
1	Elephant/Napier grass	*Pennisetum purpureum*
2	Guatemala grass	*Tripsacum laxum*
3	Rhodes grass	*Chloris gayana*
4	Star grass	*Cynodon dactylon*
5	Ruzi grass	*Brachiaria ruziziensis*
6	Palisade/signal grass	*Brachiaria brizantha*
7	Giant star grass	*Cynodon plectostachyus*
Legume species		
1	Green leaf Desmodium	*Desmodium intortum*
2	Silver leaf Desmodium	*Desmodium uncinutum*
3	Lucerne/alfalfa	*Medicago sativa*
4	Siratro	*Macroptilium atropurpureum*
5	Glycine	*Neonotonia wightii*
6	Blue pea/Kordofan pea	*Clitoria ternatea*
7	Tropical kudzu (Stylo)	*Pueraria aphaseoloides*
8	Wild groundnut	*Calopogonium muconoides*



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Fodder tree species		
1	Leucaena	*Leucaena leucocephala*
2	Sesbania	*Sesbania sesban*
3	Calliandra	*Caliandra calothyrsus*
4	Gliricidia	*Gliciricidia sepium*
5	Morus	*Morus alba*
6	Albizia	*Albizia lebbeck,*
7	Moringa	*Moringa oleifera*

Pasture agronomy

The knowledge of pasture agronomy is necessary when it comes to pasture establishment. Pasture agronomy refers to the management of pastures which include practices such as land preparation, planting, irrigating, controlling pests and disease, and fertiliser application to support the proper growth of pasture species. Pasture production follows similar principles considered in production of other crops. Its production requires proper attention on choice of the type (s) of pasture plant to be grown. The pasture agronomic practices are described hereunder:

(a) Site selection

These are factors that govern the selection of suitable areas for pasture establishment. The factors include:

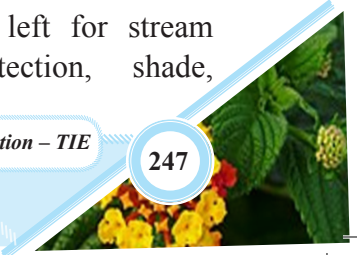
(i) Topography: The area should be level to undulating topographical nature, so as to facilitate the use of machines. If the area is below the hilly side, proper drainage systems should be developed since water logging is not ideal for most pasture species.

(ii) Soil conditions: Soils should be deep, well-drained, loose and friable. It should have enough nutrients to allow the fast establishment of the plants. It should also permit the use of machines as soils with a hardpan are not easy to work with. Soil pH should be ideal for the type of pasture plants to be established.

(iii) Climate: Temperatures and rainfall are important for the growth and production of forage plants. Choice of a species to be grown should consider its temperature and water requirements. Where rainfall is not enough, possibilities of irrigation may be sought out.

(b) Land preparation

(i) Land clearing: Big trees should be minimized to avoid competition for light, water, space, and nutrients with forage plants. Clearing of all trees from the grazing land is not recommended. Some should be left for stream bank protection, shade,



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and act as windbreaks. Big stumps should be removed to facilitate machinery movement

(ii) Cultivation: Depending on the nature of the soil, several ploughing and harrowing operations may be necessary. Care should be taken not to create soil compaction or facilitate soil erosion as a result of structure disturbance. Fine till is recommended for easy seed germination, sprouting, aeration and water infiltration. A well-prepared field reduces weed competition.

(iii) Levelling: Features like anthills, termite mounds, and ditches should be well levelled for easy machines movement.

(iv) Seedbed preparation: Seed beds should be with fine till and not very wide for easy management. These are suitable for cuttings that need to be raised before being planted.

(v) Sowing/planting: This is done by use of seeds or vegetative materials. Sowing should be done when soil moisture is adequate. Sowing depth of most pastures does not exceed 3cm. Some pasture seeds might need seed treatment for breaking dormancy before sowing. Example, hot water (80^0C) treatment for two minutes is normally done for most leguminous pasture seeds. Drilling and broadcasting and vegetative propagation are the most common methods used in sowing pastures.

(c) Managerial practices

Fertiliser application, irrigation, pest and disease control have to be done accordingly to ensure good pasture performance. In most areas, nitrogen-based fertilisers should be applied to grass pastures to encourage vigorous vegetative/leaf growth. Timely harvesting is an important factor to consider. Note that, pastures that are harvested too early will have low dry matter yield despite of relatively high nutritional quality. On the other hand, late harvested pastures will produce relatively high dry matter yield with high crude fibre and lignin contents, which lower the digestibility of the feed. Appropriate time for harvesting of most grass pasture species is close to the flowering stage. Figure 8.3 (a) and (b) show examples of improved pastures, while Figure 8.4 demonstrates harvesting and balling the dried established pasture.

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Figure 8.3 (a): *Setaria splendida*

Figure 8.3 (b): *Brachiaria spp.*

Figure 8.4: Harvesting, balling and transportation of dried established pasture

Activity 8.2

In a group, perform the following task:

(a) Prepare seed beds for raising established pastures;

(b) Prepare plots for planting two pasture plants, grass and legume species; then,

(c) Manage the plots properly and write a report about the establishment procedures, growth patterns and challenges encountered.

Nutritional status of pasture species

The nutritive value of pasture species is a measure of the nutritional composition and nutrients available to the animal body. Apart from the genetic makeup of the plant, other factors that influence nutritional status of a given pasture species include stage of maturity, edaphic influences, climate and management practices. These factors are further explained hereunder:

(a) Plant species

Different plant species vary in their nutritional status. Generally, leguminous plants contain higher protein content than grasses as shown in Table 9.2.

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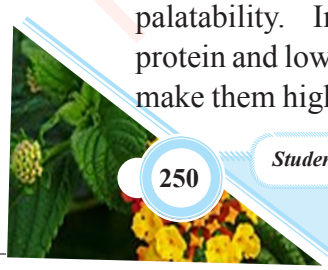
Table 8.2: Crude protein contents (% DM) of different grass and legume pasture species

Common name	Scientific name	Type	Crude protein
Fountain grasses	*Pennisetum mezianum*	Grass	4.45
African foxtail grass	*Cenchrus ciliaris*	"	5.09
Guinea grass	*Panicum maximum*	"	6.62
Rhodes grass	*Chloris gayana*	"	5.11
Guinea millet	*Brachiaria deflexa*	"	6.60
Elephant/Napier grass	*P. purpureum (Bana)*	"	8.80
River tamarind	*Leucaena leucocephala*	Legume	23.2
woman's tongue tree/ flea tree/ lebbek tree	*Albizia lebbeck*	"	21.2
Cocoa shade tree	*Gliricidia sepium*	"	15.15
Centro or butterfly pea	*Centrosema puberscens*	"	15.38
Siratro	*Macroptilium atropurpureum*	"	13.43
Calliandra	*Calliandra calothyrsus*	"	20.25
Tamarind	*Tamarindus indica*	"	11.85
Wild ground nut	*Calopogonia muconoides*	"	16.50
Black seed stylo	*Stylosanthes guianensis*	"	12.56
Tropical kudzu	*Pueraria phaseoloides*	"	15.45
Butterfly pea	*Clitoria ternatea*	"	15.25

(b) Stage of maturity

The stage of growth is the most important factor affecting the chemical composition and digestibility of pasture plants. In general, all pasture plants are highly succulent in early stages of growth which markedly enhance their palatability. In addition, their high protein and low fibre content at this stage make them highly nutritious as livestock feed. Grasses and forbs are referred to as "watered concentrates" while in the early stages of growth. Browse species are less affected by drought periods than forbs and grasses because of their deeper root systems. Minimal changes normally occur in the nutritive value of range plants during the dry grazing season. Normal leaching and translocation of nutrients occur before the dry grazing



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season, accounting for the constancy in the chemical composition of these pasture species.

The trend in crude fibre content regarding the stage of maturity is normally the reverse of protein, resistant to decomposition and it often envelops digestible nutrients rendering them unavailable. The content of soluble carbohydrates normally decreases with the advancing season in all plant parts. Phosphorus content normally parallels that of protein regarding seasonal changes. Phosphorus and magnesium both decreased significantly with the advancing season. Calcium, in contrast, generally increases as the season advances. Vitamin content also vary with seasons. They are unstable in dry forage and quickly disintegrate as leaves and stems desiccate. Carotene content of shrubs decreases, although slower than in grasses and forbs, as the season progresses. Seasonal variations affect grasses and forbs in similar manner with an exception to perennial grasses which retain their nutrients after maturity.

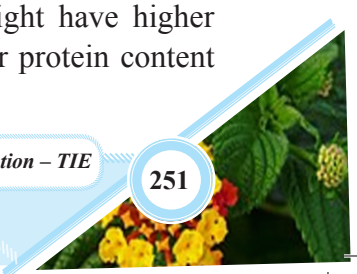
(c) Edaphic influences

The physical and chemical properties of soils influence nutrient content of plants. Mineral composition within species of pasture is determined primarily by soil mineralogical composition. It has long been known that plants that are grown on soils rich in certain nutrients are also rich in those nutrients. Physical properties of soil, such as texture and porosity affect the nutritive quality of forage more or less indirectly. Poorly aerated soils greatly limit or decrease the absorption of essential elements, especially phosphorus. Soils rich in biotic life show enhanced aeration and fertility. The chemical properties of the soil may determine the nutrients that plants can absorb. Plants have specific soil pH requirements for optimum growth. Most pasture grasses and legumes prefer a pH value of 6.5-7.0. For example, phosphorus is most available between pH value of 6 and 7. Phosphorus in soils of low pH reacts chemically with hydrous oxides of iron, aluminium and magnesium to form insoluble compounds which are unavailable to plants. At pH value of 7 and above, phosphorus combines with calcium forming calcium phosphate and becomes insoluble.

(d) Climatic Influences

Factors such as temperature, humidity, precipitation, light intensity and altitude may be dominant in controlling the nutritive value of plants. Temperature is the most important climatic factor to initiate the transformation of starches into plant sugars which are used in plant metabolism.

Although plants depend upon the soil for their mineral nutrients, climatic factors affect respiration, assimilation, photosynthesis, and metabolism to the extent that the mineral and organic matter content of plants may be strongly modified by climatic factors even though grown on the same soil. Plants grown under full sunlight have higher carbohydrate and lower protein content



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than plants grown under shade.

Precipitation may have direct and indirect influences on the quality of forage plants. Rainfall, in general, tends to increase nitrogen, phosphorus, and the soluble fat constituents. There is a close relationship between precipitation and the calcium and phosphorous balance. Increased precipitation results in an increase in phosphorus and a decrease in calcium and vice versa. Droughts may decrease the phosphorus and protein contents and increase the calcium and crude fibre contents. However, calcium and phosphorus decrease in forage during periods of drought. Precipitation greatly alters plant nutrients when they are matured. Leaching causes a decrease in all plant nutrients except crude fibre; thus, the plant forage becomes less digestible.

Activity 8.3

In a group, visit a school farm or nearby established pasture farms: then,

(a) Collect samples of available pasture plant species and group them into legumes and grasses groups;

(b) Write a summarized classification in a tabular form; and

(c) Share your summary in class.

Exercise 8.2

1. Describe factors influencing the nutritional values of pastures plants.
2. Describe the differences in nutritional values between grass and legume species.
3. Briefly explain about the following:
   (a) Pasture agronomy.
   (b) Pasture nutritional values.
   (c) Edaphic factors in relation to pasture nutritional values.

Pasture improvement

The term pasture improvement refers to a series of actions that leads to long term change in botanical composition of a pasture. Pasture improvement is also considered to include rejuvenation and enhancement of existing pastures that is partial renovation or complete removal of the existing pasture, followed by re-establishment of either the same or other species, referred to as total renovation. Partial renovation is done when there are poor forage stands due to drought, flooding, or other environmental stresses. Extensive bush encroachment, loss of vegetative cover and soil erosion may require total renovation. Figure 8.5 (a) and (b) show partial and total renovated pasture fields.

Figure 8.5 (a): Partial pasture improvement

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Figure 8.5 (b): Total pasture improvement

Methods of pasture improvement

(a) **Over-sowing:** Over-sowing is a practice of seeding/sowing in the plot already having either natural or established pasture with the aim of introducing a new pasture species or increasing the population. Natural pastures with right legumes and or reseeding with improved grass species which are adapted to the area and which can yield higher than the existing ones.

(b) **Under-sowing:** Under-sowing is a practice of sowing pasture seeds after the previously established pastures have reached a reasonable height. It helps to ensure minimum competition between weeds and pastures.

(c) **Adoption of good agronomic practices:** These include proper land preparation, weeding, fertiliser application and irrigation.

(d) **Minimum grazing pressure approach:** This involves a controlled grazing system where a newly established pasture is grazed at first (first-year crop) with young animals or winners. As the field matures and several re-sprouts have occurred larger animals can be introduced. If you start to graze larger animals in a first-year crop they might over consume and reduce its rejuvenation ability.

Importance of pasture improvement

The overall benefit of pasture improvement includes replacement of old or diseased pastures, increase productivity of pastures, improvement of nutritional value of forage, enhance animal productivity and reduces soil erosion and pollution. These are further discussed hereunder:

(a) Replacement of old or diseased pastures

Diseased branches in fodder trees can be removed to allow sprouting of new health branches. Similarly, a low yielding pasture or the one with low nutritive value can be completely removed followed by establishment of an improved variety. Bana grass is a good example of improved pasture variety.

(b) Extends or increases the productivity of pastures

In the previous section above we noted that productivity of natural pastures is generally low due to either genetic makeup or exposure to harsh environmental conditions such as low rainfall and poor soils characteristics. Hence, productivity of these pastures

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may be improved through changing the management and agronomic practices as well as breeding activities that enhance their desired genetic traits.

(c) Improvements of the nutritional quality of the forage

Pasture quality in terms of its nutritional value and palatability is improved when pastures are well managed or are genetically modified. Pasture improvement may result into plants with low rates of lignification, resistance to pests and diseases. Similarly, incorporation of legumes in the natural pastures increases concentration of nutrients in the plants and increase digestibility of the pastures.

(d) Enhances animal productivity

Improved pastures through following proper agronomic practices or genetic improvement results into forages with increased nutrients. These improve productivity of animals fed on such plants.

(e) Reduce soil erosion and pollution

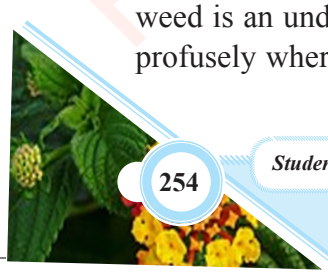
Grass pastures are good soil covers. They reduce rain drop splashes and runoff. Fodder trees are good carbon dioxide sinks and hence helps to reduce air pollution.

Undesirable plant species in pastures

Undesirable plant species are those species in pasture plots that are generally unpalatable or toxic. They include woody weeds and succulent weeds. A weed is an undesirable plant that grows profusely where it is not wanted and its negative characteristics outweigh any positive characteristics. They interfere with the utilization of land, minerals, and water resources. Weeds can be plants from one area that have escaped cultivation and become invasive species once transported to new climate. Weeds in grazing systems are those noxious plant species found growing together with more desirable forage species. They do not contribute to the well-being of the target grazing animal. They are detrimental to forage plants as well as the animal that grazes on the rangeland. Noxious plant species compete with forage species for growth requirements, such as water, nutrients and sometimes light, resulting in lower yields and quality of the desired species.

When weeds or bushes encroach into grazing rangelands and pastures, desirable forage species are replaced, reducing productivity and profitability of the farm. Encroachment of undesirable pastures lowers the overall yield and quality of a forage stand, increases costs of managing and producing livestock and can reduce the value of rangeland. The undesirable or invasive species can impact wildlife habitats when encroachment alters native ecosystems. Proper identification is important to ensure that desirable plants are not targeted for weed and bush control.

Some weeds may be lethal or have complicated health hazards. When consumed in large amounts, some weeds can create unpleasant flavours in milk. Some plants contain substances that can be poisonous to livestock. Grazing



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animals to a vigorous pasture reduce the risk of poisoning, as they will usually avoid poisonous plants if adequate forage is available. Certain toxic plants begin growth early than others and may be grazed if cattle are turned out too early before the rest of the pasture is active. Although animals can avoid feeding on some plants due to their smell, palatability or toxin content, it is also possible to chop and mix them with animal feed if unaware of poisonous plants. Table 8.3 shows some examples of poisonous plants and their effects.

Table 8.3: Some examples of poisonous plants and their effects on animals

Poisonous plant	Effects on high consumption
Tulip (*Narcissus spp)*	Intense gastrointestinal irritation, drooling, loss of appetite, depression of the central nervous system, convulsions, and cardiac abnormalities.
Marijuana (*Cannabis sativa*)	Depression of the central nervous system and coordination problems, as well as vomiting, diarrhoea, drooling, increased heart rate and even seizures and coma.
Sago palm (*Cycas Revoluta*)	The seeds or "nuts" contain the largest amount of toxin. The ingestion of just one or two seeds can result in very serious effects, which include vomiting, diarrhoea, depression, seizures, and liver failure.
Azalea (*Rhododendron spp*)	Grayantoxin is a toxin found in members of Azalea. It can cause vomiting, drooling, diarrhoea, weakness, and depression of the central nervous system in animals. Severe Azalea poisoning could ultimately lead to coma and death from cardiovascular collapse.
Castor bean (*Ricinus communis*)	Castor bean contains ricin, a highly toxic protein that can produce severe abdominal pain, drooling, vomiting, diarrhoea, excessive thirst, weakness and loss of appetite. Severe cases of poisoning can result in dehydration, muscle twitching, tremors, seizures, coma, and death.
Chrysanthemum (*Chrysanthemum spp*)	It contains pyrethrins. Ingestion of pyrethrins may produce gastrointestinal upset including drooling, vomiting, and diarrhoea. In certain cases depression and loss of coordination may also develop if any part of the plant is consumed in large quantities.

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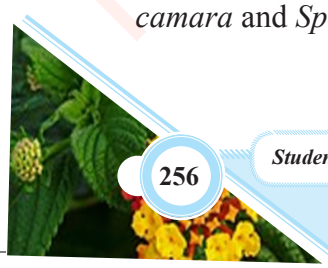
Umbrella tree (*Schefflera* and *Brassaia actinophylla*)	These species contain calcium oxalate crystals that can cause oral irritation, excessive drooling, vomiting, difficulty in swallowing. In addition, may cause intense burning and irritation of the mouth, lips, and tongue.
Nightshade species e.g., Sodom apple (*Solanum incanum)*	Loss of appetite, salivation, weakness, trembling and paralysis.
Pigweed e.g., *Amaranthus species*	They contain nitrate oxalate which may cause kidney disease, weakness, oedema and rapid respiration.

Encroachment of undesirable plant species in pastures and their control

Undesirable species encroachment is the gradual establishment and taking over of unwanted plant species. Normally, in natural pastures under high grazing pressure, there is a tendency of decreasing in desirable pasture species and there is an increase in undesirable ones such as *Sporobolus spp*, *Lantana camara* and *Kongwa weeds*. These are very adaptable species, which can inhabit a wide variety of ecosystems. Once they have been introduced into a habitat they spread rapidly. They compete with native species, leading to a reduction of unpalatable species. They have ability to form dense bushes which, if left unchecked, can greatly reduce the productivity of farmland. Leaves and unripe green berries of *L. camara* can cause minor skin irritation. It is also toxic to livestock such as cattle, sheep, and goats. Figures 8.6 (a) and (b) show undesirable pastures spicies of *Lantana camara* and *Sporobulus pyramidalis*

Figure 8.6 (a): *Lantana camara*

Figure 8.6 (b): *Sporobulus pyramidalis*



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Methods of controlling encroachment of undesirable plant species in pastures

The principles used in managing problems of weeds in crops are similarly applicable in managing encroachments of undesirable plant species. Undesirable species can be avoided, resisted, restricted or controlled. The methods commonly used to solve the problem of encroachment of undesirable plant species in pastures are summarised hereunder:

(a) **Use of clean seeds**: When a farmer wants to establish a new pasture land, clean seeds obtained from a known authorized seed source are recommended. This will help to control the introduction of species that are not wanted.

(b) **Controlled grazing**: When animals are limited to move from one place to another, spreading of undesirable seed species is also controlled.

(c) **New seeding**: When unwanted species dominates a given area it is wise to completely plough them, and plant new species of interest with maximum care so as to ensure its good establishment.

(d) **Increase density of the current species:** This is important when the existing pasture species is thin and does not provide adequate soil cover. Increased population density of the species will limit the growth of other unwanted species.

(e) **Using high seed rates during initial field establishment:** Dense population will limit light penetration that may stimulate growth of undesirable species.

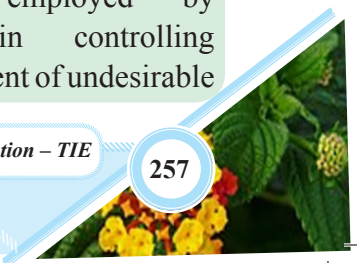
(f) **Maintaining proper fertility and pH:** This will help to maintain health stand and decrease encroachment.

(g) **Use of eco-friendly approaches:** This involves the use of various approaches that target the removal of unwanted species without polluting environment or killing other organisms.

(h) These may include biological control and repeated weeding before flowering of the undesirable species. This will help to reduce seed reserve in the soil and with time reduce its population to a greater extent.

Activity 8.4

1. In a group perform the following tasks:
   (a) Collect and identify features of undesirable pasture plant species;
   (b) Prepare herbarium of undesirable pasture plant species; and
   (c) Write a report and present in class for discussion.
2. Visit a nearby pasture farm, then:
   (a) Observe the different methods employed by farmers in controlling encroachment of undesirable



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species in their environment;

(b) Participate in the different operations employed in solving the problem of undesirable plant species in pastures; and

(c) Write a report on the experience obtained from such activities.

3. Write a summary of what you have learned from this chapter in your portfolio.

Exercise 8.3

1. Outline the following:
   (a) Common methods for pasture improvement; and
   (b) Importance of pasture improvement.
2. Write a brief essay on undesirable plant species in pastures which are common in Tanzania.

Exercise 8.4

1. Discuss the advantages and disadvantages of natural and established pastures.
2. Explain the significance of leguminous plants in pasture.
3. Describe major problems of legumes in pasture.
4. Write the favourable conditions for high productivity of established pastures.
5. How best can natural pastures be improved under the prevailing situation in Tanzania?
6. Outline five agro-ecological zones and explain the pasture plant species found in each.

Revision Exercise 8

1. Explain any five vegetative planting materials used for pasture establishment.
2. Outline:
   (a) Six limitations of natural pasture.
   (b) Five advantages of zero-grazing system.
3. Write short notes on the following terms as applied in pasture agronomy:
   (a) Pasture renovation or improvement;
   (b) Pasture establishment;
   (c) Undesirable pasture; and
   (d) Herbarium.
4. Explain the potential of agro ecological zones on pasture productivity.
5. Describe six methods of pasture improvement
6. Outline any six effects of weeds in pasture land
7. Suggest any four control measures of weeds in pasture land.
8. Show how soil influence the growth and development of pastures.

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Chapter Nine

Agricultural production economics

Introduction

In order for agricultural sector to be successful, effective use of resources such as land, capital, labour, and entrepreneurship is vital. These resources have to be transformed efficiently into outputs such as crops, livestock and fish products. The efficient transformation and allocation of agricultural resources is the main essence of agricultural production economics. In this chapter, you will learn about the concept of agricultural production economics, producer decisions, the effects of diseases on labour productivity and the valuation of farm assets. The competencies developed will enable you to efficiently allocate scarce production resources in a way that maximizes farm profits and apply appropriate measures to manage the effect of diseases including HIV/AIDS and COVID 19 in agricultural production.

Concept of agricultural production economics

In agricultural production, inputs called factors of production are needed. These factors are land, labour, capital, and entrepreneurship, without them production can not take place. For maximization of farm profit these inputs ought to be properly allocated and managed. Agricultural production means the production of plant and animal products useful to man nutritionally economically and socially. It involves the transformation of factors of production/inputs to agricultural goods and services as presented in Figure 9.1.

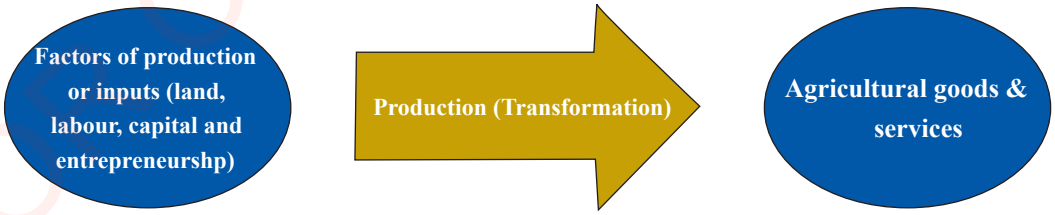

Figure 9.1: Agricultural production process

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Economics refers to the study of how to allocate scarce production resources which have alternative uses for maximizing profit and household satisfaction. It is the study of how individuals, make choices about how to allocate these production resources.

Production economics is the application of economic principles such as scarcity, supply, demand, costs, benefits, and incentives to solve production problems. Therefore, agricultural production economics is the use of economic principles in solving agricultural production problems. It deals with how scarce resources such as land, labour, capital and entrepreneurship can best be allocated. Production process is a way of maximizing satisfaction and profit. Its importance rests in ensuring that, agricultural production as a business, pays profitably to farmers given limited resources at their disposal.

Activity 9.1

Visit some farms around or nearby your school and do the following:

(a) Identify agricultural production activities taking place in that area;

(b) Identify the type of inputs or factors of production used in producing the outputs or services;

(c) Determine the quantity of each identified input on the farm;

(d) Evaluate the:

  (i) amount of outputs produced by using the inputs; and state whether the farm (s) have enough resources to accomplish the intended production activities;

  (ii) allocation of the resources among the competing demand; then

(e) Write a report and present in class for discussion.

Exercise 9.1

1. Briefly explain the following terms as applied in Agricultural economics:
   (a) Economics;
   (b) Production;
   (c) Production economics;
   (d) Factors of production; and
   (e) Input and outputs.

2. Outline the kind of inputs you will need to have when starting an agricultural enterprise of your choice.

3. You have been appointed by school master/mistress as a production manager for the new rabbit farm project to be established. Outline any four important factors you will consider to maximise production of the project.

Factors of production

In agricultural production economics, factors of production are the resources used to produce agricultural goods and services. These factors are divided into

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four categories namely: land, labour, capital and entrepreneurship**.** Figure 9.2 shows a schematic diagram of factors of production.

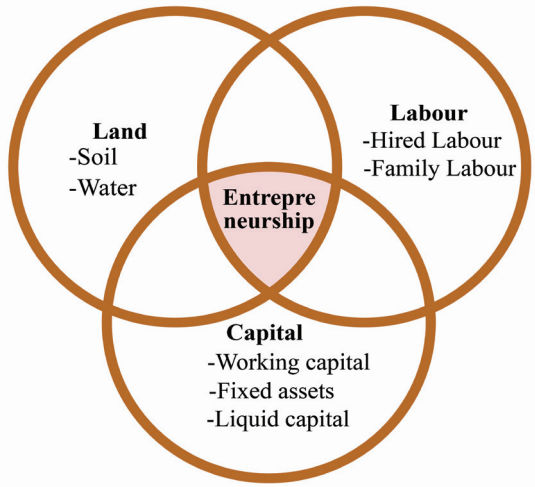

Figure 9.2: Factors of production

(a) Land

From an economic point of view, the land is a resource that includes the natural resources used in agricultural production. But in a broad sense, this includes anything that comes from the land. Some common land or natural resources are natural gas, oil, water, coal, and forests. These resources can be renewable for example forests, or non-renewables for example oil and natural gas. The income that resource owners earn in return for land resources is called rent. Land being a fixed and scarce resource needs to be allocated efficiently in the production process.

(b) Labour

Labour encompasses both mental and physical effort that people contribute to the production of agricultural goods and services. In production economics, farm labour includes both family and hired labour. Labour is a scarce production resource in agriculture and therefore an efficient allocation of labour will result in improved productivity and profit. The income earned by labour resources is called wages and is the largest source of income for most people. The value of labour depends on human capital, which is a result of an individual's skills, education, training and productivity measured as the unit of output per unit of input.

(c) Capital

Capital is also among the factors of production. It is divided into working capital such as stocks of seeds, fertilisers, and pesticides. Liquid capital which refers to money at hand or bank, and fixed capital (durable assets) such as machinery, tools, and other structures used to produce agricultural goods and services. They are capital goods because they are used in the production process and contribute to the productivity of farm work. The income that comes from capital is referred to as interest.

(d) Entrepreneurship

The role of entrepreneurship as a factor of production is to enable the management of a farm enterprise through combining, organizing, controlling, and allocating the other factors of production i.e., land, labour and capital to produce goods and services. An agricultural entrepreneur is a person who organizes, manages and take the risks of agricultural business or enterprise. The entrepreneur sets

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up business, takes financial risks hoping to make profit. The payment to entrepreneurship is profit and or satisfaction.

Activity 9.2

In a group, visit your school or nearby farms and study on land, capital, labour and production activities taking place in the visited farm; then make your assessment on:

(a) Labour working in the farm in terms of quantity, and whether they are hired or family members;

(b) Amount of both, (working and fixed) capital engaged in the production;

(c) Ownership and amount of land devoted to the production process;

(d) Qualities of an entrepreneur who organize farm resources;

(e) Challenges faced by a farm owner and (suggest how can each identified challenge be overcome); finally,

(f) Write a report and present it in class for discussion.

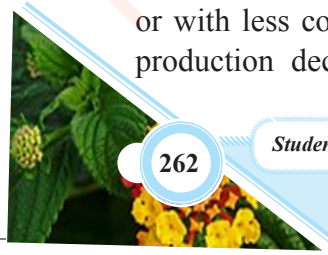
Producer decisions

The major goal of a producer is to maximize profit and satisfaction given the resources at hand. There are a lot of risks involved in the production process and the producer has to make good farm operational decisions that will enable making a profit. These decisions can be reversed without incurring a cost or with less cost. There are three basic production decisions for producers to make. These decisions are what, how and how much to produce as discussed herein under.

(a) **What to produce (combination of products to be produced):** Every farmer has to decide at the beginning of every crop season about the type of farm commodities to produce with the resources available on the farm. It means whether to produce crops alone or livestock alone or a combination of crops and livestock. While selecting the products and their combinations the farmer always aims at profit maximization.

(b) **How much to produce (level of output to be produced):** Once the decision about the products and their combinations to produce is made, the next immediate operational management decision to be made is the manner in which resources are combined or the production technology to be chosen. In the selection of resources and their combinations, farmer is concerned with the cost minimization.

(c) **How to produce (combination of inputs to be used to produce each product):** Having made the above two decisions, now the farmer has to decide about the amount of output to achieve in the production of farm commodities. This implies deciding upon the quantities of various inputs to be used in production as the level of



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production depends on amount of inputs used.

The objective of the farmer is to maximize profit within the limits of available resources. Before embarking on the discussion of specific production decisions, let us see the concepts of profit maximization.

Producer decisions for profit maximization

In the production process, producers use inputs to get outputs. For example, in the production of layers, a farmer needs to buy feeds, veterinary medicines, feeders and drinkers. In all of these, a farmer has to incur costs. The output resulting from using these inputs are the eggs sold to get revenue from the layer enterprise. Therefore, for the inputs, a farmer incurs costs in purchasing the inputs, and from the output, a farmer gets revenue after selling. The profit or loss is the difference between the total revenue and total costs used in the production process. If the total revenue is greater than the total costs, the farmer earns a profit, while if costs are greater than revenue, a farmer get a loss. Various concepts of production are explained hereunder;

(a) Production

Production is the process whereby certain raw materials (inputs) for example, fertilisers, are converted into other finished goods or services (output). Mathematically, this is expressed as Y=f (X). Where, Y = products X=inputs and f=function of. Terms associated to production are total physical product, average physical product, marginal physical product.

(i) Total physical product (TPP): Refers to the total amount of output produced with a given amount of input during a certain period.

(ii) Average physical product (APP): Refers to the total product per unit quantity of inputs used. Mathematically is expressed as APP = Y/X where APP is the average product, Y is the amount of output, and X is the amount of input.

(iii) Marginal physical product (MPP): This is the increase in output per increases in an additional unit of input. For example, if a farmer uses one more bag of a fertiliser on his farm, the additional output he gets as a result of adding the bag of fertiliser, is what is referred as MPP. Mathematically it is expressed as: MPP = $\Delta Y/\Delta X$ where MPP is the marginal product, ΔX is the change in the levels of inputs used and $\Delta Y\Delta Y$ is the change in the levels of output obtained.

Relationship between TPP and MPP

Since MPP is a measure of rate of change, therefore the following are important to note:

(a) When TPP is increasing, MPP will be positive.

(b) When TPP is constant MPP will be zero.

(c) When TPP decreases, MPP will be

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negative.

(d) So as long as MPP moves upward, TPP increases at an increasing rate.

(e) When MPP remains constant, TPP increases at a constant rate.

(f) When MPP starts declining, TPP increases at a decreasing rate.

(g) When MPP is zero, TPP will be at maximum.

Concept of production function

Production function is a physical relationship describing the relationship between quantities of inputs used and quantities of outputs obtained in a production process, while other factors are considered to be constant (i.e. not changing). The production function can be expressed in three ways, as explained hereunder:

(a) As a table: The table shows the quantitative relationship of inputs (X) and outputs (Y) numerically. Example: After being educated on the importance of fertiliser in cereal production, Ms. Jitegemee applied fertiliser in her maize plot as follows:

Input X: Fertiliser (Kgs)	Output Y: Maize (Bags)
0	12
12	18
24	24
36	30
48	36

In this example, three key issues should be noted, the land used for production is fixed at one ha; fertiliser is varied in 12 kg units and maize yield increases at the rate of 6 bags for each additional unit of fertiliser.

(b) As a mathematical equation: The relationship between input (X) and output (Y) in the table above can be transformed into a mathematical equation of the form $Y = a + bx$

Where: Y = output

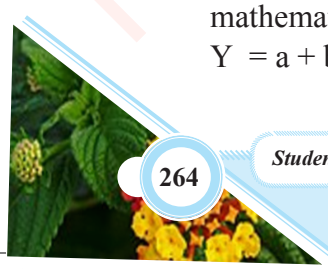
x = input

a = a constant

b = the slope of the production function

Thus, converting data from the table in part (a) above into an equation, we obtain the equation of the nature $Y = 12 + 6/12x$ (i.e. $Y = 12 + 0.5x$)

(c) As a graph: When the data from the XY plane in part (a) are



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plotted, we obtain the graph. Such a graph, is another way of expressing the production function.

Regions of production function

Production function is a mathematical relationship between input and output. Production function can be divided into three regions or stages, each being important from the standpoint of efficient resources use (Figure 9.3).

Stage I: Occurs when marginal physical product (MPP) > average physical product (APP). APP is increasing throughout this stage, indicating that the average rate at which X is transformed into Y, increases until APP reaches its maximum at the end of stage I. Elasticity of production (Ep) = > 1

Stage II: Occurs when MPP is decreasing and is less than APP but greater than zero. The physical efficiency of the variable input reaches a peak at the beginning of stage–II. On the other hand, physical efficiency of fixed input is greatest at the end of stage-II. This is because the number of fixed inputs is constant and therefore the output/ unit of fixed input must be the largest when the total output from the production process is maximum. Elasticity of production (Ep) ≤ 1

Stage-III: Occurs when MPP is negative. It occurs when excessive quantities of variable input are combined with the fixed input, so much, that total physical product (TPP) begins to decrease. At this point, elasticity of production (Ep) is ≤ 0

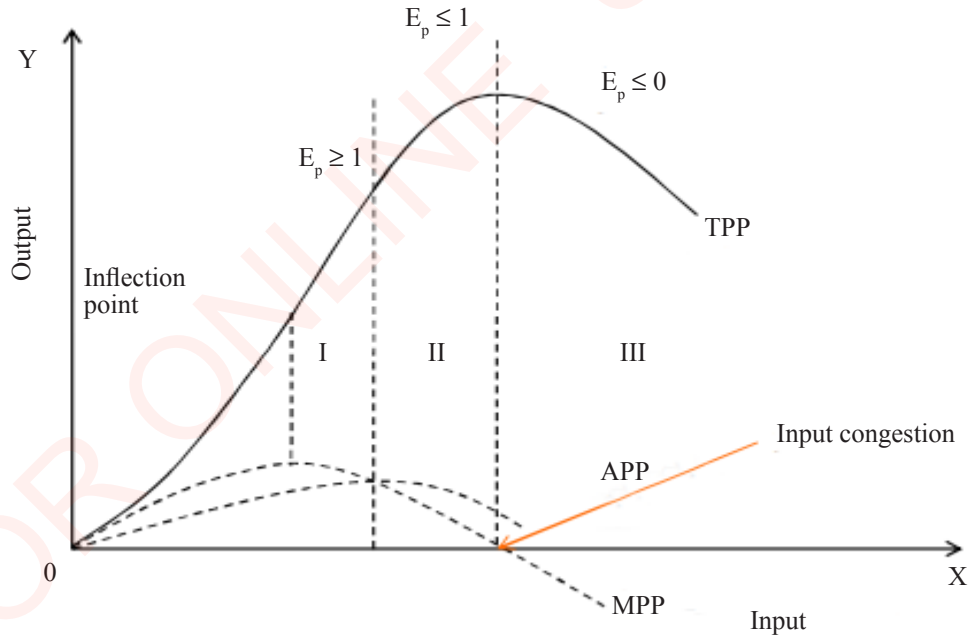

Figure 9.3: Production function curve

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Economic recommendations and production function analysis

Production function knowledge and information on input and output prices can be used to know the most profitable input and output levels. However, even when price information is not available, some recommendations about the input use can be made from the production function itself.

(a) If the product has any value at all, input use once begun, should be continued until Stage II is reached. That is because physical efficiency of variable resources, measured by APP, increases throughout stage I.

(b) Even if input is free, it will not be used in stage III. Maximum output occurs when Stage II closes. It is of no use applying variable input when TPP starts coming down.

(c) Stage II defines the area of economic relevance. Variable input use must be somewhere in stage II, but exact input amount can be determined when choice indicators (input and output prices) are known.

Relationship between MPP and APP

There is a close relationship between MPP and APP in the production process as summarized hereunder:

(a) When MPP is increasing, APP is also increasing. So long as MPP is above APP, the APP keeps increasing.

(b) When MPP curve goes below APP curve, APP starts declining, that is, when APP is decreasing the MPP is always less than APP.

(c) When MPP = APP, APP will be at maximum here MPP curve must intersect APP curve from above at its highest point.

(d) So, when MPP > APP, APP increases; MPP < APP, APP decreases; MPP = APP, APP is at maximum.

The law of diminishing return

The law of diminishing returns describes the relationship between output and the variable input when other inputs are held constant. It is defined as an increasing amount of one input are added to a production process while all other inputs are held constant, the amount of output added per unit of variable input will eventually decrease. It is also known as law of diminishing productivity or the law of variable proportions.

Application of the law of diminishing returns to the production concept can result in a production function of classical type indicated in Figure 9.3. It displays increasing marginal returns first and then decreasing marginal returns. Diminishing start to set in when TPP is maximum and MPP is zero.

Cost of production

The term cost of production refers to all the costs that are involved in production of goods and services. Production costs are comprised of various expenses including cost of inputs such as fertilisers, employee wages, repair and maintenance and transport. These

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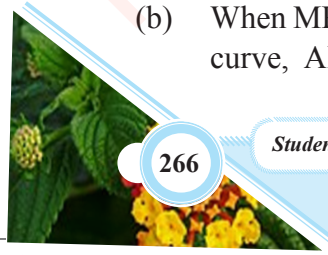

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include expenses incurred in the process of producing goods and services. They are divided into total variable cost (TVC) and total fixed costs (TFC).

(a) Total costs (TC)

On the farm, there are two kinds of costs that a farmer incurs in the production process. These costs are fixed and variable costs. Total cost is the sum of these two costs.

Total cost (TC) = Total fixed costs (TFC) + Total variable costs (TVC)

(b) Total fixed costs (TFC)

These are sunk costs or costs that have already been incurred on the farm. They do not change with level of production; they have already been paid. For example, buildings and other farm structures, insurance, taxes and permanent labour salaries.

Fixed costs (FC) = Fixed inputs (X) × Price of per unit input (Px)

(c) Total variable costs (TVC)

Variable costs are costs that vary with the level of production. They are only incurred if there is production. For example, costs of buying seeds, fertilisers, manures, and pesticides.

Variable costs (VC) = Variable inputs (X) × Price of input (Px)

(d) Average costs (AC)

Average costs are the total costs divided by output.

Average cost (AC) = Total cost (TC)/Output (Q)

(e) Average fixed costs (AFC)

Are total fixed costs divided by output

Average fixed cost (AFC) = Fixed cost (FC)/Output (Q)

(f) Average variable costs (AVC)

Are total variable costs divided by output

Average variable cost (AVC) = Variable cost (VC)/Output (Q)

(g) Marginal cost (MC)

This is the change in total production cost that comes from making or producing one additional unit of output. Mathematically expressed as:

$$MC = \frac{\Delta C}{\Delta Y}$$

Where: MC = Marginal cost; ΔC = Change in the total variable cost; ΔY = Change in output

(h) Opportunity cost

Farm resources are limited but these can be put to different uses. When resources are used in production, some alternative usage is always forgone. The opportunity cost is the value of best alternative forgone.

Relationship of costs incurred in production

There is close relationship between costs. TFC is incurred without considering the level of production. Therefore, it is presented by horizontal line. TVC is cost which is incurred and depends on the level of production. Its curve starts from the original upwards. Whereas TC is the sum of TFC and TVC. It assumes the same shape of TVC but appears above

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TFC. Relationship between curves is better presented in Figure 9.4 (a).

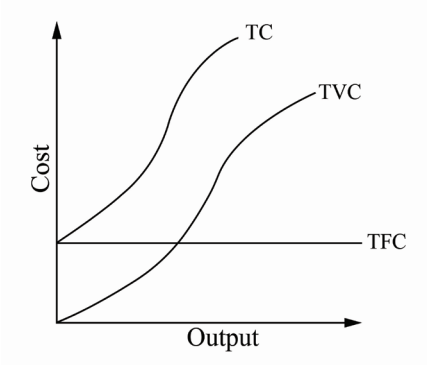

Figure 9.4 (a): Total cost, total variable cost and total fixed curves

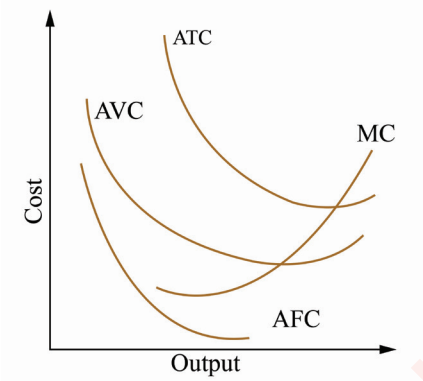

Figure 9.4 (b): Average and marginal cost curves

Likewise, relationship between average curves (Figure 9.4 (b)) is as follows:

(a) AFC curve decreases with increasing level of production. It is always below all other average cost curves and it never reaches zero.

(b) MC decreases at initial stages of output production but later increases as output increases. MC cuts all average variable costs (AVC) and average total costs (ATC) at their lowest points.

(c) AVC and TVC costs decreases as the level of output increases and at the later stage of production both curves increase. As in the case of TC and AVC curves, always ATC is above the AVC curve.

Revenue

Revenue is the total amount of income generated by sale of good or services related to the farm. In this section, total revenue. marginal revenue and profit are discussed.

(a) Total revenue (TR)

Total revenue is obtained as a product of the output multiplied by unit price of the produce. For example, if the output from simsim is 100 kg and per unit price is TZS 2 000 per kg, the revenue is the product of output (kg) times the price per kg.

Revenue (R) = Quantity of output (Q) × Price (Py)

= 100 kg × TZS 2 000 /kg

TR = TZS 200 000

(b) Marginal revenue (MR)

Marginal revenue is the additional revenue that results from the sale of one additional unit of output. For example, if a farmer sells one more kilogram of simsim, what is the additional revenue from the sale of this additional kilogram?

Mathematically it is computed as:

$$MR = \Delta Y_1/\Delta X_1 \times PY_1$$

Where; $\Delta Y_1/\Delta X_1$ = Marginal product and PY1 is the per unit price of output.

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(c) Profit (P)

This is the difference between total revenue (TR) and total cost (TC). Recall in the previous section, TC is the quantity of input (e.g., fertiliser) times price of inputs and TR, is the quantity of output (e.g., maize) times price of output. Hence:

Profit (P) = Total Revenue (TR) – Total cost (TC).

This implies that, profit is maximized by lowering the production costs.

Activity 9.3

In a group or individually, visit a school or nearby farm, then:

(a) List all agricultural inputs available on the farm;
(b) Distinguish between fixed and variable inputs or capital assets;
(c) Find the price of all variable inputs in the nearby agro-shop;
(d) Find price of all outputs marketed in the nearby agro-shop;
(e) Determine revenue, cost and profit per unit area;
(f) Collect information on the application rate per hectare; then
(g) Write a report and present in class for discussion.

Exercise 9.2

1. Mention and explain the important producer decisions involved in any agricultural enterprise.
2. Describe, how you can use producer decisions for profit maximization in your farm enterprise.
3. Write short notes on:
   (a) Marginal cost;
   (b) Average product;
   (c) Marginal revenue;
   (d) Total product;
   (e) Total cost;
   (f) Total fixed costs; and
   (g) Relationship between cost curves.

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4. Study and complete the following table by filling in the empty boxes.

Output	Total cost	Fixed cost	Variable cost	Average cost	Average variable cost	Marginal cost
0		20		NA	NA	NA
1		20			15	
2	49	20				
3		20	44			
4		20				17
5		20		20		
6		20				24
7		20		22		
8		20		24		

Production relationship

Production relationship defines how products and or factors are relating to one another in production process given the available scarce resources. For example, one hectare of land can either be used to produce maize, sorghum, legume, beef, building a house or converting it to recreational ground. Therefore, you can draw a relationship between beef cow and manure, maize and beans, and between beef and hides. If farmers face limited resources, then how production of one product (beef) affect production of another product (e.g. hides) or how production of maize affect production of beans. In principle, there are four types of production relationship as outlined hereunder.

(a) Factor–Product relationship

The how much to produce decision problem depicts the relationship between the number of factors to be used to attain a certain level of output. This mathematical relationship between the factors of production and outputs produced is called the production function. Assume there are two-factor inputs: labour (L) and capital (K), then the production function can be written as:

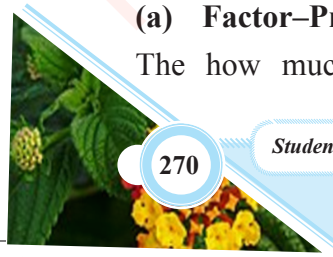
$$Y = f(L, K)$$

Where; Y = quantity of output

f = thefunctionof(depicting the relationship between the output and inputs)

L = labour

K = Capital or units of labour



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This implies that, the quantity of output depends on units of labour or capital used in production.

The following are the procedures for finding an optimal input use in factor –product relationship.

(i) Identify the levels of input use (X_1);
(ii) Identify the quantities of output produced at each level of input use (Y_1);
(iii) Compute the changes in the levels of inputs used (ΔX_1);
(iv) Compute the changes in quantities produced at each level of input use (ΔY_1);
(v) Calculate the marginal product ($MP = \Delta Y_1/\Delta X_1$);
(vi) Find the marginal revenue ($MR = \Delta Y_1/\Delta X_1 \times PY_1$ and
(vii) Determine the profit-maximizing area by equating the marginal revenue (MR) with marginal cost ($MC = PX_1$).

Worked example: 1

Use the following data to find the optimum level of input use that will maximize profit:

Kilograms of urea fertiliser per hectare	Kilograms of wheat per hectare
0	700
300	1 000
500	1 500
700	2 100
900	2 500
1 300	2 650
1 700	2 590
2 100	2 100

Note: The price of urea fertiliser is TZS 2 100 per kilogram, while the selling price of wheat is TZS 700.

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Solution

Input (Kg) X_1	Output (Kg) Y_1	ΔX_1	ΔY_1	$\frac{\Delta Y_1}{\Delta X_1}$ (MP)	PY_1 (TZS)	$\Delta Y_1/\Delta X_1 * PY_1 = PX_1$
0	700	300	300	1	2 100	1 × 700 = 700
300	1 000	200	500	2.5	2 100	2.5 ×700 = 4 375
500	1 500	200	600	3	**2 100**	3 ×700 = **2 100**
700	2 100	200	400	2	2 100	2 ×700 = 1 400
900	2 500	400	150	0.375	2 100	0.375 ×700 = 262.5
1 300	2 650	400	60	0.15	2 100	0.15 × 700 = 105
1 700	2 590	400	0	0	2 100	0 × 700 = 0
2 100	2 100					

The optimum use of urea fertiliser will be attained if a farmer uses between 500 – 700 kgs per hectare. At that point, the marginal revenue will be equal to the marginal cost, which is TZS 2 100.

Activity 9.4

Visit a nearby broiler-producing farmer, and study:

(a) How different feeds are rationed to produce the desired broiler weight in a prescribed period;

(b) How are the concepts learned in class about the input-output relationship applied in the visited farm; then

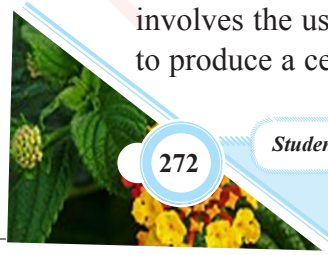
(c) Summarize your observation and present it in class for discussion.

(a) Factor – Factor relationship

Agricultural production normally involves the use of more than one input to produce a certain level of output. For example, in the production of maize, a farmer will require labour, capital, and land. These inputs substitute each other in the production process, meaning that when one input is used at a high level the other one must be used at a minimum level. The rate at which inputs substitute each other in the production process is called Marginal Rate of Technical Substitution (MRTS).

The question which arises is, what is the optimum combination of these inputs that can maximize profit? To answer this question, the concept of factor-factor relationship is important. The factor-factor relationship deals with the kind of decision-making on the farm. Reaching decision for finding an optimal input use in factor-factor relationship requires to go through some procedural steps as follows:

(i) Identify the levels of input use (X_1) to produce a fixed quantity of output;



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(ii) Identify the levels of input use (X_2) to produce a fixed quantity of output;

(iii) Compute the changes in the levels of inputs used (ΔX_1);

(iv) Compute the changes in the levels of inputs used (ΔX_2);

(v) Calculate the marginal rate of inputs substitution (MRS) = $\Delta X_1/\Delta X_2$;

(vi) Find the price inverse ratio of the two inputs (PX_2/PX_1); then

(vii) Find the optimum combination of inputs by finding the point where the MRS column and price inverse ratio column are equal or nearly equal.

Worked example 2

Ms. Mnange did a study to investigate the optimum combination of protein concentrate from soya bean and energy concentrate from maize bran to produce a 2 kg broiler in six (6) weeks.

Results showed the following combinations:

Soya bean concentrate (kg)	Maize bran concentrate (kg)
10	90
20	80
30	70
40	60
50	50
60	40
70	30
80	20
90	10
100	0

The unit price of Soya bean concentrate is TZS 1 205 while that of maize bran concentrate is TZS 2 000. Find the optimum combination of the two inputs that will maximize profit.

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Solution

Soya bean concentrate cake (X_1)	ΔX_1	Maize bran (X_2)	ΔX_2	MRS= $\Delta X_1/\Delta X_2$	PX_2/PX_1
12	15	88	25	0.6	1.66
27	25	**63**	15	**1.66**	**1.66**
52	25	**48**	20	1.25	1.66
77	25	28	10	2.5	1.66
102	25	18	16	1.56	1.66
127					

To produce a 2 kg broiler in six (6) weeks, Ms. Mnange has to feed between 27 – 52 kg of Soya bean concentrate and 48 – 63 kgs of maize bran concentrate.

Activity 9.5

Visit a nearby farm dealing with either crops or livestock production, then:

(a) Identify the kinds of crops or livestock kept;

(b) Ask the farmer the main goal of engaging in that particular farming;

(c) Inquire about some key questions the farmer asked themselves before engaging in that particular farming enterprise.

(d) Write a report and present in class for discussion

Exercise 9.3

1. (a) Explain the concept economics as applied in agricultural production.

   (b) Briefly describe the significance of economics in agricultural production.

2. Write short notes on production resources and describe their categories.

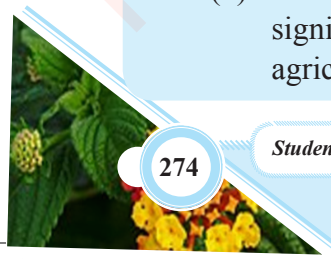
3. State the return payment for the following factor of production:
   (a) Land;
   (b) Labour;
   (c) Capital; and
   (d) Entrepreneurship.

4. Why does a farmer have to make correct decision before engaging in any farming enterprise?

5. Explain why profit maximization is the main goal of producers.

6. Outline any three producer decision problems encountered in agriculture.

7. Show the criteria for profit maximization decision in the following:
   (a) Factor – Product combination;
   (b) Factor – Factor combination; and
   (c) Product – Product combination



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(b) Product – Product relationship

In a farm setting, a farmer may decide to produce two or more products given the resources at hand. For example, a farmer may decide to produce sunflower and maize, sorghum and cotton, or broilers and layers using available resources such as land, labour and capital. The question is, on how to optimize combination of those agricultural enterprises that can enable a farmer to maximize the profit with the resources available and given technology.

Procedure for finding an optimum combination of product – product relationship

(i) Construct a table with eight columns as shown on a solution part of worked example 1 below;

(ii) Plot the quantities of products Y_1 and Y_2 to be produced at each level in a table;

(iii) Find the marginal rate of substitution between the two products (MRS) i.e. $(\Delta Y_1/\Delta Y_2)$. This ratio is called the marginal rate of substitution (MRS). It shows the rate at which the two products substitutes each other in the production process;

(iv) Find the price inverse ratio of the two products as prevail in the market. The price inverse ratio is equal to PY_2/PY_1;

(v) Draw a table and insert the value of MRS and the price inverse ratio; therefore,

(vi) The point where the MRS is equal to the price inverse ratio is the optimum combination of the two products i.e. MRS = Price inverse ratio.

$$\Delta Y_1/\Delta Y_2 = PY_2/PY_1 \text{ or } \Delta Y_1 \times PY_1 = \Delta Y_2 \times PY_2$$

Worked example 3

Suppose Bondeni agricultural secondary school found that, considering limited resources the school have it can produce sorghum and cotton at the combinations shown on the following table, and sell products at TZS 1 000 per kg for sorghum and TZS 1 500 per kg for cotton. Find an optimum combination that will maximize the profit of the school farm.

Sorghum (Kg) = Y_1	Cotton (Kg) = Y_2
20	800
40	782
60	768
80	758
100	752
120	750

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Solution

Sorghum (Kg)=Y_1	ΔY_1	Price of Y_1	$\Delta Y_1 * PY_1$	Cotton (Kg)=Y_2	ΔY_2	Price of Y_2 (TZS)	$\Delta Y_2 * PY_2$
20	20	1 000	20 000	800	-18	1500	-27 000
40	20	1 000	20 000	782	-13.5	1500	-20 250
60	20	1 000	20 000	768.5	-10	1500	-15 000
80	20	1 000	20 000	758	-6	1500	-9 000
100	20	1 000	20 000	752	-2	1500	-3 000
120				750			

Therefore, to maximize the profit, the school should produce between 40 and 60 kg of sorghum and 768 and 782 kg of cotton.

Basic product-product relationship

(a) Joint products: Joint products result from the same production process whereby production of one without the other is not possible. For instance, cotton lint (Y_2) and seed Y_1), wheat (Y_1) and straw (Y_2). In such cases the quantity of one product produced decides the quantity of other product. For production decisions, joint products can be treated as one product (Figure 9.5).

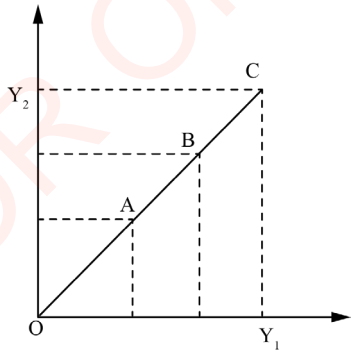

Figure 9.5: Joint product curve

(b) Complementary products: Complementarity between two enterprises exists when with a change in the level of one, the other also changes in the same direction for example, maize after legume. Figure 9.6 shows complementary product between fodder and milk production.

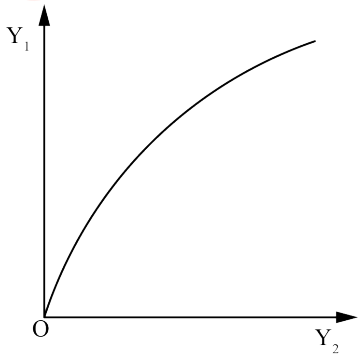

Figure 9.6: Complimentary product curve

(c) Supplementary products: Exists when increase or decrease in one product does not affect the production level of the other product. All supplementary relationships should take advantage of producing both products to the point where the products become competitive as shown in Figure

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9.7. Production of Y_1 can expand without affecting Y_2. Therefore, Y_2 is supplementary product to Y_1. Similarly, production of Y_1 is supplementary to Y_2 since it can expand from O to D without affection production of Y_1

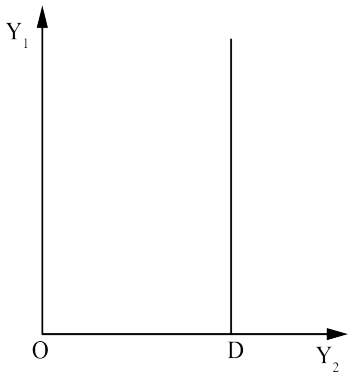

Figure 9.7: Supplementary product curve

(d) Competitiveness product: This relationship holds when increase or decrease in the production of one product affects the production of another product inversely. Competitive enterprises compete for farm resources and substitute for each other. When two products are competitive, some amount of one product must be given up to increase the level of other product. MRPS between products is negative. When two products are competitive, they may substitute at constant rate, increasing rate or decreasing rate. Figure 9.8. (a), (b) and (c) show competitive product curves.

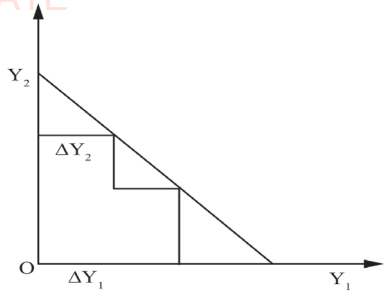

Figure 9.8 (a): Substitute at constant rate

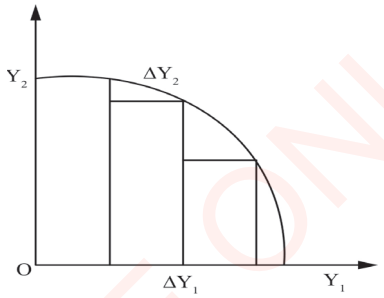

Figure 9.8 (b): Substitute at increasing rate

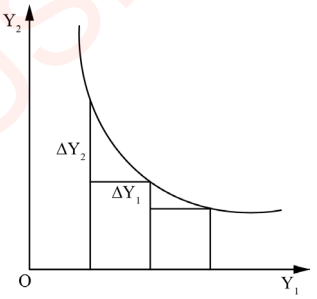

Figure 9.8 (c): Substitute at decreasing rate

Worked example 4

Suppose Wabunifu agricultural secondary school found that given the available resource it has, it can produce sorghum and cotton and sell at TZS 1 000 per kg for sorghum and TZS 1 500 per kg for cotton. Find an optimum combination that will maximize the profit of the school farm.

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Sorghum (Kg) = Y_1	Cotton (Kg) = Y_2
20	800
40	782
60	768
80	758
100	752
120	750

Solution

Sorghum Kg = Y_1	ΔY_1	Price of Y_1 (TZS)	$\Delta Y_1 * PY_1$	Cotton (Kg) = Y_2	ΔY_2	Price of Y_2 (TZS)	$\Delta Y_2 * PY_2$
20	20	1 000	20 000	800	-18	1500	-27 000
40	20	1 000	20 000	782	-13.5	1500	-20 250
60	20	1 000	20 000	768.5	-10	1500	-15 000
80	20	1 000	20 000	758	-6	1500	-9 000
100	20	1 000	20 000	752	-2	1500	-3 000
120				750			

Therefore, to maximize the profit, the school should produce between 40 and 60 kg of sorghum and 768 and 782 kg of cotton.

Activity 9.6

Visit a nearby farm dealing with the production of more than one crop, and collect

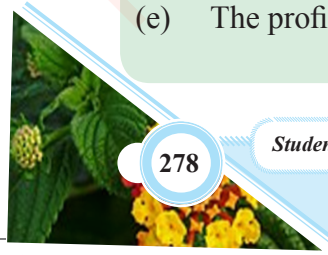
information on the following:

(a) The kinds of crops produced;
(b) The quantity harvested from each kind of crops;
(c) The price used to sell those products in the market;
(d) The cost of production;
(e) The profit obtained;
(f) Strategies employed by a farmer to optimize combinations for maximizing farm profit; then,
(g) Prepare a report for presentation and plenary discussion.

Exercise 9.4

1. Given that you want to produce broilers and layers on your farm, state any seven steps you will follow to ensure that you produce at an optimum combination and hence maximize profit.

2. Before starting any agricultural production enterprise, there are about three basic questions one has to ask. With examples explain them.



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3. What is the condition for profit maximization in a product-product relationship?

4. Given the data below, find the optimum level of production required to maximize profit

Carrots (Kg)	Cucumber (Kg)
1 500	14 000
2 500	12 560
3 500	11 200
4 500	8 260
5 500	8 440
6 500	4 815
7 500	2 314
8 500	1 000

5. If the price of carrots is TZS 1 471 per kg while that of cucumber is TZS 500 per kg.

   (i) What is an optimal level of combination?

   (ii) What is the total revenue at an optimal level of combination?

Human diseases and labour productivity

Labour productivity and resource allocation in agriculture is critical as far as profit maximization is concerned. However, among the factors that affect labour productivity and resource allocation is diseases, as they affect human capital (health).

There are several human diseases, however, HIV/AIDS malaria and other emerging diseases such as COVID–19 are some of the well-known human diseases with noticeable effects on labour productivity and resource allocation.

Effects of human diseases on labour productivity

A human being as a living thing, is affected by various diseases. Some of the diseases are temporary and others are chronic. The effects of the diseases on agriculture are directly linked to labour, which in turn affects its productivity. Diseases such as HIV/AIDS, COVID-19, and other diseases had a devastating effect on farm labour (both family and hired) productivity through their consequences on human health. When labour is infected with diseases, the following are likely to occur; absenteeism from work or working below standard due to ill-health; loss of manpower due to death and hence loss of farming knowledge. All these in turn, lead to low labour productivity, hence low income and food insecurity problems. In the following section effects of HIV/AIDS are discussed.

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How diseases affect resource allocation in agricultural production is summarized in Figure 9.9.

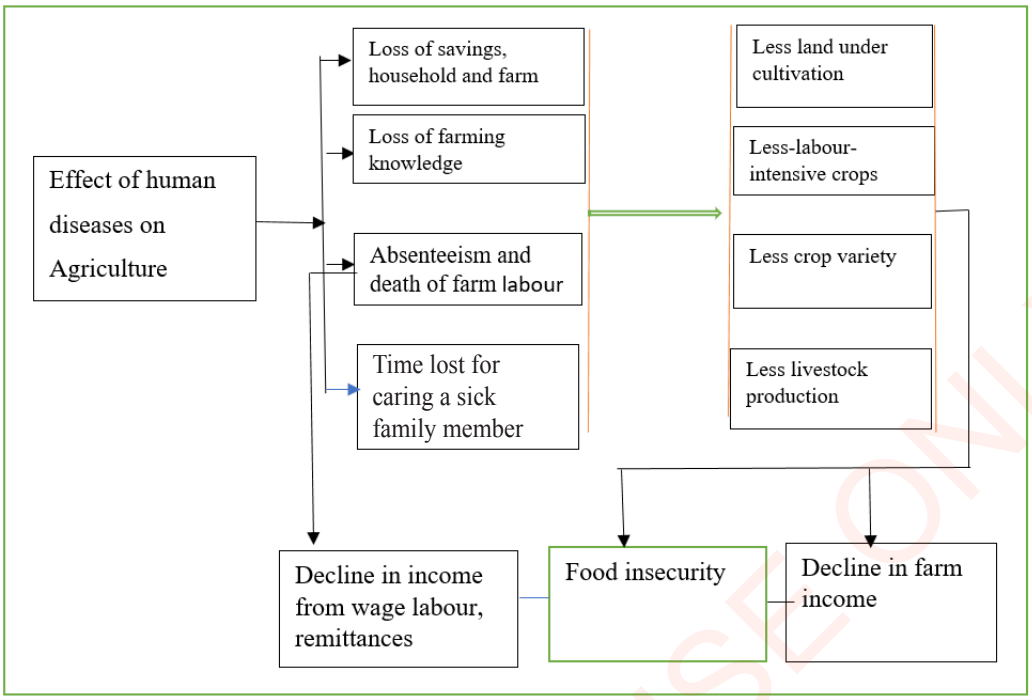

Figure 9.9: A conceptual framework on the effect of human diseases on Agriculture

Effects of HIV/AIDS on resource allocation in agricultural production

One of the factors of production is human labour which can suffer from various diseases including HIV/AIDS. Human diseases affects human resources and entrepreneurship hence resulting in a reallocation of the production resources. Once HIV/AIDS has infested some members of the households, there can be a diversion of resources such as capital from farming to the treatment of the diseased. Sometimes farmers may be forced to sell some of their farm assets to get money for the treatment of their sick family members, spend time caring for the sick person instead of providing labour in the farm.

These, in turn, result in less land under cultivation, less labour-intensive crops, less crop variety and less livestock production. The final effect of all these is a decline in income from wage labour, remittances, food insecurity, and a decline in farm income and hence, poverty.

Activity 9:7

Mr. and Mrs. Bukile are among the major rice producers in Luiba village. The main labour force for their farming, depends on their family of five members. Unfortunately, one member is infected with HIV/AIDS and several times the member becomes seriously sick hence, requiring close attention. Based on this scenario:

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(a) Explain how does this affect Mr and Mrs. Bukile in their rice production.

(b) Present your explanation in class for discussion.

Measures to control HIV/AIDS among vulnerable groups

With a case study of HIV/AIDS, both international and national policies on HIV/AIDS control generally focus on four primary areas which are:

(a) Prevention (e.g., male circumcision, pre and post-exposure prophylaxis, condom use, sexual and other risk reduction, testing, and counselling);

(b) Care for HIV/AIDS patients, orphaned and vulnerable children;

(c) Antiretroviral therapy, nutrition, and related services; and

(d) Establishment and strengthening of the HIV/AIDS response system. Raising awareness through educational programs (Figure 10.10) is the most important factor in the success of all of these strategies.

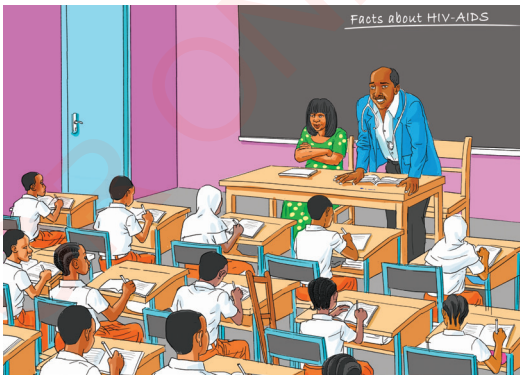


Figure 9.10: HIV/AIDS control through education

Exercise 9.4

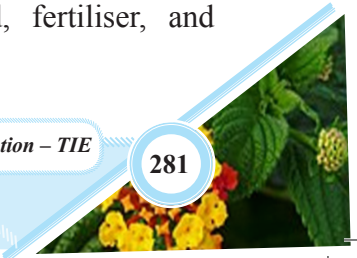
1. Briefly (two paragraphs only) write short notes on HIV/AIDS.
2. Account for the effects of HIV/AIDS on labour productivity.
3. State how HIV/AIDS affects resource allocation in agricultural production.
4. Suppose you are employed by the government as an extension manager in one of the districts in Tanzania, account for any four ways in which you will address or control the problem of HIV/AIDS.
5. Account for how HIV/AIDS affects the profitability of farm enterprises.

Valuation of farm assets and calculation of depreciation

Assets are items owned by the farm enterprise that have use value. They include the items that the farmer uses to produce agricultural products that they sell. Farm assets are categorized into current, intermediate and long-term assets as further described herein:

(a) Current assets

These are cash or items that can be easily converted to cash in one year or less. Common current assets include: cash, savings, prepaid expenses, growing crops, harvested crop inventories, marketable livestock, accounts receivable, seed, feed, fertiliser, and other supplies on hand.



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(b) Intermediate assets

These are assets that have assumed useful life from (1 to 10) years. They include: breeding livestock, machinery and equipment, and vehicles.

(c) Long-term assets

These are fixed assets and permanent items with an assumed useful life of more than 10 years and include farmland, fence, buildings, and farmsteads. Farm assets especially fixed assets and machinery do lose value over time due to wear and tear. To find their current value, one needs to compute the loss in value that has occurred during that particular period. The process of finding a value of an asset is called valuation. Moreover, to find the current value of an asset, the pre-requisite is to calculate the depreciation which is the loss in value of an asset.

Valuation of farm assets

Valuation of farm assets is an important task as it helps in the preparation of the financial position of the farm. It involves setting value or attaching prices. on farm assets. Valuation of livestock and crops is based on the prevailing market prices, While, valuation of farm machinery and buildings (capital assets), involves calculation of depreciation.

Procedure for valuing capital assets

(a) Prepare an inventory - a list of all assets present in-farm at a particular date;

(b) Calculate the depreciation of the farm asset; then:

(c) Find their current value as a difference between the original cost and the depreciation cost.

Methods for computation of depreciation

There are three known methods of calculating the depreciation of farm assets. The methods are namely: straight-line, diminishing balance and the sum of years digit methods.

Straight-line method

This is the commonest method used in calculating the annual depreciation of farm assets. The method is called the straight line because it assumes a constant loss in the value of an asset each year in use. However, the method is not very useful for assets like machinery and equipment in which the rate of turnover declines with life span. According to the straight-line method, depreciation is calculated using the formula:

$$\text{Annual depreciation (AD)} = \frac{C - S}{N}$$

Where, C= Origin cost of purchasing an asset

S= Salvage value (the value remaining after an asset is out of use)

N= Number of years an asset is expected to be used

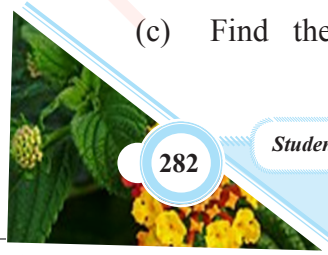
Procedure for calculating depreciation by using the Straight-line method

(i) Identify the origin cost of the asset (C)

(ii) Indicate the salvage value (S)

(iii) Find the life span of the asset (N)

(iv) Compute the annual depreciation (AD)



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Worked example 4

A farmer purchased computer for TZS 770 000 which he expected to last for 10 years before writing it off. At the time of writing off, the value of the computer will be TZS 70 000 Using a straight-line method, calculate the annual depreciation of the computer.

Solution

Data given: Original cost (C) = TZS 770 000, Time lifespan (N) = 10 years, Salvage value (S) = TZS 70 000.

Annual depreciation (AD)

$$= \frac{C - S}{N} = \frac{(770\,000 - 70\,000)}{10}$$

$$= \text{TZS } 70\,000$$

Therefore, a farm computer will depreciate at the annual rate of TZS 70 000.

Activity 9.8

1. In a group, visit your school or any nearby agricultural workshop and collect information from any of the following machinery: tractors, power tillers, two-stroke engines, or any other farm implements, about:
   (a) the original cost of buying the farm machinery,
   (b) the year expected to be in use, and
   (c) its value when out of use.
   (d) Use straight-line method, to compute the depreciation rate of the machine/ implement.
2. In a group, prepare an inventory and valuate assets for Maseta Agricultural Secondary School which by 31st December 2021, had the following farm assets:
   (a) 20 bags of animal feed each Worth TZS 60 000
   (b) 15 bags of urea fertiliser each worth TZS 75 000
   (c) 50 bottles of pesticides each worth TZS 15 000
   (d) 10 cattle each worth TZS 400 000, and
   (e) 20 goats each worth TZS 60 000.
   (f) In addition, the school had a power tiller bought early in 2010 at TZS 5 000 000, with an expectation that it will last after 10 years of use before writing it off at a salvage value of TZS 1 000 000.

Declining balance method

The declining balance method of depreciation is also called as reducing balance method where assets are depreciated at a higher rate in the initial years than in the successive years. Under this method, a constant rate of depreciation is applied to an asset's (declining) book value each year. This method results in accelerated depreciation and results in higher depreciation values in the early years of the life of an asset.

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Procedure for computing depreciation using the declining balance method

(i) Draw a table with five columns;

(ii) In the 1st column indicate the useful life in years of the asset in ascending order;

(iii) In the 2nd column indicate the rate of depreciation (%) which should be constant;

(iv) Netbook value is presented in the 3rd column (the 1st row of this column is obtained by subtracting the residual value from the original cost and for the following years will be the value of an asset from the preceding years);

(v) The 4th column is for depreciation, which is obtained as a product of depreciation rate (%) and net-book value; and

(vi) The 5th column indicates the value at the end of the year obtained by subtracting depreciation from net book value.

Worked example: 5

Moses purchased farm machinery for $ 11 000 with a useful life of 10 years and a residual value of $ 1 074. Depreciation as per the declining balance method is:

Solution

Year	Depreciation (20%) A	Netbook value B	Depreciation C (A*B)	Value at the end of the year- D (B - C)
1	0.2	11,000	2,200	8,800
2	0.2	8 800	1760	7040
3	0.2	7 040	1408	5632
4	0.2	5632	1126	4506
5	0.2	4506	901	3608
6	0.2	3608	721	2887
7	0.2	2887	577	2310
8	0.2	2310	462	1848
9	0.2	1848	400	1448
10	0.2	1448	290	1158

Declining balance method have two major advantages. First, the results are in accelerated depreciation and it is a preferable method when recording depreciation of assets that quickly lose their value or become obsolete like computer equipment and other technology products thereby, depicting fair market value. Secondly with this method compared with other method, there is no need to estimate salvage value.

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Activity 9.9

1. Visit a nearby farmer or company owning farm machinery then, collect data on the:
   (a) Original cost of buying the tractor;
   (b) The expected useful life and salvage value as an estimate of the value;
   (c) When it will be out of use; then,
   (d) Use declining balance method to find annual depreciation of the tractor based on the above collected information.
2. Make a summary of what you have learned from this chapter in your portfolio.

Sum of years digit methods

The sum of years' digits method is a form of accelerated depreciation charge that assumes the productivity of the asset decreases with time.

Procedure for using sum of years digit methods

(i) Identify the original cost of the asset;
(ii) Compute the depreciation base (original cost of the asset - salvage value);
(iii) Align the remaining life of the machine from the highest year to the lowest;
(iv) Sum up the expected lifetime of the asset (years) to get the sum of years;
(v) Align the fraction of years, the sum of the year should be a denominator;
(vi) Calculate the depreciation expense; then
(vii) Compute the book value.

In this method, a fraction is computed by dividing the remaining useful life of the asset on a particular date by the sum of the year's digits. This fraction is applied to the depreciable cost of the asset to compute the depreciation expense for the period.

The formula for calculating depreciation by using the sum of years digit method:

$$\text{Depreciation} = \frac{\text{Remaining useful life of the asset}}{\text{Sum of the years digits}} \times \text{Depreciable cost}$$

Worked example 6

The company purchased a machine on January 1, 2018. The cost of the machine was $250 000; the expected useful life of the machine is 5 years and the salvage value is $25 000. Using the sum of years digit method, compute the depreciation of the machine.

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Solution

(i) Depreciable Base: Origin cost – Salvage value

(ii) $250 000 – $25 000 = $225 000

(iii) Sum of years is 5 + 4 + 3 + 2 + 1 = 15

(iv) Depreciation expense at the end of the first year: $225 000 × (5/15) = $75 000

(v) Book value at the end of the first year: Origin cost - Depreciation expense at the end of the first year. That is, $250 000 – $75 000 = $175 000

The information can be summarised in tabular form as follows:

Year	Original cost ($)	Depreciation base ($)	Remaining life of the machine	Depreciation fraction	Depreciation Expenses	Book value
1	250 000	225 000	5	5/15	75 000	175 000
2	250 000	225 000	4	4/15	60 000	115 000
3	250 000	225 000	3	3/15	45 000	70 000
4	250 000	225 000	2	2/15	30 000	40 000
5	250 000	225 000	1	1/15	15 000	25 000

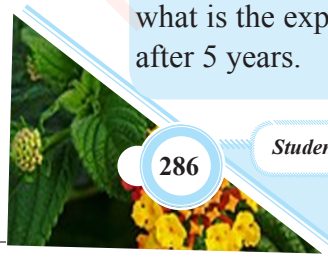
Exercise 9.5

1. Define the term valuation.
2. With example, outline steps to be followed when valuating farm assets.
3. Describe any three methods of determining depreciation of farm assets.
4. Show the procedural steps of computing depreciation of farm assets by using each of the mentioned methods in (3) above.

If you have purchased a tractor at 11000 USD and the salvage value at 1074 USD what is the expected value of the tractor after 5 years.

Revision exercise 9

1. Briefly explain the meaning of the following terms:
   (a) Inventory;
   (b) Asset; and
   (c) Depreciation.
2. Give the meaning of the straight line, declining balance, and the sum of the year's digit method.
3. Differentiate between straight line, declining balance, and the sum of the year's digit method.
4. Based on your view, which do you think is the best method? Why?
5. The following are the information about one of a machine purchased on January 1, 2016: Cost of the



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asset =$35 000; Salvage value =$3 000; Useful life=10 years. Calculate the annual depreciation expense of this asset using the straight-line method.

6. You open a rice farm in Mvomero area, and buy 2 power tillers for a total of $60 000. The useful life of the power tillers is 5 years and a total salvage value of $15 000. Compute the depreciation by using the sum of the year's digits.

7. If the cost of the input of labour is $100 per unit and this is the only cost of production: Calculate the cost of producing each level of output, the change in Q, the change in total cost, and the resulting marginal cost associated with increasing the input levels listed in the first column.

Input level (L)	Output level (Q)	Total production cost Q	Change in Q	Change in total cost	Marginal Cost
0	0	0	NA	NA	NA
1	110				
2	210				
3	300				
4	380				
5	450				
6	510				
7	560				
8	600				
9	630				

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Chapter Ten

Farm planning

Introduction

Farmers are known to grow crops, keep livestock, fish and honey bees, from which they get income after selling the products. Therefore, farming is a business activity, and its major aim is to make profit out of the scarce resources employed in the production process. These scarce farm resources include land, labour and capital. The resources should be properly planned so as to maximise profit. In this chapter, you will learn the concept of farm planning, important tools used in farm planning and how to make rational production decisions. The competencies developed in this chapter will enable you to make rational farm planning for a given agricultural enterprise.

Concept of farm planning

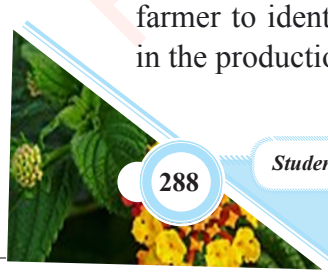
Farm planning is a decision-making process in the farm business which involves the organisation and management of limited resources such as land, labour, and capital to realize the intended goals, normally maximizing profits and or satisfaction. It involves the selection of the most profitable course of action from among all possible alternatives. Farming planning enables a careful examination of the existing farm production resources and their best allocations. It enables farmers to make decisions about selection of crops, scale of production, types/classes and number of livestock to be kept. It helps the farmer to identify the resources needed in the production process.

Important tools used in farm planning

In this section, three tools namely gross margin, analysis budgeting (partial budgeting) and programme planning as used in making farm decisions will be discussed.

Gross margin

Gross margin (GM) is the difference between total revenue and total variable costs used in the production process. Total revenue is obtained as a product of the quantity of output produced and its per-unit price. Total variable costs are costs of variable inputs such as fertilisers, casual labour, seeds, pesticides, animal feeds, and fees. It should be noted that farm fixed costs such as permanent labour, insurance, machinery costs, and



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rent are not included in the computation of gross margin. The gross margin shows the profitability of the farm enterprise. The formula for computing gross margin is given as:

Gross margin (GM) = Total Revenue (TR) – Total Variable Costs (TVC)

But,

TR = Quantity of output (Q) × Price per unit (PQ) – Quantity of inputs (X) × Price per unit (PX)

Therefore, Gross margin (GM) = (Q × PQ) – (X × PX)

Note, gross margin is normally expressed per unit of production; e.g., GM/Bird, GM/Labour, GM/capital, and GM/hectare.

Procedure for computing gross margin

The following is a procedure when computing gross margin.

(a) Estimate the output and its value (TR);

(b) List all variable inputs and estimate the cost of each (TVC);

(c) Subtract TVC from TR; to obtain GM; then,

(d) Divide the GM per unit of production to obtain the productivity of each unit.

Decision criteria: If GM is positive, it is worthwhile to undertake the investment. However, if it is negative, it is not worthwhile as the production costs will exceed the revenue.

Break-even analysis

Break-even analysis is the financial calculation that aim at determining how many units of a product must be sold to cover the fixed and variables cost of production. It determines the point at which product units when sold will be enough to cover all the production costs that is, GM = 0. Break-even analysis can be used to consider how price and yield changes and how this might affect the selection of alternative enterprises.

Usefulness and limitation of GM as a tool in farm planning

(a) Usefulness:

(i) It is useful when preparing farm budget.

(ii) It is appropriate measure when comparing enterprises.

(iii) Provide and show return over variable costs.

(b) Limitations:

(i) It does not take into account the changes which might occur in fixed cost.

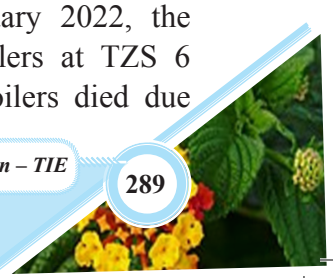
(ii) It does not provide allowance for complementary and supplementary products.

(iii) It does not take into account the economies of scale.

(iv) It is not a sufficient indicator of profitability.

Worked example 1

A company was keeping 500 broilers. In the month of February 2022, the company sold 450 broilers at TZS 6 500 each, where 50 broilers died due



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to Newcastle disease. During the same month, the company spent TZS 500 000 on broiler mash and TZS 300 000 on veterinary medicines. Calculate the GM of the broiler enterprise in March.

Solution

Total Revenue = 450 Broiler x TZS 6 500 = TZS 2 925 000

Total Variable costs = 500 000 + 300 000 = TZS 800 000

Gross Margin (GM) = Total Revenue (TR) – Total Variable Costs (TVC)

= 2 925 000 – 800 000

= TZS 2 125 000

= 2 125 000/450

Therefore, the Gross Margin for each broiler chicken = TZS 4 722

Decision: Since the GM is positive, it is worthwhile to undertake this investment.

Activity 10.1

Visit any agricultural production enterprise around your school/home and collect the following information:

(i) The size of the enterprise i.e. the number of acres or hectares, number of poultry, cattle, sheep, goat or any other as appropriate;

(ii) The amount of inputs used in the production process and their respective prices;

(iii) The output obtained from the production for example, kilograms, tonnes, a tray of eggs, or litres of milk;

(iv) Also, collect information on the selling price of each output per unit;

(v) Use that information to compute the profitability (gross margin) of the target product; then,

(vi) Advise the manager on whether the farm is making a profit or not.

Farm Budgeting

When situations change on the farm, costs and revenue also change. Changes may involve the whole farm or part of the farm. Farm budgeting is a farm planning tool that involves estimating the effect of change in costs and revenue in the farm business or enterprise. There are two types of farm budgeting namely, complete budgeting and partial budgeting.

If the producer wants to make a comprehensive change involving all aspects of the farm, then a complete budgeting tools is used in the analysis. Whereas, if the change involves just some aspects of the whole farm, then partial budgeting is appropriate. In most agricultural enterprises, the changes involve just some parts not covering the whole farm. Partial budget is commonly used and therefore a focus of this section. A partial budget is normally used in two situations. First, when a farmer intends to replace one enterprise with another for example, to change from poultry keeping to crop production. Second when a farmer wants to expand. or introduce an additional enterprise, for example, increasing production of

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layers from 400 to 600 layers on the farm. These two situations are further described hereunder:

(a) Replacing one enterprise with another

When a farmer wants to replace one enterprise with another for instance from keeping broilers to cotton production, the farmer must consider the effect of this change on revenue and loss. This is because the farmer will lose the revenue from the existing enterprise and also incur some additional costs for the new enterprise. They will also gain extra revenue from the new enterprise but save some costs incurred in the enterprise to be replaced. Therefore, to summarize, the following are basic questions one has to consider before the enterprise replacement.

(i) What amount of revenue will be lost?

(ii) What cost will be saved by getting rid of the old enterprise?

(iii) What extra revenue will be earned from the new enterprise?

(iv) What extra costs will be incurred for the new enterprise?

Once all the above questions have been answered, the information should then be presented in the form of a partial budget (Table 10.1).

Procedure for setting up a partial budget

The following are five steps to be followed when setting a partial budget:

(i) Calculate the revenue lost and extra cost, then, enter in the losses side;

(ii) Calculate cost saved and extra revenue, enter the value in the gains side;

(iii) Compute the subtotals on each sides;

(iv) Compute the differences between the two sides; then,

(v) Balance the two sides. If the gains side is greater than the losses side, enter the difference in the losses side as profit. If the losses side is greater than the gain side, enter the difference in the gains side as loss.

Table 10.1: The format of a partial budget (for enterprise replacement)

Losses	TZS.	Cts	Gains	TZS.	Cts
Revenue lost			Cost saved		
Extra cost			Extra revenue		
Profit (if any)			Losses (if any)		
Total					

The changes are worthwhile only if the gains side is greater than the losses side. In situation where the losses side is greater than the gains side, a farmer is advised not to replace the enterprise.

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(b) Expansion or introduction of an additional farm enterprise

In a situation where a farmer would like to expand or introduce an additional enterprise to the existing one, then the farmer will need two important information: the extra costs from an additional enterprise, and the extra revenue that will be gained from an additional enterprise. Once these information are gathered, they are presented in a partial budget format to realize if the expansion or introduction of an additional enterprise is worthwhile undertaking or not. A partial budget is then prepared as following a format shown in Table 10.2.

Table 10.2: The format of a partial budget (for additional enterprise)

Losses	TZS	Cts	Gains	TZS	Cts
Extra costs			Extra revenue		
Profit (if any)			Losses (if any)		

The difference from any of the two sides is then entered on the losses side as profit if any or as losses if any on the gains side. The decision criterion is to make changes if the gains side is greater than the losses side.

Worked example 2

Mr. and Mrs. Tubadilike get their income by selling milk obtained from 120 dairy cows they keep. Each dairy cow yields about 240 litres of milk per year and sold at TZS 1 500 per litre. However, currently, they are thinking of replacing this enterprise with 10 hectares of paddy from which they expect to harvest 4 000 kg per hectare and sell at TZS 1 000 per kg. Some of the basic information about the two enterprises are provided hereunder:

Variable costs of keeping one dairy cow per year (TZS)

(i)	Feeds	200 000
(ii)	Veterinary medicines	100 000
(iii)	Casual labour (total)	400 000

Variable costs of growing one hectare of paddy (TZS)

(i)	Land preparation	125 000
(ii)	Seeds	50 000
(iii)	Fertilisers	350 000
(iv)	Pesticides	70 000
(v)	Weeding	125 000
(vi)	Harvesting	300 000

Use the data above, to find out whether the changeover is economically worthwhile. Your solution should be in a form of a partial budget.

Solution

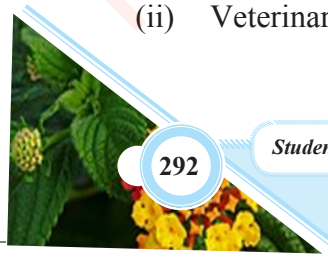
(a) Revenue lost (Dairy cow):

120 cows × 240 litres × TZS 1 500
= TZS 43 200 000

(b) Extra revenue (Paddy):

10 ha × 4 000 kgs × TZS 1 000
= TZS 40 000 000

(c) Costs saved (TZS)



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(i) Feeds: TZS 200 000 × 120 cows……TZS 24 000 000
(ii) Veterinary medicines: TZS 100 000 × 120 cows .....TZS 12 000 000
(iii) Casual labour……TZS 400 000

Total……TZS 36 400 000

(d) Extra costs (Paddy) (TZS)

(i) Seeds ……TZS 50 000
(ii) Land preparation: TZS 125 000 × 10 Ha……TZS 1 250 000
(iii) Fertilisers: TZS 350 000 × 10 Ha……TZS 350 000
(iv) Pesticides: TZS 70 000 × 10 Ha……..TZS 700 000
(v) Weeding: TZS 125 000 × 10 Ha……..TZS 1 250 000
(vi) Harvesting: TZS 300 000 × 10 Ha……..TZS 3 000 000

Total……TZS 6 600 000

Partial budget

Losses	TZS	Cts	Gains	TZS	Cts
Revenue lost	43 200 000	00	Cost saved	36 400 000	00
Extra cost	6 600 000	00	Extra revenue	40 000 000	00
Net Profit	26 600 000				
Total	49 800 000	00		76 450 000	00

Mr. and Mrs. Tubadilike are advised to change over, from keeping dairy cows to paddy production because the change will give a net profit of TZS 26 600 000.

Worked example 3

Kilimobiashara is an agricultural secondary school. The main source of its income is keeping layers. The project manager is of the view that, the income from the enterprise is not enough, and therefore, the school is planning to add 4 acres of tomatoes as an additional project. From one acre it expects to harvest a total of 3 000 kgs and sell at TZS 1 500 per kg. Mechanization will cost about TZS 50 000 per acre, other agronomic practices costs will stand at a total of TZS 70 000 per acre and harvesting costs will stand at TZS 500 000 per acre. Use the data above to find out if it is worthwhile to undertake the additional project. Set your calculation in a form of a partial budget.

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Solution

(i) Extra revenue (Tomato): 4 acres × 3 000 kgs × TZS 1 500 . TZS 18 000 000

(ii) Extra costs (Tomato): Mechanization: 4 acres × TZS 50 000 TZS 200 000

(iii) Other agronomic practices costs: 4 acres × TZS 200 000 ..... TZS 800 000

(iv) Harvesting costs: 4 acres × TZS 500 000…… TZS 2 000 000

Total tomato production costs…… TZS 3 000 000

Table 10.4: Partial budget

Losses	TZS	Cts	Gains	TZS	Cts
Extra costs	3 000 000	00	Extra revenue	18 000 000	00
Profit (if any)	15 000 000	00	Losses (if any)		
	18 000 000	00		18 000 000	00

Kilimobiashara agricultural secondary school is advised to add the enterprise in addition to that of layers since the enterprise will add a net profit of TZS 15 000 000.

Activity 10.2

Kilimohai Secondary School is considering a possibility of changing from growing 10 hectares of round potatoes to 10 hectares of finger millet. The yield from round potatoes is 4 000 kg/ha sold at TZS 1 000 per kg and the yield from finger millet is 900 kg/ha sold at TZS 2 000 per kg. The variable costs of growing round potatoes are: seed 1 800 kg/ha, cultivation TZS 125 000 per ha, fertilisers TZS 200 000 per ha, and other costs TZS 100 000 per ha. To grow finger millet, a farmer will incur total variable costs amounting to TZS 400 000 per ha. Use the data above to find out whether the change is a profitable or not and advise the school concerning changes they want to make.

Set your calculation in the form of a partial budget.

Advantages of budgeting

(i) Help to evaluate the old plans and guide the farmer to adopt new plans which is more advantageous.

(ii) Makes comparative analysis of receipts, expenses and net earnings.

(iii) Guide and encourage the most efficient and economic use of available resources.

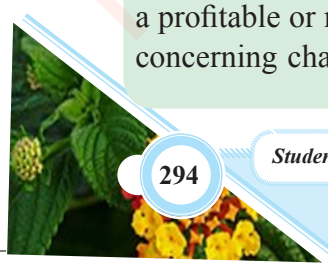
Limitation of budgeting

(i) Assumes yield and price are perfect, no risks and uncertainty.

(ii) Assumes linearity in relationship between variables.

Programme Planning

Programme planning is one of the farm planning tools with a specific profit maximisation where combination of enterprises is optimized within the



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set of resource constraint. It is defined as a method of ranking enterprises according to their profitability, given the limited available resources. Production resources are assigned to enterprises that enable the farmer to make more profit. When agricultural enterprises compete with one another for the limited available resources on the farm, program planning become a very useful tool. Resources are initially allocated to enterprise with high returns, then to those with lower returns and so on, until one of them becomes limiting. In comparison to traditional budgeting, the programme planning technique uses a logical procedure to select or reject an enterprise.

Some of advantages of programme planning is that it show the planner how much the objective function would increase if one more unit of a limited resource were available. Also, it can be used to select the optimal enterprise combination.

Procedural steps in programme planning

The following are steps followed in preparing a programme plan

(i) Make a list of all accessible farm production resources including land, labour and capital;

(ii) Make a list of all the enterprises that can be started with the available farm resources;

(iii) Determine the outputs and prices, then calculate the total revenue of each enterprise;

(iv) Determine the quantity of inputs and their respective prices, then calculate the total variable costs;

(v) Calculate the gross margin of each enterprise;

(vi) Sort the gross margins from highest to lowest;

(vii) Tabulate the available and required resources for each enterprise;

(viii) Make a list of all limiting factors;

(ix) Begin by identifying an enterprise with the best gross margin and allocate resources to it until at least one factor become limiting;

(x) Repeat step (ix) with the next highest gross margin enterprise until another resource becomes a limiting factor; then,

(xi) Repeat step (x) until the majority of the resources have been depleted.

Worked example 4

Using the data obtained from a farmer in Katavi (Table 10.5), programme planning can be done as follows:

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Table 10.5: Programme planning data layout

Item	Month	Crop enterprises			
		Cotton	Maize	Sorghum	Beans
Labour requirement per hectare during peak months	June	20	10	0	10
	July	10	8	0	5
	Aug	10	5	5	2
	Nov	30	0	0	0
	Dec	10	0	0	0
Yield per Ha (Kg)		1 400	1,100	900	600
Price per kg (TZS)		1 500	1 000	1 000	2 000
Gross output per Ha (TZS)		2 100 000	1 100 000	900 000	1 200 000
Variable costs per Ha (TZS)		400 000	250 000	100 000	300 000
Gross Margin per Ha (TZS)		1 700 000	850 000	800 000	900 000
Total labour per Ha (Man-days)		100	50	30	40
Gross Margin per Man-day (TZS)		17 000	17 000	26 667	22 500
Other information					
The total area available per family……...5.0 ha					
Total labour available each month per family…… 70 Man-days					
Each farmer insists on growing 1 ha of maize and 0.5 ha of sorghum					

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Solution

(a) Labour use calculations

Labour requirement per ha during peak months					Labour used up for growing		Remaining labour	
Month	Cotton	Maize	Sorghum	Beans	1 ha maize	0.5 ha sorghum	Total	
Man-days								
June	20	10	0	10	(1 × 10)	+ (0 × 0.5) = 10	70 - 10 = 60	
July	10	8	0	5	(1 × 8)	+ (0 × 0.5) = 8	70 - 8 = 62	
Aug	10	5	5	2	(1 × 5)	+ (5 × 0.5) = 2.5	70 - 2.5 = 67.5	
Nov	30	0	0	0	-	- -	70 - 0 = 70	
Dec	10	0	0	0	-	-	- 70 - 0 = 70	

Note: The total land used for maize and sorghum production is (1 + 0.5) ha = 1.5 ha. The possible number of hectare for cotton production is obtained by dividing the maximum labour available to the labour requirement in that month i.e., 70/30 = 2.3 ha. Table 10.5c shows the amount of labour used in cotton farm (2.3 ha) each month and therefore the remaining labour can be computed.

(b) Labour used for cotton (Crop with highest GM)

Available labour after growing maize and sorghum		Labour used in growing 2.3 ha of cotton	Remaining labour	
Man-days				
June	60	20 × 2.3 = 46	60 - 46	= 14
July	62	10 × 2.3 = 23	62 - 23	= 39
August	67.5	10 × 2.3 = 23	67.5 - 23	= 44.5
November	70	30 × 2.3 = 69	70 - 69	= 1
December	70	10 × 2.3 = 23	70 - 23	= 47

Calculating the total area (ha) already covered by maize, sorghum and cotton that is 1 + 0.5 +2.3 = 3.8 ha. The remaining land is only 1.2 ha. The next crop with the highest GM is beans. The possible area for beans is equal to labour remaining after earlier allocation divide by labour requirement in that month, i.e. 14/10 = 1.4 ha however, we are left with only 1.2 ha. Therefore, only 1.2 ha will be allocated to beans.

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(c) Calculating hectares for beans based on remaining labour

The total area (ha) already covered by maize, sorghum and cotton that is 1 + 0.5 +2.3 = 3.8 ha. The remaining land is only 1.2 ha. The next crop with the highest GM is beans. The possible area for beans is equal to labour remaining after earlier allocation divide by labour requirement in that month, i.e. 14/10 = 1.4 ha however, we are left with only 1.2 ha. Therefore, only 1.2 ha will be allocated to beans.

Available labour after cotton allocation		Required labour	Possible area for beans (Available labour/required labour)
Man-days			Ha
June	14	10	14/10 = 1.4
July	39	5	39/5 = 7.8
August	44.5	2	44.5/2 = 22.2
November	1	0	1/0 = infinite
December	47	0	47/0 = infinite

The final stage is drawing the optimum farm plan, followed by calculating the expected returns based on the new allocations as presented in Table 10.5e.

(d) Drawing the optimum farm plan

Crop enterprise	Possible area (Ha)	GM/Ha (TZS)	Total value (TZS)
Cotton	2.3	1 700 000	3 910 000
Beans	1.2	900 000	1 080 000
Maize	1	850 000	850 000
Sorghum	0.5	800 000	400 000
Total	5	4 250 000	6240 000

Therefore, the optimum plan for this farmer is to grow 2.3, 1.2, 1.0, and 0.5 hectares of cotton, beans, maize, and sorghum respectively. This combination will yield a total of TZS 6 240 000 net revenue.

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Exercise 10.1

1. Explain the concept of farm planning.
2. Describe the important tools of farm planning.
3. A farmer planted 5 hectares of wheat, whereby the following costs were incurred: seeds worth TZS 5 000, fertiliser worth TZS 750 000, weeding cost TZS 750 000 and harvesting costs were TZS 200 000 per hectare. The total yield was 250 bags sold at TZS 120 000 per bag. Calculate the:
   (a) total revenue;
   (b) total variable costs; and
   (c) gross margin of this farm.

Activity 10.3

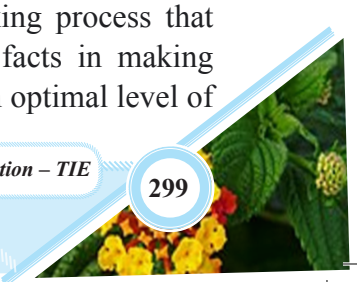
Refer procedural steps for computing and using a partial budget and a programme planning in making farm decisions learnt in previous sections. Use the data below to prepare a programme plan for a given agricultural enterprise.

Month	Man-hour available	Labour requirements (Man-hour per Ha)				
		Green peas	Finger millet	Round potatoes	Maize	Beans
December	9 000	0	0	0	100	100
January	9 500	0	100	0	200	250
February	8 900	0	200	0	300	300
March	9 000	0	100	300	250	400
April	9 000	300	50	3 000	0	0
May	9 000	400	50	250	0	0
June	9 000	220	150	400	0	0

Rational production decisions

Normally, in the production process, producers are faced with situations that require them to decide between alternatives or choices. Such decisions require availability of correct information, i.e. all data relevant to a particular decision should be known and available to the producer. A rational producer will make choices that will maximise benefits and minimise production costs.

Making rational decision refers to a scientific decision-making process that is based on available facts in making choices that result in an optimal level of



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benefit. Therefore, from the definition, it follows that, a rational production decision is a logical and multi-step process involving problem identification to implementation of alternative considered to be the best solution.

Rational decision-making process

The rational decision-making process approach follows a sequential pattern as described hereunder:

Step 1: Identify a problem

Identifying a problem is a starting point in rational decision-making. Failure to identify the problem clearly can disrupt the entire process. It can sometimes require serious thought to find the central issue that must be addressed. Examples of problems in the production process are what to produce, how to produce, how much to produce, where to buy inputs, where and when to sell the output. All these are central problems a producer should gather information to reach a correct decision.

Step 2: Identifying the decision criteria

A decision criterion is a base on which the final decision will be made. At this step, a producer needs to determine what is relevant in making the decision. The decision criteria should be measurable and should be within the scope of the problem a producer is trying to solve. For example, in deciding what to produce, the decision criterion should be profit maximisation where the marginal value product of one enterprise is equal to the marginal value product of the second enterprise ($MVP_1 = MVP_2$). In deciding how to produce, the decision criterion is the point where the marginal product (MP) is equal to the price ratios of the inputs and the output (MP = Px/Py); and for deciding how much to produce, the decision criterion is the point at which the marginal rate of technical substitution of the two inputs is equal to their price ratios ($MRTS = PX_2/PX_1$).

Step 3: Gap analysis

After a problem has been analysed and the desired end is known, what follows is to carry out a gap analysis exercise which means mapping how to move from the problem to the solution. Gap analysis allows the formulation of action plan for implementation.

Step 4: Gathering facts, options, and alternatives

This step involves gathering facts or information to support decision-making, followed by listing potential options or alternatives available for solving the problem at hand. Lack of reliable facts may lead to improper decision-making and hence failure for the farm to realize its objectives.

Step 5: Analysing option outcomes

At this stage, a full list of possible alternatives has been prepared, each alternative can now be analyzed and evaluated. Which choice is most desirable and why? Are all of the options equally feasible, or some are unrealistic or impossible? Now is the time to identify both the merits and the challenges involved in each of the possible solutions.

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Step 6: Selecting the best possible options

Following a careful evaluation of alternatives, a producer must choose a solution and implementation must follow based on the identified alternatives.

Step 7: Implementation

Implementation is the final stage in rational decision-making process, which involves putting into action all the selected best options. It is a stage of ensuring that the target or goal of the farm is being achieved. Evaluation of the options is an integral part of the implementation process.

The process can be summarized as shown in Figure 11.1.

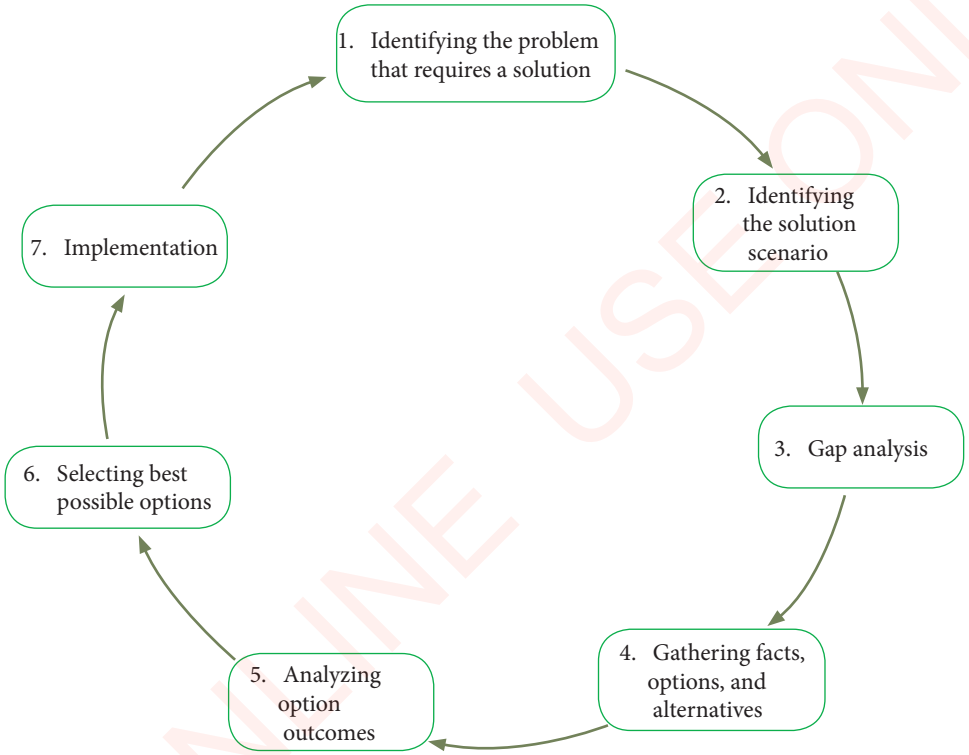

Figure 10.1: Rational decision-making process

Sources and management of risks in farm planning

Imperfect knowledge exists in any farming system or enterprise, thus, farmers cannot control all variables that are important. Farming deals with many unknown situations thus involves risks or uncertainty. For example, a farmer is not sure when rainfall will start, when it will end and if rain will be sufficient for the target crop, as well is not sure with occurrence of pests and diseases. Therefore, the earlier discussed profit maximization, cannot be completely realized in a situation where risk and

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uncertainty prevail. Hence risk and uncertainty management must be incorporated in farm planning. Some of the risks and ways to manage them are listed herein:

Production (yield) risk

Actual crop/livestock yield will be different from expected yield due to poor weather, diseases, pests, and climatological events. Production risks can be managed by:

(a) Reducing level of variable inputs to avoid full loss incase output fail.

(b) Enterprise diversification – For example, planting maize and sorghum, keeping chicken and rabbits.

(c) Strategic selection of biological and physical technologies.

(d) Use of insurance cover.

Price/market risk

Market risk occur when actual price is different from the expected one. Price is determined outside farmers' control and it depend on forces of demand and supply. It also depends on action and interaction of national and international markets systems. Price/market risk can be managed by:

(a) Transferring risk to the market through forward contracting of inputs/outputs.

(b) The use of short-term planning horizon since the future is more uncertain.

Political risk

Changes in political priorities may have effect in demand and supply. Political risk can be managed by:

(a) Maintaining neutral positions in politics.

(b) Maintaining contacts with politicians.

Financial or investment risk

The need to preserve capital, enough cash flow, use of debt capital is important to the farm. However, there is a risk of losing equity capital and credit reserve. You have to be prepared to reduce this kind of risk by the following approaches.

(a) Maintaining credit and cash reserve.

(b) Insuring your properties to avoid large but unknown losses.

(c) Flexible arrangement to permit less expensive change.

Human

Human risks include diseases, disability, and death. These can be managed by the following means:

(a) Be informed about social, political, and cultural changes.

(b) Train and maintain assistants.

(c) Transfer risks to specialists (insurance).

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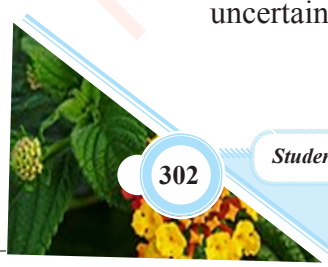

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Activity 10.4

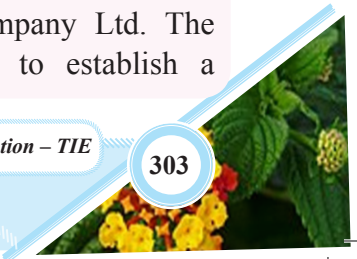
1. Using your school farm as a case study, work in a group to:
   (a) Identify the problem facing your school farm,
   (b) Use a rational decision process to solve the problem.
   (c) Outline some important risks facing the farm.
   (d) Outline some possible risks and uncertainty facing your school farm. Suggest possible ways to avoid or minimise the outlined risks and uncertainty.
   (e) Prepare a report and present it in class for plenary discussion.
2. Write a summary of what you have learned from this chapter in your portfolio.

Exercice 10.2

1. What do you understand by the term rational decision-making?
2. Explain why rational decision-making is important in agricultural production?
3. Discuss the process of rational decision-making in farm production.
4. Mwanakwetu heard that growing simsim is more profitable than beans. Based on this piece of information, she then decided to uproot all the ten acres she had grown beans to grow simsim. Basing on the knowledge you have, comment on whether Mwanakwetu had made a rational decision or not? Give at least five reasons to justify your answer.
5. Describe three different ways that can be employed in making rational farm decision.

Revision exercise 10

1. Briefly explain the term farm planning.
2. List any three tools of farm planning.
3. Write a short description on the following:
   (a) Gross margin
   (b) Partial budget
   (c) Programme planning
4. List down important steps involved in computing the following:
   (a) Gross margin
   (b) Partial budget
   (c) Programme planning
5. Suppose you want to make changes to your farm, which planning tool will you prefer to use (Give at least three reasons)
6. What is the rationale for a farmer to apply the concepts of farm planning?
7. You are employed as a farm manager at Mazao Bora Agricultural Company Ltd. The company intend to establish a



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10-acre rice farm, from which it expects to harvest 20 bags per acre and sell at TZS 100 000 per bag. The farm will require 2 bags of fertiliser per acre costing TZS 75 000 per bag, 2 litres of 2-4-D herbicide costing TZS 15 000 per litre, cultivation costs at TZS 50 000 per acre, and 200 kgs of seed sold at TZS 1 000 per kg. Using the data provided:

(a) Calculate the total revenue of the farm;

(b) Compute the total variable costs of the farm;

(c) Calculate the gross margin of this farm;

(d) Calculate the per-unit gross margin of the farm; then

(e) Advise the company if it is profitable to invest in rice production or not.

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Chapter Eleven

Information and communication technology (ICT) in agriculture

Introduction

Information and communication technology (ICT) has a great role as a decision support system in several development sectors including agriculture. Through ICT, farmers can be updated with real time agricultural related information, reduce drudgery through automation of agricultural practices and improve resource use efficiency thus improving agricultural productivity. In this chapter, you will learn about the concept of ICT and precision agriculture, applications of ICTs in precision agriculture, and Technologies supporting application of ICT in precision agriculture. Competencies developed will enable you to apply appropriate technologies to improve agricultural production and productivity.

The concept of ICT in agriculture

Information and communication technology (ICT) is a tool, or application that permits the exchange or collection of data through interaction or transmission. A wide range of technologies are developed and used in sustainable agriculture. The use of information and communication technologies in agriculture is increasing, as it can help to reduce geographical handicaps. These technologies range from simple to sophisticated. However, economic, environmental, and social considerations should be taken into account when evaluating and selecting the technologies.

The use of ICT tools and their applications in agriculture significantly improve access to modern agricultural technologies which help to prevent crop losses and mitigate effects from natural calamities, management of insect pest, weed and diseases. In addition, it improves irrigation water and nutrient use efficiency, allows precision livestock management and enhances access to agricultural extension and marketing services.

Application of ICT in agriculture allow automation of farm operations, making farming more efficient in terms of resource use thus reducing the environmental impacts. Generally, ICT application in agriculture addresses major issues like ever-increasing food and fibre demand due to increasing global population, farm labour shortages, and changing consumer preferences. Youth can therefore take the advantage of existing ICT potential to improve agricultural productivity and

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profitability, thus, creating employment opportunities and contributing towards sustainable economic development.

Application of ICT in agriculture

Among the major use of ICT in agriculture is the application in precision agriculture (PA), also known as precision farming (PF)/ satellite farming (SF) or site specific crop management (SSCM). It is a science of improving agricultural yields, and assisting farm management decision using high technology sensors and analysis tools. PA increases production, reduces labour time and ensure the effective managerial practices such as fertilisers and pesticides application, irrigation, and animal feeding. It is a data-driven farming management that uses information technology (IT) to ensure that crops, livestock and soil, receive the exactly what they need for optimum health and productivity. It entails highly controlled, precise and optimized agricultural production. The main purpose of precision agriculture is to support farmers by providing customized information and technological services that enhance productivity, increase profitability and reduce environmental pollution. It improves crop and livestock production through enhancing the contribution of different factors like soil fertility, water and nutrient use efficiency, livestock feeding efficiency, pest population, and information access.

ICT contribution in agriculture can either be directly or indirectly.

Direct contribution of ICT in agriculture

ICT contributes directly to agricultural production through the use of data intensive technologies. The process is facilitated through the use of remote sensors techniques with the support of Global Information System (GIS) and satellite technologies. For example, a farmer's computer, can be connected to the meteorological stations to get information about air temperature, relative humidity, rainfall moisture, wind speed and solar radiation.

Indirect role of ICT to agriculture

This deals with facilitating and supporting decision making and networking. They provide timely and reliable information sources at three stages:

(i) Pre-cultivation: Information on crop selection, land selection, crop calendar and access to credit.

(ii) Cultivation and harvesting: ICT provides information about land preparation and sowing, input and water management, fertiliser and pest management

(iii) Post-harvest: ICT Play great role in information, transportation, packaging, processing and marketing.

Therefore, for farmers to increase production, they need information about production techniques, equipments

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agricultural inputs, market information and other information of their interest in agricultural production.

Technologies supporting precision agriculture

Mobile phone based technologies

The mobile phone is the most impactful technology for making precision agriculture feasible to farmers worldwide. For example, by 2021, about 70% of households owned a mobile phone around the world and Tanzania in particular. Mobile phones enable two-way communication between farmers and experts, real-time monitoring and digitization of filed data collection. Typical examples of application of mobile phones in support of precision agriculture include:

Phone camera

Phone cameras are used to capture visual data of farm conditions for analysis. Examples of applications based on the use of mobile phone cameras include:

(a) A crop diagnosis application which enables farmers to take picture of their infected crop/livestrock on WhatsApp and get connected to an agricultural expert who replies with a diagnosis and recommended treatments. An example of such mobile phone application includes *Plantix (https:/plantix.net)*.

(b) An application which enables a farmer to document and post pictures and recorded voices relating to agricultural practices by using smart phones. This application promotes reciprocal exchange of knowledge between farmers engaged in agro-ecological practices and scientific researchers. An example of such application is *Machosauti app (https://www.fao.org/3/BU717EN/bu717en.pdf)*.

Short Message Services (SMS)

Short message services (SMS), allow farmers to send queries and receive advisories and alerts. The use of SMS as the main media for communication accommodates users who otherwise are limited to internet connection. *WeFarm,* is an example of sms-based social networking platform in East Africa, which allows farmers to interact with peers, exchange ideas, and sell or trade agricultural equipment and supplies.

Unstructured Supplementary Service Data (USSD)

This is a phone based application similar to SMS but slightly different from SMS in the sense that USSD users can select a customized advisory service from a menu. Example of USSD based phone application is *Mobile Kilimo or M Kilimo (http://exts.kilimo.go.tz)* under the ministry of Agriculture. The application enables a farmer to access real-time information about agricultural markets and extension services by referring to a USSD menu (Figure 11.1).

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Figure 11.1: A flier bearing instructions on how to use Mobile kilimo app (Kiswahili)

Interactive Voice Response (IVR)

This is a phone-based application mainly used to deliver pre-recorded agricultural advisories to farmers. This app was successfully used by SOLIDARIDAD, an international civil society organisation to provide agricultural extension services to smallholder farmers in West Africa when face to face meetings were burned as part of COVID-19 safety measures.

Phone based sensors

These include position and motion sensors. Position sensors are used to locate the position of a device. Examples include magnetometers, GPS and orientation sensors which provide location data for crop mapping and alerts on diseases and pests. Motion sensors on the other hand, are used to measure the user's movements. By tracking the user's movements, motion sensors help

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to inform farmers if they are performing farm activities optimally. Motion sensors are also useful in monitoring livestock movements and feeding behaviour especially for outdoor grazed animals.

Mobile Processors and Applications

This technology, enable on-site calculation of optimal decisions without the need to connect to cloud servers. The following are some developed mobile processors and applications to support precision agriculture:

(a) **Fertilisers optimization tool:** The application allows extension workers to input crop and acreage data, fertiliser cost, and forecasted crop price. It also enable them to input optimal amount of fertiliser cost to be used for each crop, the expected yield improvement, and calculated return on investment (ROI). An application developed by the Consultative Group on International Agricultural Research (CGIAR) is an example of such tools.

(b) **Nutrient expert tool:** This is a decision support tool developed for wheat and maize. It integrates on-farm research data into a simple delivery system that allows growers to quickly adopt site specific nutrient management for their own fields.

(c) **Extension information tools:** Some mobile processor and applications have been developed to overcome extension information gaps. For example, *MWANGA* is a mobile-based platform which provide farmers with such information as, when key scheduled farm activities are to take place. The application also serves as a communication channel to agricultural extension agents who are on the ground to offer subsequent advice to farmers. The platform was first introduced in Babati and later on, in Mbeya and other parts of Tanzania under the Africa RISING Project.

(d) **Conservative application tools:** Some smartphone applications are potential tools to help farmers conserve water and nutrients, reduce drudgery, and maintain high crop yields. The tools facilitate monitoring of soil moisture content and plant water requirement in a farm on a real-time basis (Figure 11.2). *SmartIrrigation™ (https://smartirrigationapps.org)* is an example of smartphone application used to schedule irrigation based on crop coefficients and real-time weather data. The application enhances the generation of messages that are sent via smartphone as notifications to promote irrigation scheduling.

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Figure 11.2: Monitoring soil moisture and plant water requirement using a smartphone

Remote sensing using satellites

Satellite imagery provides a snapshot of a large area of farmland in a single image. The information in satellite image is analysed and used to monitor changes in soil conditions, crop health, pasture quantity and quality. Satellites are also used for insect pest, parasites and disease detection for better land management. Some specific applications of satellites in precision agriculture are as summarized herein:

Production of spectral index maps

Spectral data from satellites is used to generate spectral index maps that visualize farm health and inform the farmer which parts of the farm to focus on. Examples of commonly used spectral indices include the Normalised Difference Vegetation Index (NDVI) which measures the greenness of vegetation and can be used as a proxy for understanding crop health across the field; Normalised Burn Ratio (NBR) used to assess burn extent and is deployed for monitoring active fires, and the Atmospherically Resistant Vegetation Index (ARVI) used to track particulate matter in the atmosphere for identifying areas with pollution or even slash-and-burn practices.

Geo-positioning

Satellite-based navigation systems such as the global positioning system (GPS) help to collect georeferenced data and identify accurate field locations for precise placement of seeds and agrochemicals, irrigation water management, pasture management and overall farm management practices. The combination of satellite and navigation systems characterise the farms' soil and crop/pasture variability, allowing for more intensive and efficient cultivation and grazing practices.

Unmanned aerial vehicles (UAVs)

Unmanned aerial vehicles (UAVs) also known as 'drones' are used to carry a variety of accessories (e.g., sensors, cameras and spray equipment) for various applications in precision agriculture. In combination with other technologies, drones are used in soil analysis, seed sowing, crop spraying, and field monitoring as well as deciding the right moment for harvesting. In addition, they can also be used for the precise application of pesticides and herbicides (Figure 11.3 (a) and (b)).

Figure 11.3 (a): Monitoring crop performance

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Figure 11.3 (b): Pesticide application

Robotic /unmanned ground vehicles (UGV) technology

Robotic technology is another area of interest in precision farming. It is part of proximal sensing where unmanned ground vehicles (UGV) collect data and manage various farm activities including soil analysis, seeding, transplanting, mowing /weed control (Figure 11.4), crop scouting, pesticide application (dusting), irrigation and harvesting. The use of UGVs allow a continuous field data collection process to monitor crop status and growth conditions. They are also used to facilitate different field activities such as weeding.

Figure 11.4: Robotic tractor (UGV) with a mower clearing service roads in a tea plantation

Hydroponic production

Hydroponic crop production also called vertical or soilless farming involves growing crops in nutrient solutions thus eliminating the need for soil as a media for plant growth. It is a technology of growing plants in nutrient solutions (water containing fertilisers) with or without using an artificial medium (sand, gravel, sawdust, vermiculate or coconut coir) (Figure 11.5 (a) and (b)). It is mostly practiced in urban centers where accessibility of land for agricultural production is limited. Crop like tomato, pepper, cucumber and Chinese cabbage can be grown using this system. The system has great potential to supply food in a sustainable fashion, allow degraded landscape to restore ecosystem functions and services and reduce the cost of managing crop pests.

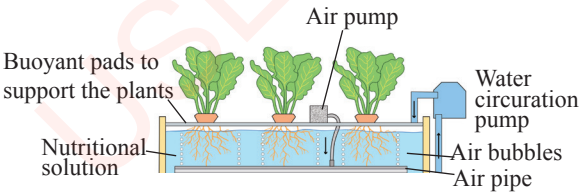

Figure 11.5 (a): diagrammatic representation of hydroponic system

Figure 11.5 (b): Hydroponic production of leafy vegetables

Source: *https://www.gothicarchgreenhouses.com/blog/hydroponic-greenhouses/*

Hydroponic crop production has a potential to take advantage of abandoned and unused urban spaces e.g. those with salt affected soils and allow year-round

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food production without loss of yields due to climate change or weather-related events thus considered as part of climate smart agriculture. It is less labour demanding especially when the hydroponic system encompasses the use of digital technologies to monitor crop growth factors such as water level, pH, temperature, flow and light intensity. With this system all the nutrients and water that the plants needs are available at all times.

However, irrespective of the advantages, some of challenges associated with hydroponic production is that, the system demands relatively high initial capital investment and high level of expertise is required.

Activity 11.1

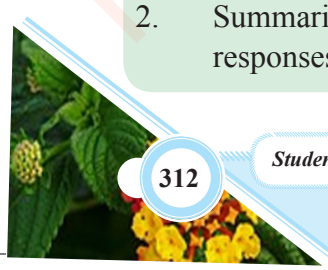
1. In a group:
   (a) Identify available ICT-based technologies in your area
   (b) Discuss the various applications of identified technologies in agriculture part (a)
   (c) Summarize key challenges in the crop and livestock sector that can be addressed using the identified technologies and applications in parts (a).
   (d) Debate the possible limitations of using ICT-based technologies and applications in your area.
2. Summarize your findings and responses to question 1 (a-d) into a report and present it in class for further discussion.

Exercise 11.1

1. Using an appropriate ICT tool create a message indicating key challenges facing agriculture in your area and the available technologies to solve them.
2. Discuss how key opportunities offered by ICT can help to reduce unemployment among Tanzanian youth?
3. Based on your understanding of applications of ICT in agriculture, explain how you can attract your fellow youth into agriculture?

Revision exercise 11

1. Most youth believe that agriculture is for old generation. Argue for or against this statement.
2. In tabular form, compare and contrast precision agriculture and conventional agriculture.
3. Outline five main ICT technologies supporting precision agriculture.
4. Discuss the potential opportunities offered by ICT in commercializing agriculture sector in Tanzania.
5. Explain how ICT development can influence Tanzanian youth engagement in agriculture.
6. Discuss possible factors limiting ICT literate Tanzanian youth to apply ICT knowledge and skills in Agriculture.



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Glossary

Adiabatic	a thermodynamic process in which there is no heat transfer from in or out of the system.
Agronomy	a branch of agriculture that deals with field crop production and soil management.
Assets	a resource with economic value that an individual, corporation, or country owns or controls with the expectation that it will provide a future benefit.
Automation	the creation and application of wide range of technologies to produce and deliver goods and services with minimal human intervention.
Average costs	it is the per unit cost of production obtained by dividing the total cost (TC) by the total output (Q) or mathematically expressed, AC = TC/Q.
Average fixed costs	the total variable cost per unit of output
Average product (AP)	the average output (or products) produced by each input (factors of production like labour and land).
Average variable costs	are total variable costs divided by output.
Belching	the act of expelling air from the stomach through the mouth. It usually occurs when the stomach distends, or expands, because of too much swallowed air.
Bile	secretions of the liver that aid in the digestion of fat.
Bile duct	a duct that carries bile from the gall bladder to the small intestine.
Biogas	renewable energy gas mixture of methane, hydrogen sulphide, and carbon dioxide, produced from manure, agricultural wastes, plant materials, sewage system and food energy.
Biophysical properties	soil properties in terms of their biological and physical features.
Biota	animals and plants living in a particular place, time, or habitat (one type of natural environment).

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Browse a type of herbivory in which a herbivore (or, more narrowly defined, a folivore) feeds on leaves, soft shoots, or fruits of high-growing, generally woody plants such as shrubs.

Browse plants woody plants that provide forage palatable trees, shrubs, and herbs with a high nutritive value which are preferred by goats and sheep.

Capital the machinery, tools, and buildings humans use to produce goods and services.

Carrying capacity the number of animals the land can sustain without destroying plants and soil.

Climax vegetation the final stage of plant succession that is possible within prevailing climatic and edaphic conditions.

Depreciation the monetary value of an asset decreases over time due to use, wear and tear, or obsolescence.

Diesel type of fuel which is used in the internal-combustion engine where the ignition of the diesel is a result of heat produced by air compression.

Draught animals power sources from animals used in performing different activities such as ploughing, weeding and transportation.

Dusting a pest control method whereby dry fine powdered chemicals may be mixed with inert carriers and are applied with some types of blower.

Ecology the study of interactions among living things and their environment.

Economic injury level of a pest

the lowest population density of a pest that will cause economic damage. It may also refer to the amount of pest injury which will justify the cost of control.

Engine stroke displacement of the piston inside the cylinder. One complete travel of the piston from TDC to BDC and vice versa in a vertical engine is one stroke of the piston.

Entrepreneurship is the process of developing, organizing, and running a new business to generate profit while taking on financial risk.

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Ergonomic	an applied science concerned with designing and arranging things people use so that the people and things interact most efficiently and safely.
Exhaust gases	are waste gases expelled from the engine as the result of fuel-air mixture combustion.
Farm planning	a decision-making process in the farm business, which involves the organisation and management of limited resources to realize the specified goals continuously.
Fauna	is a term that refers to all of the animal's life within a specified region, time period, or both.
Feed	is food given to domestic animals, especially livestock, in the course of animal husbandry.
Field capacity	the piece of work completed by a machine per hour. For example, in harvesting, is the area harvested per hour. In threshing is the amount of crops harvested per hour.
Field efficiency	the actual work completed by a machine as compared to total work that could have been done if the machine could utilize fully the working hours and working capacity.
Fixed costs	refers to the cost of a business expense that does not change even when there is an increase or decrease in the number of goods and services produced or sold. Fixed costs are commonly related to recurring expenses that are not directly related to production, such as rent, interest payments, and insurance.
Fodder	grasses, legumes, herbs, and shrubs that are used to feed livestock while still at the green stage.
Forage crops	crops are grown specifically to be grazed by livestock or conserved as hay or silage. Forage crops assist in achieving production targets for attributes such as growth or weight gain and make up seasonal shortfalls between feed demand and supply.
Frons	the forehead or equivalent part of an animal, especially the middle part of an insect's face between the eyes and above the clypeus.

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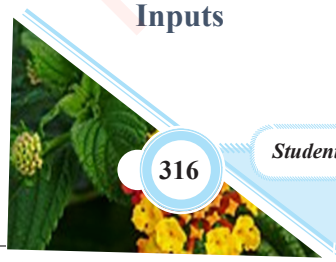
Gall bladder	a sac-like structure that serves as a storage compartment for bile.
Gasoline	the refined petrol used as fuel and it is commonly used by light duty engines.
Gena	the lateral part of the head of an insect or other arthropod below the level of the eyes.
Geothermal energy	Heat generated within the earth that can be harnessed for human energy use.
Grasses	plants belonging to the Gramineae family having fibrous root systems, soft cylindrical stems, and parallel-veined leaves.
Grassland/rangeland	the land that carries vegetation for domestic animals and games.
Grazing	the process of animals feeding on the vegetation that grows near the ground such as grass and any other low-growing vegetation.
Gross domestic product (GDP)	the monetary value of all finished goods and services made within a country during a specific period.
Gross margin	the difference between total revenue and total variable costs. Normally expressed per unit of production.
Hay	a grass or legume cut/standing, dried, and preserved for the future, especially during dry season for feeding livestock.
Herb	the soft-stemmed dicot plant species used to feed livestock.
Hydrology	the study of the distribution and movement of water on and below the earth's surface and their impacts on human activity on water availability and condition.
Infiltration	the process by which precipitation or water soaks into subsurface soils and moves into rocks through cracks and pore spaces.
Inputs	resources used to create goods and services.



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Isothermal a process in which a system changes—whether it be the pressure, volume and/or contents—without the temperature changing.

Labour productivity the sum of use values produced per worker employed in production. It is calculated with reference to some unit of time i.e. hour, day, month or year.

Leaching the movement of nutrients from the root zone to the soil below where crop plants can not absorb it.

Legumes a plant in the family Fabaceae (or Leguminosae), or the fruit or seed of such a plant. When used as a dry grain, the seed is also called a pulse.

Unmanned aerial vehicle (UAV)

a class of aircrafts that can fly without the on board presence of a pilot.

Maintenance a set of processes and practices which aim to ensure the continuous and efficient operation of machinery, equipment, and other types of assets typically used in business.

Marginal cost the change in total production cost that comes from making or producing one additional unit of output.

Marginal product (MP) the increase in output per unit increase in an additional unit of input.

Marginal revenue (MR) the additional revenue that results from the sale of one additional unit of output.

Mechanical power an energy responsible for driving machines. It is derived from different sources such as steam, fuel combustion, electricity and wind.

Meteorology the study of the atmosphere and motions within the atmosphere on short-time scales. Commonly known as 'weather'. Weather elements include temperature, humidity, precipitation amount and type, wind direction and strength, atmospheric pressure, and cloud cover.

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Mobile power the power exerted by moving source of power such as a tractor hitched with machinery or equipment and tasks are performed while the machines are in motion.

Optimum combination The combination of factors with which a firm can produce a specific quantity of output at the lowest possible cost.

Outputs the quantity of goods or services produced in a given period, by a firm or industry whether consumed or used for further production.

Pancreas a gland that secretes digestive juices necessary for the digestion of fat, carbohydrate, and protein.

Pancreatic duct a duct that carries secretion of the pancreases to the small intestine.

Partial improvement/ renovation

rejuvenation and enhancement of existing pastures, generally done when there are poor forage stands due to drought, flooding, or other environmental stress.

Pasture a cover of grass or legume, or a grass-legume mixture that is artificially or naturally established and grazed directly, fed after harvesting, or conserved as hay or silage.

Pasture establishment planting pasture where there was no existing pasture.

Production the transformation of goods and services called inputs to other goods and services called outputs.

Profit the difference between total revenue and total costs incurred in the production process.

Prolific producing offspring, young, fruit etc., in large quantities or with great frequencies; highly fruitful or productive.

Renewable energy is energy derived from natural sources that are replenished at a higher rate than they are consumed.

Renovation series of actions that lead to long term change in botanical composition of pasture. In an actual sense, pasture improvement is considered to represent the concepts of pasture renovation which embraces two types of renovation such as partial renovation and total renovation.

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Revenue	obtained as a product of the output and per-unit price of the produce.
Runoff	movement of water on the earth's surface, associated with carrying away of soil particles.
Saliva	a watery, mucoid secretion of the salivary glands in the mouth that lubricates food and contain enzymes that aids in digestion
Scape	the basal segment of an insect's antenna, especially when it is enlarged and lengthened (as in a weevil).
Sclerite	a component section of an exoskeleton, especially each of the plates forming the skeleton of an arthropod.
Sediments	the build-up of eroded soil particles that are transported from their site of origin and deposited elsewhere.
Shrubs	is the small to medium sized perennial woody plants that are edible/eaten by livestock.
Silage	moist succulent feed produced as a result of controlled fermentation of fresh forage when stored in the silo under anaerobic conditions. It is normally mixed with molasses to increase appetite and palatability to livestock.
Solar energy	is radiant light and heat from the sun that is harnessed using a range of technologies such as solar power to generate electricity, solar thermal energy (including solar water heating), and solar architecture. It is an essential source of renewable energy.
Stationary power	the power used to drive equipment stationed at a point such as water pumps, generators, factory machinery and mills.
Stocking rate	the number of animals on a given amount of land over a certain period of time.
Thermostat	a regulating device component which senses the temperature of a physical system and performs actions so that the system's temperature is maintained near a desired setpoint.

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Total costs (TC)	the sum of variable and fixed costs incurred on the farm.
Total product (TP)	the total amount of output produced with a given amount of input during a certain period.
Valuation	the process of determining the present worth or value of a company or an asset.
Variable costs	the costs that are incurred only when there is production. They vary with production.
Windmill	the device which is used to tap wind energy by means of a raised turbine mounted on a rotating shaft that converts mechanical energy into electric energy. The output energy is used for pumping water among other activities.
Yoke	usually made of wood and is used to fasten the necks of two working draught animals so that they can pull implements such as plough, weeder and cart.

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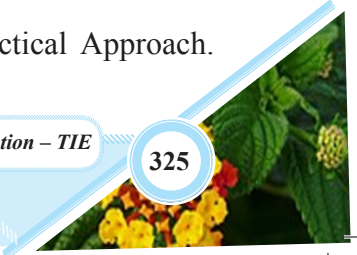

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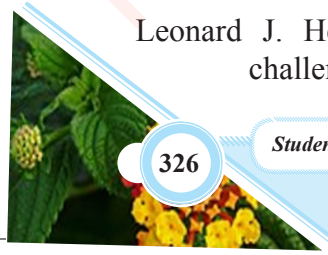

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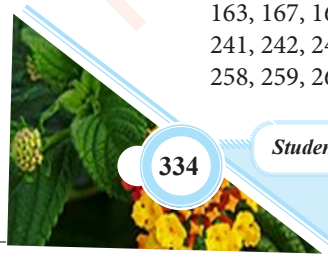

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