Dawn Webber

Study Guide

Via Afrika Agricultural Sciences

Grade 11

Via Afrika Publishers

Our Teachers. Our Future.

Contents

Introduction to Agricultural Sciences

Agricultural Sciences is the study of the relationship between soils, plants and animals in the production and processing of food, fibre, fuel and other agricultural commodities that have an economic, aesthetic and cultural value. Agricultural Sciences is an integrated science. It combines knowledge and skills from Physical Sciences, Life Sciences, Social Sciences, Earth Sciences, Engineering, Mathematics and Economics. This subject must be seen within the holistic science framework rather than as an isolated science.

In Agricultural Sciences you will:

- develop an awareness of the management and care of the environment, natural resources and the humane treatment of animals through application of science and related technology
- develop problem-solving mechanisms within the contexts of agricultural production, processing and marketing practices
- be aware of the social and economic development of the society at large through personal development in commercial and subsistence farming enterprises
- become informed and responsible citizens in the production of agricultural commodities, caring for the environment and addressing social justice issues
- be aware of agricultural indigenous knowledge and practices through understanding agricultural sciences in historical and social contexts.

Rationale for Agricultural Sciences

The interdependence of people and natural resources and the increasing demand on the latter has led to a need for proper utilisation, management and conservation of agricultural and natural resources. Relevant education at secondary school levels can contribute to meeting these demands in a sustainable way. An appreciation and awareness of the importance of natural resources and a responsibility towards their preservation should be fostered from an early age through the Natural Sciences learning area.

To fulfil the increasing demand for food and fibre and to meet the aspirations of communities, the acquisition of relevant knowledge, skills, attitudes and values is of vital importance.

Topic 1

Basic agricultural chemistry

Overview

TOPIC 1 Page 2
Basic agricultural chemistry

UNIT 1 Page 3
Introduction to basic chemistry

- Important terminology
- Differences between elements, molecules, compounds and mixtures
- Interpreting the periodic table
- General structure of the atom
- Types of atom particles and their charges
- Relationship between atomic numbers and number of particles in the nucleus
- Formation of ions
- Arrangement of electrons around the nucleus and valency
- Differences between acids and bases

UNIT 2 Page 10
Chemical bonding

- Basic chemical bonding to form a molecule
- Ionic bonding
- Covalent bonding

UNIT 3 Page 13
Inorganic and organic compounds

- Difference between inorganic and organic compounds
- Formulae, structures and functions of inorganic compounds
- Characteristics of the carbon atom and organic compounds
- Important groups of organic compounds

UNIT 4 Page 19
Alkanes and alcohols

- Basic types of alkanes
- Chemical and structural formulae of alkanes
- Importance of alkanes in plant and animal metabolism
- Isomers
- Basic types of alcohols
- Comparison between alcohols and alkanes

UNIT 5 Page 23
Fatty acids and bio-molecules

- Chemical structure of fatty acid
- Differentiation between saturated and unsaturated fatty acids
- Differences between fatty acids and alcohols
- Composition of lipid/fat
- Differences between fats, oils, saturated and unsaturated fats
- Functions and importance of lipids/fats

UNIT 6 Page 28
Proteins

- Structure of the monomers of proteins
- Differences between simple and complex proteins
- Structure of polypeptides or simple proteins
- Synthesis and hydrolysis of proteins
- Functions and importance of proteins in living organisms

UNIT 7 Page 32
Carbohydrates

- Basic chemical composition of carbohydrates
- General formulae of carbohydrates
- Structural and chemical formulae of monosaccharides
- Main classifications of carbohydrates
- Main functions of carbohydrates in living organisms

Unit 1

Introduction to basic chemistry

1 Important terminology

Chemistry is the study of the properties, composition and structure of matter, the changes that occur in matter, and the energy that is released during these changes.

1.1 Matter

This section defines and explains fundamental concepts in chemistry that apply to all matter or materials.

- The smallest part of matter is an atom. Atoms combine to make up elements, whereas elements make up molecules, and molecules make up compounds. These are all pure substances of matter.
- Objects contain an amount of matter called its mass. The weight of an object is measured by the force with which that object (of a certain mass) is attracted towards the centre of the earth. Although mass and weight are often used interchangeably, their meaning is different: mass is a quantity of matter, and weight is a force.
- All matter can be described by a set of characteristics or properties that are unique to it. Intrinsic properties are properties that are common to all samples of the same kind of matter.
    - A particular material can be made up of various constituents (parts).
        - The way that these are arranged constituents is called the composition of the material.
        - The composition of a material shows its structure.
    - We need knowledge of the way in which the constituents are arranged, or the structure of the material, to understand how the material will behave and possibly how to change a particular property.
- Elements are structural units of matter that cannot be broken down using chemical methods.
    - Elements are pure substances made up of atoms.
        - Atoms consist of electrons, neutrons and protons. Examples: carbon (C), oxygen (O), hydrogen (H), chlorine (Cl).
        - They adhere to themselves or other elements by chemical bonding to form molecules.
        - This bonding process will result in the formation of new pure substances.
- Molecules can be broken down chemically into the elements they are composed of. Examples: carbon dioxide (CO_2), water (H_2O).
    - They can take part in chemical reactions with other molecules by interactions between their atoms.
    - Atoms contained in molecules can react chemically to form compounds.
    - A pure compound can be broken down or be decomposed to two or more pure substances only by chemical means.

- A pure substance (element, molecule or compound) is a form of matter whose composition is uniform: All samples of that substance will have the same intrinsic properties.
- A mixture is any material that does not meet the requirement of a pure substance.
  - Different samples of a specific mixture will have different constituents.
  - A mixture can be separated into its constituent substances without the need for a chemical reaction. Example: table salt dissolved in water (salt and water are both pure; the mixture can be separated by evaporation of water which is not a chemical reaction).
  - We get homogeneous mixtures, heterogeneous mixtures and colloidal mixtures:
    - Homogeneous mixture: the composition appears uniform to the naked eye. Examples: seawater and air.
    - Heterogeneous mixture: the composition does not appear uniform and samples of the same mixture will contain visibly different constituents, e.g. granite (rock of lava origin), fog.
    - Colloidal mixture: this is obtained when molecule sizes increase or when clumps of molecules (micelles) occur to form colloids that are only visible using an electron microscope. Colloids do not dissolve in water and form a heterogeneous mixture called a suspension. Examples: protoplasm in living cells, clay minerals in soil.

Changes in matter and the role of energy are fundamental in chemistry.

- A chemical change in matter involves the disappearance of one or more substances, and the appearance of one or more new substances, each with its own intrinsic properties.
- Chemical changes are usually accompanied by either the release or the absorption of energy.
- Plants use their leaves to capture the energy of the sun (contained in light particles or photons) in a process called photosynthesis.
  - They use this energy to break up carbon dioxide and water that are rearranged to produce carbohydrates → Plants utilise energy stored in carbohydrates through the process of cellular respiration.
- The study of energy changes associated with chemical changes in living organisms is known as biochemistry.
- The Law of Conservation of Energy: energy may be changed from one form to another, but it cannot be created or destroyed.
  - Kinetic energy (KE): the energy that matter contains when it is in motion → $KE = 0{,}5mv^2$ where m is the mass and v is the velocity of the matter.
  - Chemical energy: the energy released when coal, which consists of mostly carbonised plant matter, is burned.
  - Heat energy: all other forms of energy can be readily converted to heat energy; it is indicated by temperature.

1.2 The atom

The atom is the smallest particle of which matter is composed and the nature of the atom directs the behaviour of matter.

- The word atom originates from a Greek word meaning indivisible.
- Early scholars supported the atomic theory of matter which stated that matter was made up of tiny, indivisible particles which combined to give its characteristic properties.
- Dalton's Atomic Theory modified the former theory in the early 19th century:
  - Idea 1: Elements are composed of extremely small, indivisible particles called atoms. Atoms retain their identity through all chemical reactions.
  - Idea 2: Atoms of a particular element have the same average mass, and their other properties are also the same. Atoms of different elements generally have different average masses and different properties.
  - Idea 3: Compounds are formed by combinations of the atoms of different elements.
  - Idea 4: Atoms of two or more elements may combine in more than one ratio to form more than one compound.
- The four ideas contained in Dalton's Atomic Theory supports the three fundamental laws of Chemistry:
  - The Law of Conservation of Mass
  - The Law of Constant Composition
  - The Law of Multiple Proportions.
- The mass of an atom is usually referred to as its atomic weight.
  - Relative weights are used; all weights are expressed relative to the stable form of carbon, 12C, which has an assigned atomic weight of 12.

1.3 Molecules

- Molecules and compounds are formed by the chemical reaction or bonding of atoms.
- Their atomic weight is a function of the atomic weight of their constituent atoms. Example: H_2O has a molecular weight of 18,016 ($2 \times 1{,}008 + 16$).

1.4 The periodic table of elements

The periodic table displays 118 known chemical elements according to selected properties of their atomic structures. (See the next page for an example of a periodic table.

- Elements are in rows in order of their atomic number.
- Elements with similar atomic structure and hence similar chemical properties are arranged in vertical columns called groups.

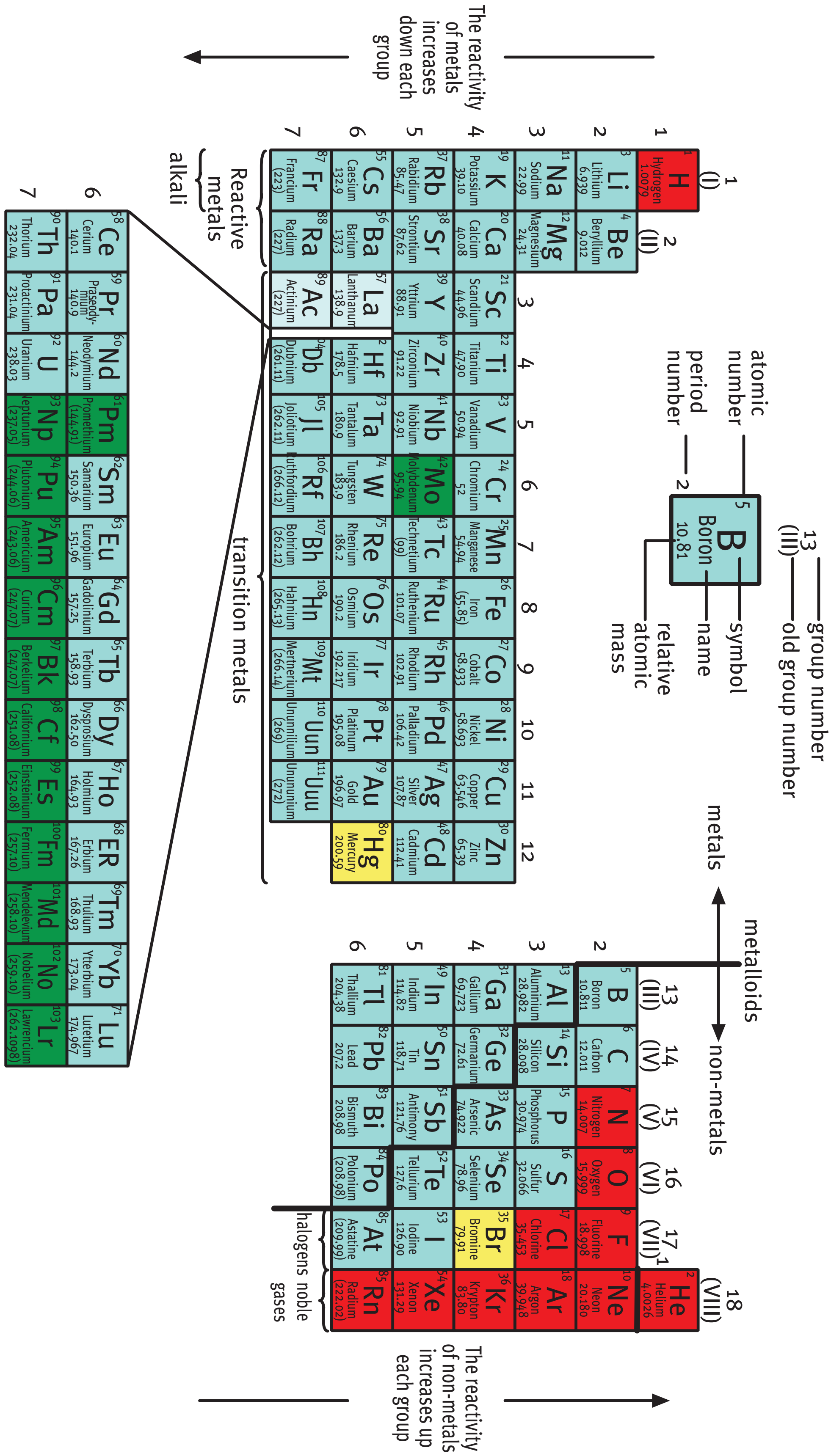


FIGURE 1 The periodic table of elements

1.5 Isotopes

- Isotopes are atoms of the same element with different atomic weights. Example: chlorine has an average atomic weight of 35,453 but occurs in nature as a mixture of isotopes with weights of 34,969 (75,53%) and 36,966 (24,47%)
- They have different physical properties but the same chemical properties.

2 Interpreting the periodic table

The periodic table arranges elements into groups according to their chemical and physical properties. Thus chemists can predict the nature of their reactions with one another and use various chemical methods to build molecules from them.

- The subscript before the symbol for each element (e.g. 12C) indicates the atomic number.
- The atomic number indicates the number of protons in the nucleus. The atomic number is equal to the number of electrons in the electron cloud of one atom of the element.
- Special names are given to certain groups of elements (arranged in columns) that have similar properties:
  - Groups I to III can be classified as metals.
  - Group I elements are called alkali metals, e.g. lithium (Li), sodium (Na).
  - Group II elements are called alkaline-earth metals, e.g. beryllium (Be), magnesium (Mg).
  - Groups IV to VII can be classified as non-metals.
  - Group VII elements are all halogens, e.g. fluorine (F), chlorine (Cl).
  - Group 0 elements are known as noble gases, e.g. helium (He), neon (Ne).

3 General structure of the atom, atom particles and their charges

The atom has a small, positively charged core called the nucleus. The atom is electrically neutral and consists of:

- electrons – negatively charged particles → contained in a large outer volume called an electron cloud → surrounds the core of the atom → weighs 1,840 times less than a proton or neutron
- protons – positively charged particles → concentrated in a small inner volume → contain most of the mass of the atom
- neutrons – electrically neutral → occur in the nucleus → mass nearly equal to that of protons.

4 Relationship between atomic numbers and number of particles in the nucleus

The symbol for an element can be preceded by a:

- subscript – indicates the atomic number; this is also the number of protons and the number of electrons in one atom (these are always equal in number)
- superscript – indicates the atomic weight.
  - Example: $^{16}_{8}O$: Oxygen has an atomic number of 8 and an atomic weight of 16 (mass of 8 protons + mass of 8 neutrons; 8 electrons have negligible mass)
  - Example: $^{56}_{26}Fe$: Iron has an atomic number of 26 and an atomic weight of 56 (mass of 26 protons + mass of 30 neutrons; 26 electrons have negligible mass). The number of neutrons is not the same as the number of protons and electrons and thus the atomic weight is not double the atomic number.

5 Formation of ions

- Atoms can either lose or gain one or more electrons to form an ion.
  - cation = positively charged ion resulting from the loss of an electron
  - anion = negatively charged ion resulting from the gain of an electron.
- The charge on an ion is shown by a superscript after the symbol, e.g. K^+ ($^+$ means +1).
  - ions with opposite charges are attracted to one another
  - ions with the same charge are repelled
  - if the charge of the atoms add up to zero then the molecule is neutral.

6 Arrangement of electrons around the nucleus and valency

Valence electrons

- are the outermost electrons around an atom
- are the most likely to be involved in chemical reactions
- help to explain the combining power or valency of atoms.

An element usually has the same number of valence electrons as its group number.

- Na is in Group I and has a single valence electron → upon ionisation it loses one electron to form the cation, Na+
- Noble gases in Group 0 do not react readily react with other elements and have 8 valence electrons, except for helium (He) which has a valence number of 2.
- Some elements have a fixed valence, e.g. sodium (Na) and potassium (K) always have a valence of 1 when they take part in chemical reactions.
- Many elements have a variable valence, e.g. iron (Fe) can have a valence of 2 (as in $FeCl_2$) or 3 (as in $FeCl_3$).

7 Differences between acids and bases

The definition of acids and bases is as follows:

- An acid is a substance that can donate a hydrogen ion or proton (H^+).
- A base is a substance that can accept a hydrogen ion, or yield a hydroxyl ion (OH^-) when dissolved in water.
- Examples:
  - $HCl \rightarrow H^+ + Cl^-$ (HCl is the acid which donates H^+).
  - $HCl + H_2O \rightarrow H_3O^+ + Cl^-$ (reactions usually occur in water; H_2O is the base which accepts H+).
  - $NaOH \rightarrow Na^+ + OH^-$ (NaOH is the base which yields OH^-).

The pH of a solution indicates the concentration of H+ ions and it can range from 0 to 14.

- It is defined by $pH = -\log[H^+]$.
  - If $[H^+] > [OH^-]$ then the pH is high and the solution is acidic (i.e. $pH < 7$).
  - If $[OH^-] > [H^+]$ then the pH is low and the solution is basic or alkaline (i.e. $pH > 7$).
  - If $[H^+] = [OH^-]$ then the pH is 7 and the solution is neutral (e.g. water).

Unit 2

Chemical bonding

1 Basic chemical bonding to form a molecule

There are two main ways in which electrons can interact in a chemical reaction:

- ionic bonding – electrons are transferred from one atom to another
- covalent bonding – electrons are shared between atoms.

Two other types of bonding are also important in the formation of compounds:

- hydrogen bonding – a strong, electrostatic attraction between a hydrogen atom and an electronegative atom, e.g. nitrogen, oxygen, fluorine
- Van der Waals attractions – an attractive force between molecules.

The outermost electrons in the electron cloud of atoms take part in chemical reactions to form chemical bonds. The number of valence electrons in an atom determines the ratio in which atoms enter into combinations with each other.

- These valence electrons are spread in shells around the nucleus of an atom.
- Moving outwards from the nucleus, each shell represents a higher level of energy of the electron found in that shell.
  - The electrons usually fill the lowest shell or energy level first.
- Chemical bonds form when two or more atoms interact to fill their outer shells with electrons. This happens as follows:
  - As the atoms approach each other, each nucleus begins to attract the electron held by the other nucleus.
  - Eventually, the electron clouds overlap and fuse into one molecular orbital.
- Like an atomic orbital, a molecular orbital is most stable when filled by a pair of electrons.
  - This shared orbital acts as a chemical bond between the two atoms.
  - The number of electrons needed to fill each shell differs from shell to shell.

1.1 Chemical formulas and formula weight

The atomic weight of the elements in a compound can be used together with its chemical formula to calculate the formula weight of the compound.

- Chemical formula = combination of the symbols for atoms that make up a compound.
- The symbol for each element represents one mole of atoms of that element.
- The term mole is used as a unit for the amount of a substance.
- Avogadro's number is $6{,}02 \times 10^{23}$ and represents the number of atoms in exactly 12 g of the element carbon, which has an atomic weight of exactly 12.
  - Thus $6{,}02 \times 10^{23}$ elementary particles (of anything) is equal to 1 mole (of that thing).

- Examples:
  - 1 mole of hydrogen contains $6{,}02 \times 10^{23}$ atoms and weighs 1,008 g
  - 1 mole of KCl contains $6{,}02 \times 10^{23}$ ions of K^+, $6{,}02 \times 10^{23}$ ions of Cl^- and weighs 74,55 g (39,10 g K + 35,45 g Cl)
  - The formula weight (or molecular weight) of Na_3PO_4 is:

3Na	=	$3 \times 22{,}99$	=	68,97 g
PO_4	=	30,97 + 4(16,00)	=	94,97 g
			=	163,9 g

1.2 Oxidation number and chemical bonding

An element's oxidation number, sometimes called valence, is the number of electrons gained or lost when forming compounds. The concepts may be defined as follows:

- Oxidation: the loss of electrons (usually from left to right in a chemical reaction).
- Reduction: the gain of electrons (usually from right to left in a chemical reaction).
- Oxidation number: the charge of an atom if the compound was composed of ions only.
  - Example: $Cu^{+1} \leftrightarrow Cu^{+2} + e^-$
    - Cu^{+1} loses one electron and is oxidised to Cu^{+2}
    - Cu^{+2} gains one electron and is reduced to Cu^{+1}
    - Cu^{+1} has an oxidation number of +1 and Cu^{+2} has an oxidation number of +2.
  - Example: $CaCO_3$
    - $CaCO_3$ contains Ca^{+2} and CO_3^{-2} ions
    - Since calcium exists as Ca^{+2} in its ionic state, it has an oxidation number of +2.

2 Ionic bonding

Example: Potassium bromide (KBr) contains an ionic bond.

- Potassium (K) is in Group I and has one valence electron → upon ionisation it can donate one electron and form the cation, K^+.
- Bromine (Br) is in Group VII and has seven valence electrons → upon ionisation it can receive one electron to form the anion, Br^-.
- K donates one electron to Br, and Br receives one electron from K (i.e. transfer of an electron from K to Br), thus forming an ionic bond.
  - The strong electrostatic attraction between oppositely charged ions forms a stable bond.

3 Covalent bonding

Electrons are shared in a covalent bond and this can occur between:

- atoms of identical elements, e.g. Cl_2
- atoms of different elements, e.g. H_2O.

- Hydrogen (H) is in Group I and has one valence electron.
- Oxygen (O) is in Group VI and has six electrons of which two are valence electrons available for bonding.
  - Oxygen shares each of its two electrons with one hydrogen atom resulting in the formation of two covalent bonds.

3.1 Polarity

When two atoms of different elements form a bond, one atom will have a stronger attracting power or electronegativity.

- The shared electron cloud will be closer to the more electronegative element.
  Example:
  - In a H_2O molecule, oxygen is more electronegative than hydrogen.
    - Thus, O obtains a partial negative charge and the water molecule has a negative pole, whereas H obtains a partial positive charge and represents two positive poles.
    - → The water molecule is called polar.
- Only covalent molecules can possess this polarity.

3.2 Hydrogen bonding

This is a very strong type of electrostatic interaction between two water molecules.

- The negative pole (that is, oxygen) and the positive pole (that is, hydrogen) of adjacent water molecules are attracted to one another.
  - This linkage is called a hydrogen bond.
  - It gives water many unique properties including its ability to aggregate together and form a body of water, as well as:
    - flexibility and flow characteristic
    - unexpectedly high boiling or vaporisation point
    - greater density than ice
    - ability to act as a solvent for a wide range of substances
    - capacity to absorb high levels of heat energy before its temperature is raised
    - high surface tension.

3.3 Van der Waals inter-molecular attraction

This is a collective name for the weak attractive forces that hold molecules together.

- They occur between molecules.
- They are much weaker than ionic and covalent bonds.
- Hydrogen bonding is the strongest type of van der Waals interaction.

Unit 3

Inorganic and organic compounds

- All green plants use simple inorganic compounds (nutrients) to form complex organic compounds.
  - Example of nutrients:
    - carbon dioxide (CO_2), nitrate (NO^{3-}), sulphate (SO^{4-}), and phosphate (PO_4^{-3}).
- Most plant tissue is made up of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S), and phosphorus (P).

1 Difference between inorganic and organic compounds

- Inorganic compounds do not contain carbon and hydrogen atoms in the same molecule.
  - e.g. sodium chloride (salt), ammonium hydroxide (used in household cleaners).
- Organic compounds contain both carbon and hydrogen atoms (called hydrocarbons).
  - e.g. ethane, butane, acetone.

Plants are divided into two groups based on the type of nutrients they require.

- Autotrophic organisms:
  - require only simple, inorganic nutrients to make complex organic compounds
    - e.g. all green plants, certain bacteria.
- Heterotrophic organisms:
  - require small amounts of inorganic nutrients
  - mostly break down complex organic materials in their food to obtain nutrients.
    - e.g. all animals and humans, certain parasitic plants.

1.1 Inorganic compounds serving as nutrients

The environment is made up of three compartments: air, water and soil.

- These can all provide elements that are essential for the growth of plants.
- Thus, essential environmental factors for plant growth are:
  - air, water, light, heat, mechanical support (e.g. soil or other plants) and nutrients.
    - Soil can supply these factors, either completely or in part, except for light.
  - All factors are needed and an imbalance will result in poor plant growth.

Principle of limiting factors:

- The level of plant (crop) production can be no greater than that allowed by the most limiting of the essential plant growth factors.

About 95% of the fresh mass of plant material consists of C, H and O.

- Seventeen elements are essential for normal plant growth.
  - Needed in large amounts:
    - C, O (obtained from air via photosynthesis)
    - H (obtained from water taken up from soil)
    - N, P, K, Ca, Mg, S (available in soil; some nitrogen taken up from air in soil by nitrogen-fixing bacteria on plant roots → called N-fixation)
  - Needed in small amounts:
    - Fe, Mn, B, Mo, Cu, Zn, Cl, Co (available in soil).

Although not essential, plants grow better with:

- soluble forms of sodium (Na)
- silicon (Si)
- iodine (I)
- fluorine (F)
- barium (Ba) and
- strontium (Sr).

2 Formulae, structures and functions of inorganic compounds

Lewis structures may be used to represent the covalent bonding in a molecule or ion.

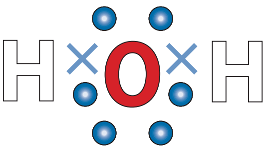
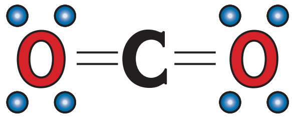
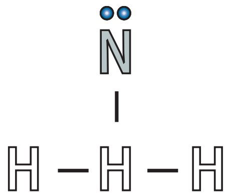
- Bonds between atoms are shown by lines:
  - → two electrons are needed to form a bond.
- Lone pairs of electrons (not involved in bonding) are shown by dots or crosses next to the atoms.

Most elements prefer to be surrounded by 8 electrons (the octet rule) except for hydrogen:

- → has only two electrons.
  - e.g. Hydrogen fluoride (HF)
    - hydrogen (H) has one single electron
    - fluorine (F) has seven electrons: three lone pairs, one single electron
    - H and F use their single electrons to form a bond between the atoms → represented by a line
    - F still has three lone pairs and these are shown as three pairs of dots around F.

2.1 Water (H_2O), carbon dioxide (CO_2) and ammonia (NH_3)

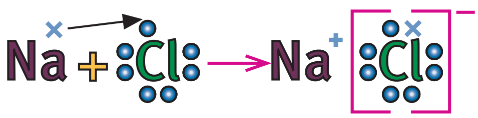
Table 1 Useful information about water, carbon dioxide and ammonia

Water	Carbon dioxide	Ammonia
	Occurrence:	
• Seas, rivers, lakes (liquid); • Atmosphere (as a vapour); • Makes up 80% of living organisms	• Atmosphere (0,03%); • Volcanic gases; • Respiration product of all living things; • Fuel combustion product	• Main source is decomposed animal and plant waste (contains N)
	Structure:	
		
	Properties:	
• No colour, odour or taste; • Density of 1 at 4 °C; • Melting point 0 °C; • Boiling point 100 °C	• Odourless, colourless, non-poisonous gas; • Freezing point -76 °C; • Reacts with water to form carbonic acid	• Gas that condenses at -33 °C; • Highly water soluble
	Importance:	
• Main solvent on Earth and ionisation in water facilitates reactions; • Main source of H, O; • Transport medium in the body; • Regulates Earth's temperature	• Plants use CO_2 and H_2O to build complex organic compounds; • Excreted by animals during respiration	• Plant and animal nutrition; • N source for protein synthesis by bacteria, plants and animals

2.2 Mineral salts

Needed by living organisms for nutrition, usually inorganic (do not contain C).

- Plants obtain from soil and humans from their food.
  - e.g. Sodium chloride or table salt (NaCl)
    - Occurrence: halite (pure rock salt), mixed evaporates in salt lakes, seawater
    - Structure:



    - Properties: clear (when pure), water soluble, slightly soluble in other liquid, odourless, characteristic taste.
    - Importance: maintain salt/water ratio in the body, maintain electrolyte balance of cells, required for hydration of the body.

3 Characteristics of the carbon atom and organic compounds

- Carbon (C) atoms form the backbone of organic compounds.
- They can be linked to another C atom by one (single), two (double) or three (triple) covalent bonds.
- Saturated organic compounds have a maximum number of hydrogen (H) atoms bonded to the C atoms.
- Unsaturated organic compounds contain one or more double or triple bonds in their C skeleton.

3.1 The most important characteristics of carbon

Two important characteristics of carbon allow it to act as the basis for the chemistry of life:
- it has four valence electrons
- forms stable and reactive molecules (because of the energy required to make or break a bond).

3.2 The most important characteristics of organic compounds

The characteristics of organic compounds are similar to that of covalent compounds.
- volatile
- low melting and boiling points
- insoluble in water; soluble in organic solvents
- poor conductors of electricity
- do not provide ions
- take part in molecular reactions.

Usually the reactions of organic compounds are slow, never proceed to completion and produce low yields.

4 Important groups of organic compounds

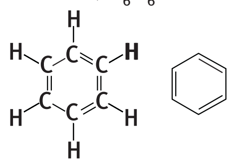
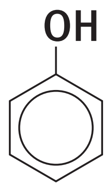
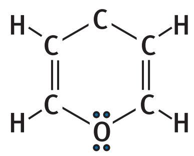
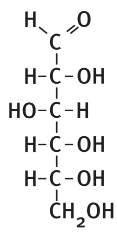
Carbon combines with four other simple inorganic elements to make up most of the organic tissue components of all living organisms:
- proteins
- carbohydrates
- lipids
- nucleic acids.

Table 2 Basic groupings of organic compounds		
Organic compound	**Elements contained in compound**	**Functions**
Proteins	C, H, O, N, S, P	• biological catalysts • form structural parts of organisms • participate in cell signalling and recognition • act as molecules of immunity
Carbohydrates	C, H, O	• major food and energy source • carbohydrate polymers are: long-term food storage molecules, protective coverings for cells and organisms, main structural support for land plants, cell constituents
Lipids	C, H, O, N, S, P	• major cell membrane constituents • food storage molecules • e.g. fats, oils, waxes
Nucleic acids	C, H, O, N, P	• storage of organism's heritable information and its conversion into proteins • e.g. deoxyribonucleic acid (DNA), ribonucleic acid (RNA) – two major classes

4.1 Examples of organic compounds

Table 3 Summary of different organic compounds (R is any radical or hydrocarbon)			
Compound	**Basic structure**	**Example**	**How it is formed**
Alkanes	Saturated hydrocarbon, only single bonds	Methane CH_4	
Alcohols	R–OH (OH: hydroxyl group)	Methanol CH_3–OH	Formed from alkane
Thiols	R–SH	CH_3–SH	Readily oxidise to form disulphide bridge: RS–SR´
Ethers	R–O–R	Dimethyl ether CH_3–O–CH_3	
Aldehydes	R–CO–H (C=O double bond)	Acetaldehyde CH_3–CO–H	Oxidation of alcohol
Ketones	R–CO–R´ (C=O double bond)	Dimethyl ketone CH_3–CO–CH_3	
Acids	R–CO–OH (C=O double bond; COOH: carboxyl group)	Acetic acid CH_3–CO–OH	Oxidation of aldehyde
Salts	–COO(X^+) (X: element that can form cation)	Sodium acetate CH_3–CO–ONa	H of carboxyl group replaced with a cation
Esters	R–CO–OR´	Ethyl acetate CH_3–CO–OCH_3	Reaction of acid and alcohol

Table 3 Summary of different organic compounds (R is any radical or hydrocarbon)

Compound	Basic structure	Example	How it is formed
Amines	R–NH_2	Methyl amine CH_3–NH_2	H of alkane replaced with NH_2 group
Amides	R–CO–ONH_2	Acetamide CH_3–CO–ONH_2	OH of acid replaced with NH_2 group
Cyclic	Contain one or more ring structures	Benzene, C_6H_6 	
Phenols	One or more OH groups on benzene ring	Phenol, C_6H_5OH 	
Heterocycles	Ring structure containing one or more N or O atoms	Pyran, C_5H_5O 	
Sugars	Simple: less than five C, no ring; Complex: six C, ring structure	Glucose 	

Unit 4

Alkanes and alcohols

1 Alkanes

Alkanes are organic compounds that consist of hydrocarbon chains that are fully saturated. The four simplest examples are:

- methane (one carbon)
- ethane (two carbons)
- propane (three carbons)
- butane (four carbons).

1.1 Basic types of alkanes and their chemical and structural formulae

1.1.1 Methane

- Principal component of natural gas:
  - = most abundant compound on Earth.
- Formed through an anaerobic (i.e. involving oxygen), multi-step respiration process called methanogenesis:
  - = $CO_2 + 8H^+ + 8\,e^- \rightarrow CH_4 + 2H_2O$ (net reaction).
- Produced by microbes in oxygen-starved environments
  - e.g. such as swamps, landfills.
- Also produced by the gut of ruminants
  - e.g. cattle.
- Important biogas produced on industrial scale through the fermentation of organic material.
  - Farmers use methane gas produced by decomposing faeces and plant matter to provide the energy for their farms.
- Chemical formula: CH_4.
- Structural formula:

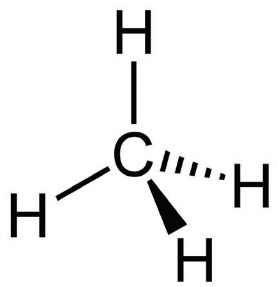


FIGURE 2 Structural formula of methane

1.1.2 Ethane

- Colourless and odourless at standard (room) temperature and pressure.
- Second-largest component of natural gas.
- Chemical formula: C_2H_6 or $CH_3–CH_3$.
- Structural formula:

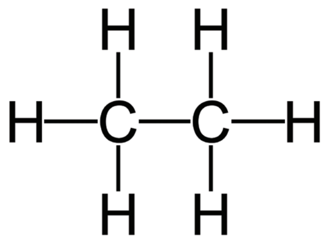


FIGURE 3 Structural formula of ethane

1.1.3 Propane

- Normally found in gas form, but compressible to a transportable liquid.
- By-product of natural gas processing and petroleum refining
- Chemical formula: C_3H_8 or $CH_3–CH_2–CH_3$.
- Structural formula:

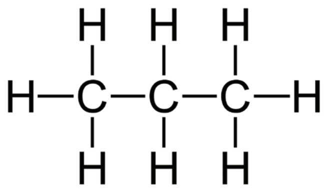


FIGURE 4 Structural formula of propane

1.1.4 Butane

- Highly flammable, colourless and easily liquefied.
- Chemical formula: C_4H_{10} or $CH_3–CH_2–CH_2–CH_3$ or $CH_3(CH_2)_2CH_3$.
- Structural formula:

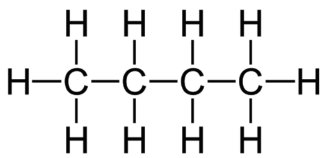


FIGURE 5 Structural formula of butane

Chemical properties of alkanes

- Inert at room temperature, but burn in air at higher temperatures.
- Gradually move from gaseous form to solids as the length of the carbon chain increases.
- React with most halogens in the presence of sunlight.

1.2 Importance of alkanes in plant and animal metabolism

- Basic building block for many compounds occurring in plants and animals.
- Play a role in the biology of the three eukaryotic groups of organisms: fungi, plants and animals. For example:
  - some yeasts use alkanes as a source of carbon and/or energy.
- Long-chain alkanes form a protective wax layer over plants; protects against water loss and bacteria, fungi and harmful insects.

1.3 Isomers

Isomers are compounds with the same molecular formula, but a different structural formula.

- Simplest isomer exists as a single chain and is called the n-isomer.
- Only alkanes with more than three carbons can exist as isomers. Example:
  - C_4H_{10} can exist as n-butane (four carbons arranged linearly) and isobutene (central carbon is bonded to three carbons).

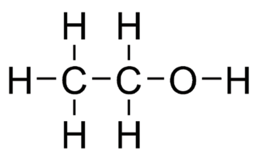
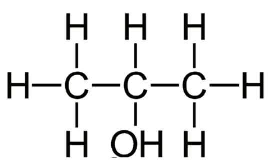
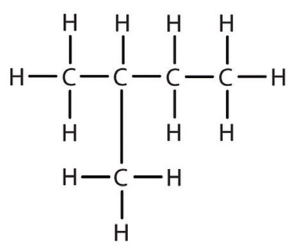
2 Alcohols

Alcohols are hydroxyl derivatives of alkanes and they are named after the alkanes from which they are derived. They have a hydroxyl group (OH) in the place of a single hydrogen (H) atom in the corresponding alkane.

2.1 Basic types of alcohols and their structures

There are three types of alcohols and they differ according to the position of the OH group.

Table 4 Basic alcohols and their structures

Type	Primary alcohol	Secondary alcohol	Tertiary alcohol
Position of OH group	attached to the terminal C; exception: methanol	attached to a C atom linked to two other C	attached to a C atom linked to three other C
Examples	ethanol	isopropanol	isopentanol
Structural formula			

2.2 Importance of basic alcohols

- Alcoholic beverage industry: fermentation of sugars to ethanol is used in the production of wine and other alcoholic beverages.
    - The same process occurs in plants in the absence of oxygen (anaerobic conditions) and results in a build-up of ethanol and subsequent tissue damage.
- Ethanol is an important, renewable source of energy.
    - The energy contained in ethanol originates from sugars stored in plants following photosynthesis.
    - The release of this energy is used as fuel to provide cooling, heating, lighting, movement and sound.
- Industrial applications: fermentation is performed by organisms (e.g. yeasts) that produce the enzyme pyruvic decarboxylase.

Unit 5

Fatty acids and bio-molecules

1 Fatty acids

Fatty acids may be thought of as long-chain carboxylic acids. They are attached to the glycerol backbone of lipid molecules.

1.1 Chemical structure of a fatty acid

- General chemical formula: R-COOH.
  - a carboxyl functional group (COOH) is attached to the terminal carbon atom
  - R is a long, unbranched fatty hydrocarbon chain consisting of 12–24 carbon atoms.

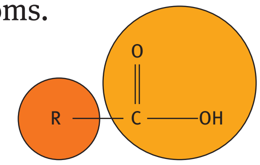


FIGURE 6 The general chemical structure of a fatty acid

1.2 Differences between saturated and unsaturated fatty acids

The hydrocarbon tail of fatty acids can either be saturated or unsaturated.

1.2.1 Saturated fatty acids

- No double bonds between carbon atoms of the fatty acid chain.
- Normally solid at room temperature.
- Mostly of animal origin.
- Foods containing a high proportion of saturated fat:
  - animal fats, e.g. cheese, fatty meats
  - vegetable products, e.g. coconut oil, chocolate.
- Examples of saturated fatty acids:
  - butyric acid = $CH_3(CH_2)_2COOH$
  - lauric acid = $CH_3(CH_2)_{10}COOH$

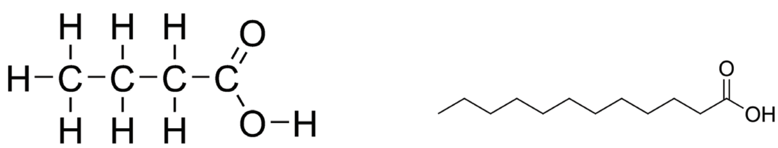


FIGURE 7 The structural formula of two saturated fatty acids: butyric acid (left); lauric acid (right)

- Saturated fatty acids play a vital role in nutrition and bodily functions, but they should be consumed in moderation.

- Their importance is shown by the following:
  - provide the appropriate stiffness and structure to our cell membranes and tissues
  - strengthen the immune system
  - involved in inter-cellular communication (e.g. protect against cancer)
  - involved in the function of cell membrane receptors (e.g. protect against diabetes)
  - lung and kidney function, hormone production
  - suppress inflammation
  - saturated animal fats carry fat-soluble vitamins A, D and K_2 which promote good health.

1.2.2 Unsaturated fatty acids

- One to three double bonds between carbon atoms of the fatty acid chain.
- Monounsaturated:
  - one double bond.
- Polyunsaturated:
  - more than one double bond.
- One to eight carbons:
  - occur in liquid form.
- More that eight carbons:
  - occur as solids.
- Properties relevant to saturated fatty acids:
- lower melting points (melting point decreases as number of double bonds increases)
- contain less energy, i.e. fewer calories
- more vulnerable to lipid peroxidation.
- Foods containing unsaturated fatty acids: avocado, nuts, and vegetable oils, meat products (together with saturated fats).

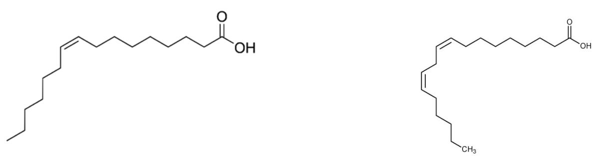


FIGURE 8 The structural formulae of a monounsaturated (left) and polyunsaturated (right) fatty acid.

- Left: Palmitoleic acid (16 carbons), $CH_3(CH_2)_5CH{=}CH(CH_2)_7COOH$,
- Right: Linoleic acid (18 carbons), $CH_3(CH_2)_4CH{=}CHCH_2CH{=}CH(CH_2)_7COOH$

Double bonds may be in either a cis or a trans conformation.

- *cis* isomer:
  - occurs when hydrogen atoms are on the same side of the double bond
  - is less flexible as the number of double bonds in the chain increases.
    - e.g. oleic acid (18 carbons), $CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$ (the most abundant fatty acid found in nature).

- *trans* isomer:
  - occurs when hydrogen atoms are on the opposite side of the double bond
  - do not cause the chain to bend much; sometimes known as trans fatty acids.
    - e.g. vaccenic acid (18 carbons), $CH_3(CH_2)_5CH=CH(CH_2)_9COOH$.

Double bonds introduce 'kinks' in the carbon chain resulting in the fluid nature of lipid membranes.

FIGURE 9 The structural formula of a cis-unsaturated fatty acid (oleic acid, left) and trans-unsaturated fatty acid (vaccenic acid, right)

In Figure 8 above, all three double bonds are in the cis conformation.

Importance of polyunsaturated fatty acids

- Contained in high amounts in membranes of animal and plant cells.
- Found in fish and a range of nuts and provide nutritional benefits, e.g. lower risk of heart attack and some cancers.

1.3 Classification of fatty acids

Fatty acids can be classified according to two factors:

- Nature of the bonds between carbon atoms of the fatty acid chain:
  - single bonds only: saturated fatty acid
  - one double bond: unsaturated fatty acid
  - multiple double bonds: polyunsaturated fatty acid.
- Number of carboxyl groups (-COOH): mono-, di- or tricarboxylic acids.

2 Lipids

Lipids are a naturally occurring group of molecules that includes:

- fats, oils and waxes
- sterols (e.g. cholesterol)
- fat-soluble vitamins (e.g. vitamins A, D, E, and K).

They are defined according to their solubility, i.e. they are all soluble in non-polar organic solvents, and not according to a physical property. The solubility of lipids is due to the presence of a large hydrocarbon portion in their structure.

2.1 Basic composition of lipids

The general structure for fats, oils and waxes is shown in the figure below. They all contain three ester functional groups (i.e. –O–CO–R). These three ester functional groups are attached to a glycerol backbone.

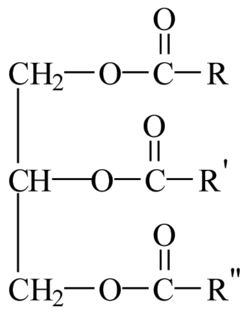


FIGURE 10 Basic structure of fats, oil and waxes

An important group of lipids is the phospholipids. Their structure is similar to the general structure of fats, waxes and oils except that a phosphate molecule is attached through an ester bond with the terminal carbon atom of the glycerol backbone.

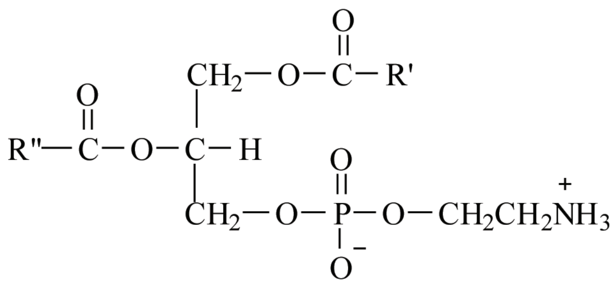


FIGURE 11 An example of a phospholipid

Phospholipids have a strong polar character due to the nature of their two ends:

- strongly hydrophilic phosphate molecule
- strongly lipophilic (or hydrophobic) fatty acids.

This makes them important components of membrane structures since they are held together by hydrophobic and polar interactions only.

2.2 Differences between fats and oils, and saturated and unsaturated fats

The distinction between fats and oils is based on the nature of the fatty acids from which they were derived, i.e. whether the fatty acids are saturated or unsaturated:

- saturated fatty acids produce unsaturated fats
- unsaturated fatty acids produce unsaturated fats or oils.
- polyunsaturated fatty acids produce polyunsaturated fats or oils.

They also differ in their phase at room temperature:

- Fats tend to be solid at room temperature.
- Oils tend to be liquids at room temperature.
  - This is influenced by:
    - size and molecular weight
    - kink caused by a *cis* double bond which prevents the orderly arrangement of molecules required by the solid phase.

2.3 Main functions of lipids

- Energy storage
  - primary means of storing energy
  - rapidly broken down to CO_2 and H_2O with the release of high amounts of energy.
- Waterproof coverings
  - this is achieved by waxes and oils in various species
  - plants have coatings on their leaves
  - mammals have oils found on skin, hair and nails.
- Cell membranes
  - membranes are composed mainly of lipids
    - allow for fluid movement and transport of molecules in and out of cells.
- Protection
  - excess lipids are stored as fats
  - act as insulators of internal organs.
- Hormones
  - some lipids function as hormones
  - they regulate stress responses, sugar levels, and sex cell production
- Absorbing vitamins
  - lipids carry vitamins out of the intestines and store them in fatty tissues, e.g.
    - vitamins A, D, E and K.

Unit 6

Proteins

1 General structure of the monomers of proteins

Proteins are polymers that are formed through the combination of amino acid molecules. Proteins are composed of a single, unbranched chain of amino acid monomers.

- Amino acids:
  - general formula $H_2NCHRCOOH$
  - made up of carbon, hydrogen, oxygen and nitrogen atoms
  - R is an organic substituent (or side-chain)
    - there are 20 possible side-chains
    - functions: allow ligand binding and protein folding, provide catalytic activity, stabilise final conformation.
  - central carbon to which R group is attached is called the alpha (α) carbon:
    - α-carbon is called chiral and has an L-configuration
    - examples: glycine, R=H; alanine, R=CH_3.

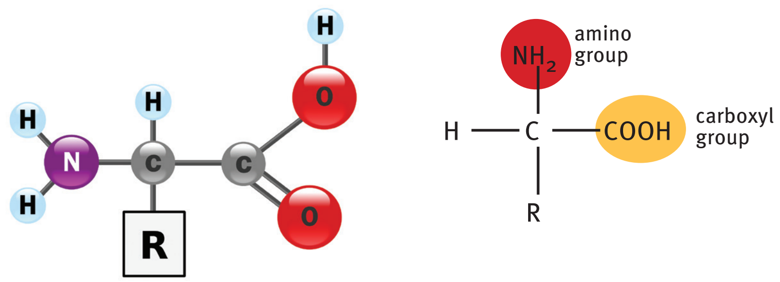


FIGURE 12 General structure (left) and formula (right) of an amino acid

1.1 Essential and non-essential amino acids

Plants are able to make all the amino acids but humans do not have all the enzymes required for the biosynthesis of the 10 essential and 10 non-essential amino acids.

Table 5 Essential and non-essential amino acids

Essential amino acids	Non-essential amino acids
• cannot be synthesised by the organism (usually humans); • must be supplied in the diet daily (typically from meat and dairy products); • obtained from degradation of proteins if they are lacking	• synthesised by the body from essential amino acids
arginine (not for adults), histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine	alanine, asparagine, aspartic acid, cysteine, glutamic acid, glutamine, glycine, proline, serine, tyrosine

2 Differences between simple and complex proteins

Amino acids are linked together by peptide bonds and they may also be cross-linked between chains by sulphydryl bonds, hydrogen bonds and Van der Waals forces.

Table 6 Simple and complex proteins

	Simple proteins	**Complex proteins**
Definition	only contain amino acids	contain amino acids and other substances; or function with other chemical groups attached by covalent bonds or by weak interactions
Hydrolysis products	amino acids and occasional small carbo-hydrates	amino acids and other chemical compo-nents
Examples	albumins, globulins	lipoproteins, glycoproteins

3 General structure of polypeptides or simple proteins

Proteins are made up of amino acids covalently linked by peptide bonds.

- Peptides = short chain polymers (< 30 amino acids).
- Polypeptides or proteins = longer chain polymers.

Peptide bond formation:

- occurs between COOH of one amino acid and NH_2 of an adjacent amino acid
- occurs in a condensation reaction during which a water molecule is lost.

3.1 The structural levels of polypeptides or simple proteins

- Primary structure:
  - the amino acid sequence of the protein, i.e. the nature of the amino acids and the order in which they are bonded.
- Secondary structure:
  - local structural arrangement stabilized by hydrogen bonds
    - e.g. alpha helix (coiled or spiral appearance), beta sheet (twisted strand).
- Tertiary structure:
  - overall shape of protein and the spatial relationship between secondary structures
  - stabilised by interactions between side-chains, e.g. Van der Waals bonds, hydrogen bonds, covalent bonds.
- Quaternary structure:
  - formed by several protein molecules which function as a single protein complex
  - structures held together by
    - hydrogen bonds
    - disulphide bonds
    - polar and
    - non-polar bonds.

4 The synthesis and hydrolysis of proteins

4.1 The synthesis of proteins

Proteins can be built up from amino acids with a particular primary, secondary, tertiary and even quaternary structure to serve particular functions.

- Proteins are polymers that are formed through the combination of amino acid molecules or monomers.
  - The amino acid monomers – using dehydration synthesis – bond together to form proteins (or polypeptide chains).
  - Dehydration synthesis is a condensation reaction because water is removed in the formation of the bonds.
  - The condensation reaction occurs between the acid carboxyl group (–COOH) and the amino (–NH_2) group.
  - The bonds that are formed in dehydration synthesis are called peptide bonds.
  - A chain of more than three amino acids held together by peptide bonds is called a polymer or a polypeptides chain.

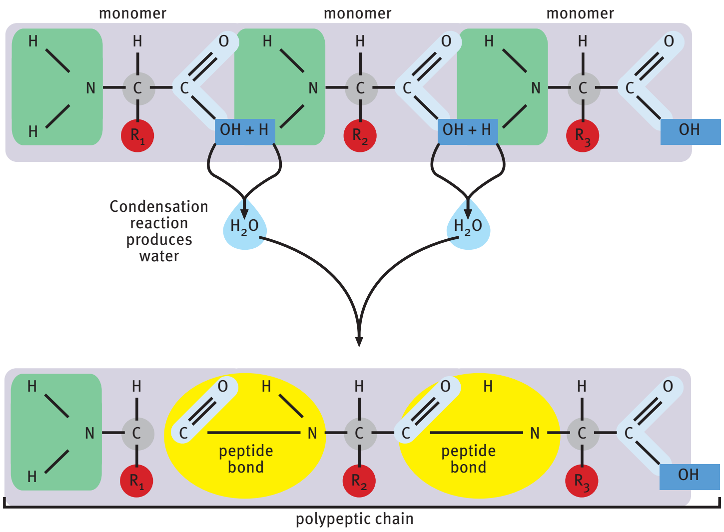


FIGURE 13 Synthesis of a protein polymer by condensation

4.2 The hydrolysis of proteins

- Involves breaking of a peptide bond in a protein.
  - reverse process of protein synthesis
  - requires water, i.e. dipeptide + water → amino acid + amino acid.

4.2.1 Protein breakdown in organisms

In animals, proteins are obtained mainly in food.

- Stomach: gastric juices contain hydrochloric acid and pepsin, an enzyme that breaks down proteins.

- Small intestine: other enzymes (trypsin and chymotrypsin) break down proteins further.
  - once completely digested, proteins / amino acids are absorbed
  - energy is released and waste products are produced (urea in humans and animals, uric acid in birds and land reptiles, CO_2 and water in plants).

5 The functions and importance of proteins in living organisms

Proteins may be grouped according to their main functions. This function is influenced by the structure of the protein.

Table 7 Function and importance of proteins

Protein	Function	Example
Antibodies	defend the body from antigens (foreign invaders) by immobilising them so that they can be destroyed by white blood cells	immunoglobulin = a large Y-shaped protein produced by B-cells that is used by the immune system to identify and neutralise foreign objects such as bacteria and viruses
Contractile proteins	responsible for movement	actin = muscle contraction and movement
Enzymes	facilitate/ speed up biochemical reactions	pepsin digestive enzyme = breaks down proteins in food in the stomach
Hormonal proteins	messenger proteins that help co-ordinate bodily activities	somatotropin = growth hormone that stimulates protein production in muscle cells
Structural proteins	maintain the structures of certain biological components, such as cells and tissues	collagen = support connective tissues like tendons and ligaments
Storage proteins	contain energy which can be released during metabolic processes	ovalbumin = found in egg whites
Transport proteins	carrier proteins that move molecules from one place to another around the body	haemoglobin = transports oxygen in blood

Unit 7

Carbohydrates

1 Composition and formation of carbohydrates

Carbohydrates are energy-rich organic compounds.

- Living organisms use a process called respiration to convert carbohydrates to energy, water and carbon dioxide.
  - Examples: sugars, starches, cellulose
- Composed of carbon (C), hydrogen (H) and oxygen (O) atoms.
  - atoms occur in a set proportion = one C atom, to two H atoms, to one O atom

2 General formulae of carbohydrates

- General formula: $C_x(H_2O)_x$
- Basic building blocks:
  - Monosaccharides or simple sugars (names end in -ose).
  - Disaccharides:
    - composed of two monosaccharides joined by a glycosidic bond
    - formed in a condensation (or dehydration) reaction in which water is released:
    - $2(C_xH_{2x}O_x) \rightarrow C_{2x}H_{2x-2}O_{2-1} + H_2O$
    - e.g. $2(C_6H_{12}O_6) \rightarrow C_{12}H_{22}O_{11} + H_2O$
  - Polysaccharides:
    - composed of more than two monosaccharides
    - formed in a condensation (or dehydration) reaction
    - monosaccharides first become monomers and then bond with other monomers
- e.g. $C_6H_{12}O6$ (monosaccharide) $\rightarrow$ $C_6H_{10}O_5$ (monomer) $\rightarrow$ $(C_6H_{10}O_5)_n$ (polysaccharide)

3 Structural and chemical formulae of monosaccharides

Monosaccharides are divided into groups depending on their number of carbon atoms.

- Triose: 3 carbons, e.g. glyceraldehyde ($C_3H_6O_3$).
- Tetrose: 4 carbons, e.g. D-erythrose ($C_4H_8O_4$).
- Pentose: 5 carbons, e.g. ribose ($C_5H_{10}O_5$).
- Hexose: 6 carbons, e.g. D-allose ($C_6H_{12}O_6$).

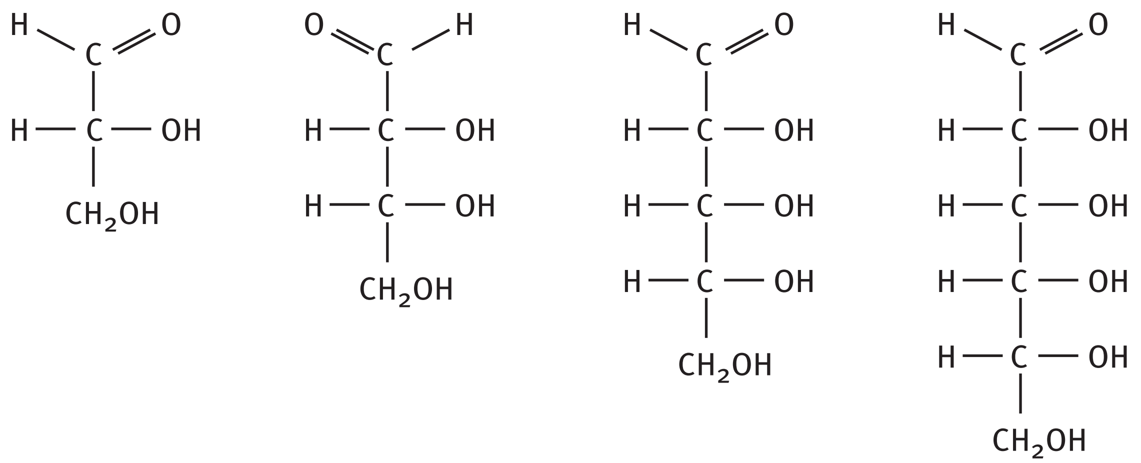


FIGURE 14 Structural formulae of monosaccharides (from left to right): Triose, Tetrose, Pentose and Hexose

4 Main classifications of carbohydrates

- Monosaccharides: simple sugars.
- Oligosaccharides (including disaccharides): short-chain polymers of 2 – 6 monosaccharides.
- Polysaccharides: very long chain polymers of monosaccharides.

Carbohydrates have different properties depending on their classification:

- Monosaccharides, oligosaccharides = crystalline, water soluble, often sweet-tasting
- Polysaccharides = non-crystalline, usually insoluble in water, tasteless

4.1 Monosaccharides

- Simple aldehydes or ketones.
- Molecules prefer to adopt a closed-chain / ring structure.
- Ring forms due to an attraction between the aldehyde / ketone and the alcohol group.
- Three important hexose isomers:
  - glucose, fructose and galactose.

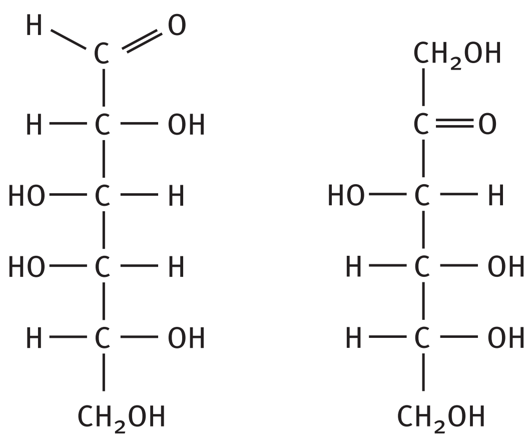


FIGURE 15 Two of the most important hexose isomers (left) galactose and (right) fructose

- Calvin Cycle (or the carbon reduction cycle):
  - sequence of reactions that build the carbon from CO_2 into monosaccharides
    - i.e. $CO_2 \rightarrow$ monosaccharides
    - six CO_2 molecules are required to build one molecule of hexose
    - intermediate products act as building blocks for the synthesis of amino acids, proteins and lipids

4.1.1 Glucose

- Most well-known monosaccharide sugar.
  - chemical formula: $C_6H_{12}O_6$
  - primary source of energy in cells
  - major product of photosynthesis
  - starts cellular respiration
  - exists as two isomers:
    - α-glucose (alpha glucose)
    - β-glucose (beta glucose).

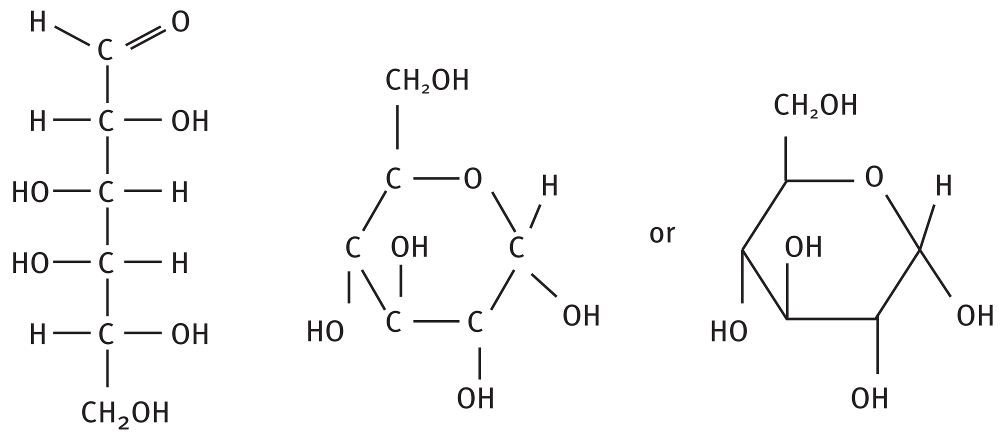


FIGURE 16 The open-chain (left) and closed-chain (right) structures of glucose

4.1.2 Ascorbic acid

- Important glucose derivative: ascorbic acid (or Vitamin C).
  - synthesised in plants and animals but not in primates (humans and apes) and guinea pigs.

4.2 Disaccharides

- Specific enzymes are involved in the linkage of particular monosaccharides to form disaccharides. Examples of disaccharides:
  - glucose + glucose → maltose
  - glucose + galactose → lactose
  - glucose + fructose → sucrose.

4.3 Polysaccharides

- Storage polysaccharides: sources of energy, occur in plants and animals. Examples:
  - starch and glycogen.
- Both consist of very long chains of glucose molecules
  - amylose + amylopectin → starch
    (unbranched glucose chain) (branched chains of glucose)
  - glycogen is similar in structure to amylopectin
- Examples of structural polysaccharides:
  - cellulose in plant cell walls, chitin in insect and fungi skeletons, pectin in fruit.

5 The main functions of carbohydrates in living organisms

Carbohydrates are obtained mainly from diet in animals whereas plants synthesise their own via photosynthesis.

5.1 Carbohydrates in animals

- Primary source of energy:
  - carbohydrates are converted to energy which is used for important cellular functions
  - fats and proteins can be an alternative energy source but toxic ketone bodies can accumulate and lead to ketosis (blood becomes unable to carry oxygen properly).

$$\text{polysaccharides} \xrightarrow{\text{[by enzyme hydrolysis]}} \text{glucose}^* \xrightarrow{\text{[oxidation reaction]}} CO_2 + H_2O + \text{energy}$$

FIGURE 17 Conversion of carbohydrates to energy in animals

* glucose is transported between cells by blood (animals) or cell sap (plants)

- Carbohydrates also:
  - act as storage food, e.g. glycogen is stored in the liver and muscles
  - act as an anticoagulant and prevents intravascular clotting, e.g. heparin
  - act as an antigen and provides blood with immunological properties
  - act as a hormone and helps in reproductive processes, e.g. FSH and LH
  - used in laxatives, e.g. agar
  - provide frictionless movement, e.g. hyaluronic acid found between joints.

5.2 Carbohydrates in plants

- Main structural material for cell walls, e.g. cellulose and lignin.
- Photosynthesis: plants produce their own carbohydrates in the form of glucose.
- Cellular respiration: plants store carbohydrates and burn them for energy.
- Food source: plants produce sugars from sunlight (i.e. by photosynthesis) and make these available to organisms that use plants as their food source.

Topic 1

Topic questions

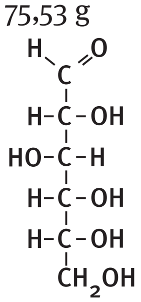
- Answer the questions below.
- Give yourself one hour.
- Check your answers afterwards and do corrections.

1 Define the following terms:
  a molecule
  b isotope
  c valence electron
  d Provide examples for a) and b). (5)

2 Describe the general structure of an atom with special reference to the three components. (6)

3 Complete the following sentences:
  a Sodium is a/an ___ found in Group I of the periodic table.
  b The group VII elements are called noble gases and ___ is an example. (2)

4 Provide a term to match the following descriptions.
  a A type of chemical bonding in which electrons are shared between atoms.
  b This is equivalent to the charge of an atom if the compound was composed of ions only.
  c The combination of the symbols for atoms that make up a compound.
  d A term used to describe a water molecule that has oxygen atoms with partial negative charges and hydrogen atoms with partial positive charges.
  e A strong, electrostatic attraction between a hydrogen atom and an electronegative atom such as oxygen. (5)

5 The molecular weight of calcium chloride ($CaCl_2$) is:
  a 151,06 g
  b 110,98 g
  c 75,53 g
  d  (1)

6 Explain the flexibility and flow characteristic of water. (3)

7 There are many elements that are essential for normal plant growth.
  a Name two nutrients obtained via photosynthesis that are required in large amounts. (2)
  b Name two nutrients that are available in soil and needed in small amounts. (2)

Topic questions

8 Provide the Lewis structure for carbon dioxide and describe its importance. (6)

9 Refer to the given examples and provide a name for the type of each organic compound. (4)

a CH_3–OH

b CH_3CH_2–CO–H

c CH_3–CO–ONH_2

10 The following questions are about methane.

a Provide a chemical formula. (1)

b Name the chemical process by which it is formed. (1)

c Is it the most abundant or the second most abundant compound on Earth? (1)

11 Name the most basic alcohol that contains three carbon atoms. Is it a primary, secondary, or tertiary alcohol? (2)

12 Answer these questions about fatty acids and bio-molecules.

a Explain the term fatty acid and describe the difference between saturated and unsaturated fatty acids. (4)

b Name the type of isomer that causes a saturated fatty acid to 'bend' the most? (2)

c Name four of the main functions of lipids. (4)

13 Draw the basic structure of an amino acid (use R for the variable group). (4)

14 Explain what is meant by an essential amino acid. (2)

15 Discuss protein synthesis in plants. (4)

16 Complete the following sentences about carbohydrates.

a Disaccharides are composed of two ___ joined by a ___ bond. (2)

b Disaccharides are formed in a ___ reaction in which water is released. (1)

c Hexose sugars contain ___ carbon atoms and the three most important hexose isomers are galactose, glucose and ___. (2)

d Glucose is the major product of ___. (1)

e Two glucose units bond to form the disaccharide ___. (1)

f Carbohydrates are the main source of ___ in animals. (1)

g Carbohydrates are the main structural material for cell ___ in plants. (1)

Total: 70

Topic 2

Soil sciences

Overview

TOPIC 2 Page 38 — Soil sciences

UNIT 1 Page 40 — Soil texture
- Main groups of soil particles
- Soil textural classes, their determination and their importance
- Influences of sand and clay particle size on soil characteristics

UNIT 2 Page 43 — Soil structure
- Classification of soil structures
- Factors influencing the development and stability of soil structure
- Factors or malpractices that cause soil structure to decline
- Methods to improve poor soil structure
- The advantages of good soil structure

UNIT 3 Page 47 — Soil colour and soil pores
- The concept: soil colour
- Soil pores

UNIT 4 Page 50 — Soil air
- Factors that affect storage and movement of soil air
- Comparison between atmospheric and soil air
- Important soil gases

UNIT 5 Page 52 — Soil moisture
- Basic types of soil water and their characteristics
- A description of soil water losses and ways to limit these losses
- Forces of nature that have an effect on soil water
- The different movements of water through the soil
- Availability of soil water to a plant at different limits of soil water content
- Scientific methods to illustrate capillary and gravitational movement of water in soil
- Effective soil water management

UNIT 6 Page 58 — Soil temperature
- The main factors influencing soil temperature and their measurement
- Effects of soil temperature on physical, chemical and biological processes in soils
- Methods to manipulate soil temperature for better production

UNIT 7 Page 60 — Soil morphology
- The terminology: soil profile, soil horizon and profile whole
- The development and description of master horizons
- Soil profiles
- A practical identification of topsoil and subsoil horizons

Topic 2

Soil sciences

Overview

TOPIC 2 Page 38
Soil sciences

UNIT 8 Page 62
Soil classification

- The binomial soil classification system in South Africa
- Diagnostic horizons of topsoil and subsoil horizons
- The benefits of soil classification in agriculture

UNIT 9 Page 64
Soil colloids and soil acidity

- Soil colloids
- Soil acidity

UNIT 10 Page 68
Soil alkalinity and soil salinity

- The concept: soil alkalinity (predominant cations)
- The concepts: saline soils and sodic soils
- Characteristics of saline or white brack soils
- Factors causing brackishness, soil alkalinity or saltiness
- The effects of alkaline or brack on crop productivity
- Methods to prevent or control soil alkalinity
- Reclamation of alkaline or brackish soils

UNIT 11 Page 71
Soil organic matter: Living organic matter

- Importance and role of soil micro-organisms and macro-organisms
- Main groups of soil micro-organisms
- Main groups of soil macro-organisms
- Requirements for soil micro- and macro-organisms
- The carbon cycle and conversion by soil micro-organisms
- The nitrogen cycle and conversion by soil micro-organisms
- The phosphorus cycle
- The process of symbiosis

UNIT 12 Page 75
Soil organic matter: Non-living organic matter

- Definitions of fresh organic matter and humus
- Effects of organic matter on soils
- Factors that affect the balance of organic matter in soils
- Effects of the decline in organic matter on soil degradation
- Making a compost heap

Unit 1

Soil texture

1 Main groups of soil particles

- Soil texture:
  - is defined as the relative proportions of sand, silt, and clay particles in a mass of soil
  - includes only the inorganic solid fraction of soils
    - proportions of sand, silt and clay are expressed as percentages (determined in a soil laboratory)
    - → textural classes are then assigned, based on the composition of the soil determined.

Soil particles are divided up into groups based on their diameter.

- It is important to include detail about diameter when conducting a soil survey because particle size has a big influence on physical properties of a soil.

Table 1 Main groups of soil particles

Clay	Silt	Sand
smallest soil particles	clay < silt < sand particles	largest soil particles (coarse)
only seen with a microscope	only seen with a microscope	seen without microscope or magnifying glass
dry particles: smooth and powdery wet then dried: hard wet particles: slick, sticky, holds mould easily	dry particles: smooth and floury wet particles: smooth, not slick and sticky	
clayey soils: = 30–35% clay e.g. sandy clay, silty clay, clay		sandy soils: < 20% clay, > 50% sand e.g. sand, loamy sand, sandy loam
		soils divided according to particle sizes: coarse, medium and fine

2 Soil textural classes, their determination and their importance

2.1 Textural classes of soils

- Soils are classified using the soil textural triangle (see Figure 1). This triangle:
  - can be classified into 12 classes with increasing proportion of fine particles:
    - sand, loamy sand, sandy loam, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, clay.

- Sand, silt, and clay soil particles are often called soil separates:
  - help scientists understand the behaviour of soil (e.g. with regard to nutrients, water holding capacity, compaction).

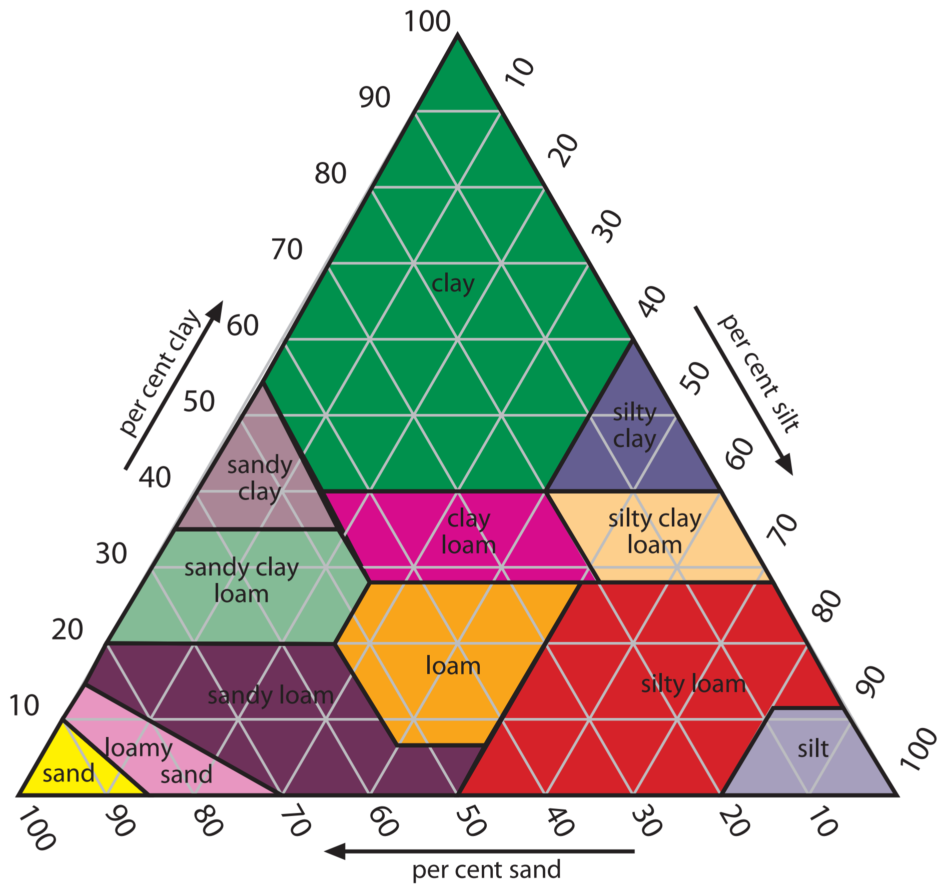


FIGURE 1 The soil textural triangle

2.2 Determination of textural classes of soil

The textural class of soils may be determined in one of two ways:

- analyse soil composition in a laboratory and use the soil textural triangle
- analyse soil in the field and estimate the soil textural class.

Commercial soil analysis laboratories in South Africa use two methods involving particle size analysis.

- Hydrometer method:
  - disperse soil particles with sodium hexametaphosphate $(NaPO_3)_6$ or Calgon agitate soil particles
  - determine amount of each particle group in the suspension using a hydrometer
  - apply Stokes Law to calculate the particle diameter.
- Pipette method:
  - same concept but different instrument used to sample
  - only used when quantity too small for hydrometer method
  - = more accurate but less convenient method.

After analysis, the soil textural triangle can be used to classify the soil texture.

- Two field methods may be used to determine the soil textural class.
  - Sausage method: moisten a small amount of soil in your hand, roll between your hands and try to form a sausage. Use a sausage method chart to classify according to when the breakage takes place:
    - high amounts of clay → forms a sausage
    - high amount of sand → forms a ball but not a sausage
    - in between amounts of clay → break during sausage-making process.
  - Feel method: moisten a small amount of soil in your hand and rub between your thumb and forefinger –
    - clayey soil → feels slippery or greasy
    - sandy soil → feels rough
    - silty soil → feels floury.

2.3 Importance of textural classes of soil

- The textural class of soil affects many factors including:
  - seed germination
  - water holding capacity
  - drainage properties
  - root development
  - pesticide movement.
- Therefore, this knowledge will allow the farmer to:
  - maximise productivity e.g.
    - cultivating suitable crops, addition of appropriate nutrients
  - minimise environmental harm, e.g.
    - cover cropping in sandy soils to reduce wind erosion.

3 Influences of sand and clay particle size on soil characteristics

- Properties of sandy soils:
  - Low water holding capacity
    - = poor for dryland farming.
  - Low organic matter content
    - = can improve by adding organic fertilisers.
  - Well aerated
    - = easy to handle in tillage operations.
- Properties of clayey soils:
  - Low infiltration rate
    - = when dry, hard clay soils limit seed germination.
  - Poorly drained and aerated
    - = become waterlogged in rainy seasons.

Unit 2
Soil structure

Soil structure refers to the arrangement of:

- solid parts of the soil
- the pore spaces between.

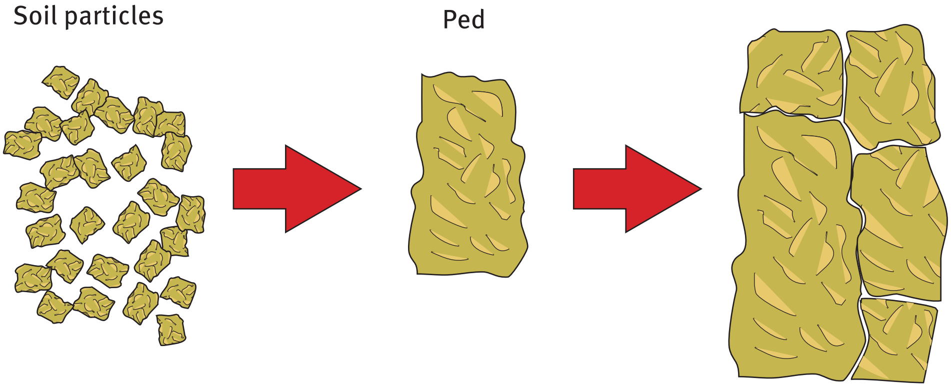


FIGURE 2 Assembly of soil particles to form soil structure

Note:

- peds: produced by natural processes;
- clods: produced by improper cultivation

Soil structure influences:

- water movement into soil
- heat transfer
- aeration
- porosity.

Soil structure is affected by:

- agricultural activities, e.g.
  - ploughing, cultivating, manuring.
- weather, e.g.
  - wetting and drying in humid climates.

1 Classification of soil structures

Soil structure is studied in situ (in the field under natural conditions). It is described according to:

- type (or shape)
- class (or size) and
- grade.

Table 2 Classification of soil structures		
Type or shape	**Class or size**	**Grade**
shape or form and arrangement of peds	size of structural units or peds	degree of distinctness of structural units or peds
• spheroidal: granular, crumb • platy • prismatic and columnar • blocky: angular, subangular	• very fine / fine • medium • coarse / very coarse / extremely coarse • (each can be applied to the different types)	• weak • moderate • strong

1.1 Classification according to type or shape

- Spheroidal soil structure:
  - consist of individual particles of sand, silt and clay grouped together in small, nearly spherical grains
  - found mostly in the topsoil (A-horizon)
  - water circulates very easily through such soils.
- Platy soil structure:
  - consist of thin, flat, horizontal peds that look like plates stacked on top of another
  - found in the surface horizon (i.e. E-horizon), subsoil, compacted soils, the horizon of forest soils
  - root penetration and water circulation are difficult.
- Prismatic and columnar soil structures:
  - consist of vertical columns or pillars separated by small vertical cracks
  - tops of the columns are either flat (prismatic) or rounded (columnar)
  - found in the B-horizon in sub-humid to semi-arid areas where clay has accumulated
  - water circulation, drainage and aeration = poor.
- Blocky soil structures:
  - consist of irregularly-shaped blocks, each can be broken into smaller block peds
  - structure is approximately cubic
  - found in medium-textured to clayey subsoils (B-horizon) in sub-humid to semi-arid areas.

2 Factors influencing the development and stability of soil structure

The development and stability of soil structure depends on natural factors and agricultural activities.

- Aggregate formation and aggregate stability:
  - clay soil particles are required because they have cohesive forces to bind particles together → high clay content soils will have more tightly formed soil structures.

- Cementing agents help form aggregates:
  - soil invertebrates ingest soil and produce faeces that maintain structure
  - fungi use hyphae that extend into soil to connect particles together
  - bacterial polysaccharides resist decomposition thus holding soil particles together
  - roots excrete sugars that bind minerals
  - iron oxides act as glue
  - aluminium oxide binds sand and silt particles
  - dehydration of colloidal matter and pressure completes the aggregation process.
- Climate:
  - affects degree of aggregation and type of soil structure
  - little aggregation in arid regions
  - greater degree of aggregation in semi-arid regions.
- Organic matter:
  - improves structure of sandy and clayey soil
  - sticky and slimy substance produced on decomposition cements sandy particles
  - reduces cohesiveness and makes clay more crumbly.
- Tillage:
  - breaks large clods into aggregates
  - optimum moisture content is necessary.
- Electrostatic forces:
  - soil particles are naturally attracted through electrostatic forces.

3 Factors that cause soil structure to decline

Soil aggregates are important because the spaces between them allow root penetration and movement of air and water. Aggregates may be destroyed in several ways leading to a decline in soil structure.

- Poor tillage practices:
  - e.g. overuse of ploughing, addition of excessive chemical fertilisers
    - → cause loss of nutrients and ability to store water
    - → decrease water infiltration rate
    - → reduce organic matter.
- Compaction:
  - cracks and pores are compressed by heavy farm machinery
    - → cause reduced oxygen diffusion
    - → cause reduced infiltration of water, thus erosion and overland flow
- Loss of organic matter:
  - humus can withhold water and nutrients
    - → gives plants the capacity for growth.
  - humus can help soil stick together
    - → allows bacteria to decay nutrients.

- Poor irrigation water:
  - high salt content can destroy soil structure
    - therefore, analyse soil for EC and SAR (electrical conductivity, i.e. soluble salts; Sodium Adsorption Ration, i.e. suitability of irrigation water for agricultural land)
    - → high SAR means that Na^+ in irrigation water can replace Ca_{2+} and Mg_{2+} in the soil, decreasing the ability of the soil to form stable aggregates

4 Methods to improve poor soil structure

- Increase organic content:
  - incorporate pasture phases into cropping rotations.
  - Green manuring:
  - grow suitable cover crops and plough these back into the soil to increase organic matter.
- Reduce or eliminate tillage and cultivation.
- Avoid soil disturbance:
  - → soil may shatter or smear during periods of excessive dry or wet.
  - Ensure sufficient ground cover:
  - = to protect the soil from raindrop impact.
- Apply gypsum (calcium sulphate) to irrigated land:
  - → displace sodium cations with calcium cations to reduce exchangeable sodium percentage and thus water quality.

5 The advantages of good soil structure

Good soil structure will increase productivity and enhance sustainability in many ways.

- Soil compaction:
  - avoid compaction to improve porosity
    - → improves water infiltration rate, retention and availability.
- Crusting:
  - reduce soil surface crusting to improve the emergence of seedlings
  - crusts cause poor infiltration, reduced air exchange between soil and atmosphere.
- Soil erosion:
  - soil aggregate strength results in decreased overland water flow and soil erosion.
- Salt imbalances:
  - avoid salt imbalances to improve ability to form stable aggregates.
- Limit the effect of a drought and excessive wetness:
  - good soil structure results in increased water storage capacity and infiltration rate.

Unit 3

Soil colour and soil pores

1 The concept: soil colour

Soil properties are influenced by biological activity, water movement and weathering.

- Soil colour is the first physical property used to differentiate soil horizons.
  - Colour changes with soil depth and is directly related to various soil properties:
    - homogeneous colour: particular soil mineral occurs in large enough quantities
    - non-homogeneous colour: mixture of colours (called mottled) due to wetting and drying.

1.1 Main factors that determine soil colour

- Amount of organic matter:
  - usually topsoil (i.e. A-horizon) is dark or black.
- Presence of compounds and elements:
  - iron oxides: yellowish-brown to reddish colour
  - manganese oxides: purplish-black soil colour
  - calcium carbonate: white
  - carbon compounds: black.
- Drainage:
  - poor drainage results in light grey colour or rust-like spots (mottles) –
  - referred to as bleached or washed out.
- Leaching:
  - loss of iron compounds and coloured minerals results in light colour.

Table 3 Interpretation of soil colours

dark	rich in nutrients and organic matter
red	contains iron compounds, e.g. hematite (Fe_2O_3) well-drained (highly oxidised iron compounds are red)
light	iron and manganese loss due to leaching lack of organic matter soils that are developed from quartzite
yellow, yellow/ brown	iron present at lower levels than in red soil, e.g. goethite (FeOOH) more poorly drained than red soil
grey, blue-grey	very poor drainage iron and manganese compounds in reduced form due to the lack of air called gleyed soils
mottled	poor aeration waterlogged or fluctuating water table

2 Soil pores

Pores are the part of the soil occupied by soil atmosphere and water. Total pore space (or porosity) is the volume of soil occupied by air and water.

- Two types of pores:
  - Macro pores:
    - large
    - allow free movement of air and water
    - under the influence of gravity.
  - Micro pores:
    - very small
    - retain water and prevent drainage, thus determine water retention or storage capacity
    - use capillary forces.

2.1 Factors that influence total pore space

- Soil texture and soil structure:
  - determine micro pore volume and thus water storage capacity
  - finer textures (i.e. higher clay content) have more micro pores and thus larger storage capacity
  - good soil structure increases total porosity: large pores between aggregates allow movement of water and air.
- Soil depth:
  - pore space decreases with soil depth
  - subsoil tends to be more compacted than topsoil.
- Soil cultivation:
  - excessive or intensive tillage destroys soil aggregates, reduces organic matter and causes compaction
  - organic matter can be used to increase soil retention.

2.2 Soil bulk density and porosity

Soil bulk density (Db) is the mass of oven-dried soil per unit volume of soil.

- Soil bulk density accounts for soil solids and spaces between soil particles (pore space)
  - → high proportion of pore space leads to a low bulk density.
- Some Db values:
  - typical mineral soils: 1,0–1,6 g cm^{-3}
  - compacted soils: → 1,6 g cm^{-3}
  - soils with high proportion of organic matter: < 1,0 g cm^{-3}.
- Soil bulk density can be determined in an undisturbed, dried soil sample
  - use a soil bulk density core sampler
  - dry soil at 105 °C for 48 hours.

- Soil bulk density can be used to:
  - assess potential for leaching of nutrients and erosion: high bulk density can restrict movement of surface water
  - estimate total water storage capacity (when soil moisture content is known).

Bulk density provides an indirect measure of the soil porosity (amount of pore space).

- Soil porosity:
  - is the ratio of the volume of soil pores to the total soil volume –
    - clayey soils: abundance of very small pores (micro pores) → higher total porosity
    - sandy soils: larger, but fewer pores → lower total porosity.

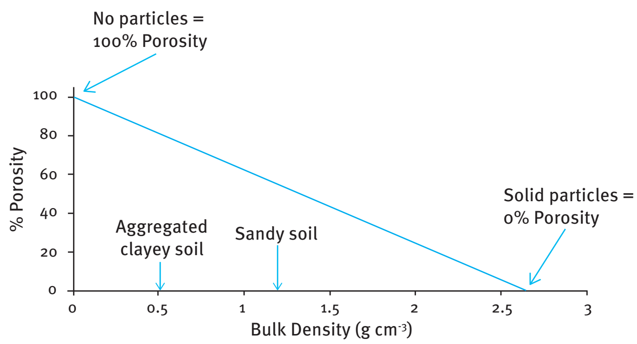


FIGURE 3 The relationship between soil bulk density and porosity

2.3 Factors that influence the bulk density of soil

- Organic matter content:
  - high organic content leads to larger pore spaces and lower soil bulk density
- Texture:
  - finer textured soils (clays and clay loams) usually have adequate organic matter content.
- Pore spaces:
  - large pore spaces occur when soils are not compacted which lowers bulk density.
- Depth in the profile:
  - at deeper levels there is less organic matter and aggregation, fewer micro-organisms and more compaction which increases bulk density.

Unit 4

Soil air

1 Factors that affect storage and movement of soil air

A soil ecosystem consists of air, water, minerals, organic matter, and macro- and micro-organisms. A constant flow of air is required. Thus, soil must not be over-saturated with water because this would exclude air.

- Factors that affect soil air
  - Macro pores:
    - facilitate drainage and diffusion of air
    - content determined by soil texture, bulk density, aggregate stability, organic matter
    - pore content determines pore volume which determines soil aeration.
  - Soil depth or soil horizon:
    - topsoil horizons are better drained thus oxygen occupies their soil pores
    - soils with a crumb structure have macro pores.

2 Comparison between atmospheric and soil air

- The percentage composition of atmospheric and soil air is very similar with regard to:
  - oxygen = approximately 20%
  - nitrogen = approximately 79% and
  - carbon dioxide = <1%.
- The following points about soil air should be noted:
  - usually saturated with water vapour
  - may contain volatile contaminants
  - contains more CO_2 and less O_2 (seasonal)
  - greater variation in composition within soil and over time.

3 Important soil gases

3.1 Oxygen

- Provides for respiration of plant roots and soil organisms.
- Lack of oxygen causes a CO_2 build-up:
  - → stunts plant growth.
- Needed for
  - seed germination
  - decomposition of organic material.
- Facilitates the release of energy from the oxidation of carbon.

- Important in chemical weathering –
  - → iron oxide is realised into the soil (haematite, Fe_2O_3)
    - → binds particles together.

3.2 Carbon dioxide

- Carbon dioxide is the product of respiration of plant roots and soil organisms:
  - soil micro-organisms mix CO_2 with water to form carbohydrates
  - CO_2 gas dissolved in water forms carbonic acid
    - → important in chemical weathering

3.3 Nitrogen

- Most important element for plant development:
  - must be processed naturally in the soil or added as fertiliser.
- Waterlogged soils contain N_2 gas (reduced form)
  - → unavailable for crops.
- Well-drained and aerated soils contain oxidised nitrogen
  - → provides crop-available nutrients
    - = nitrate (NO_{3-}) and ammonium (NH_{4+}).

Unit 5

Soil moisture

1 Basic types of soil water and their characteristics

Table 4 Types of soil water

Gravitational water	Capillary water	Hygroscopic water
found in soil macro pores	found in soil micro pores	forms thin films around soil particles
moves through soil due to force of gravity	held against pull of gravity by cohesion and adhesion forces; micro pores exert more force on water than macro pores	held on particle surface by adhesion forces; force of gravity is counteracted by forces of attraction between water molecules and soil particles and by attraction of water molecules to each other
not available to plants; moves rapidly out of well-drained soil (2–3 days)	available for plant growth	not available to plants; held tightly by soil so not taken up by roots
occupies air space needed to supply oxygen to roots, so up-land plants may wilt and die		

2 A description of soil water losses and ways to limit these losses

Table 5 Soil water losses and some solutions

Drainage	Transpiration	Evaporation
removal of water by gravity or pumping; rapid in soils with large pores (i.e. sandy soils)	loss of water vapour through stomata on leaf surfaces (mainly) and plant stems; accounts for 90% of losses	loss of water from soil surface in vapour form; influenced by crop shading and amount of water available at soil surface
solution: improve field capacity by adding organic matter	solution: controls weeds which may con-tribute to transpiration	solutions: plant groundcover or increase surface shading; plant windbreaks; provide physical structures that concentrate rainwater

3 Forces of nature that have an effect on soil water

- Adhesion:
  - attraction between soil particle surfaces and water molecules
    - → results in water being held tightly by soil particles.

- Cohesion:
  - like molecules sticking together
  - water molecules are cohesive due to strong hydrogen bonds that form between them.
- Capillarity:
  - additive force of adhesion and cohesion
  - describes ability of a liquid to flow against gravity and rise spontaneously in a narrow space, e.g.
    - stem of a plant
  - explains movement of groundwater from wet areas of the soil to dry areas.
- Adsorption:
  - adhesion of water to solid soil surfaces
  - capillary and adsorptive forces together result in soil matric potential or matric force.
- Matric force:
  - holds water from the surface of soil particles
    - → due to attraction of soil particles to water and cohesive forces between water molecules
    - water always moves from state of high to low energy
    - easier for plants to obtain water when the soil is moist than when it is dry.
  - Field capacity (FC) is the upper limit of soil water available to plants, and permanent wilting point (PWP) is the lower limit.
- Electrostatic forces:
  - retention of water molecules on soil surface based on dipole character of water
  - interaction of positive and negative charges of water with negative charge of soil particles creates successive layers of oriented water molecules
  - orientation becomes weaker as the layer thickens until capillary water begins to appear.
- Bonding forces
  - responsible for formation of water molecules (i.e. when H and O bond to form H_2O)
  - responsible for water storage in soil:
    - adhesive forces: result of chemical bond between water and exchangeable cations in soil colloids, and polar groups of soil minerals and organic matter
    - cohesive forces: due to hydrogen bonding of additional water molecules
    - large pores drains quickly due to gravitational forces
    - smaller pores are under capillary forces and are resistant to drainage
    - only a portion of the water stored in the soil is available to plants.
  - As the amount of water in the soil increases, the energy with which it is held decreases.
  - As the amount of water in the soil decreases, the strength of bonding of water to the soil solids increases.

4 The different movements of water through the soil

4.1 Movement of liquid water in soil

There are two ways in which liquid water moves through soil and they determine the amount of water available to plants.

- Saturated flow:
  - all the pores are full of water, i.e. macro and micro pores
  - water at the surface of the soil possesses a high potential
    - → depends on the difference in potential between two points, the soil and the ease with which the soil allows the water movement (i.e. hydraulic conductivity).
- Unsaturated flow:
  - micro pores are filled with water and macro pores are filled with air
    - → water flows through micro pores and the surface of the soil particles (lower negative potential) to another zone of a higher negative potential
    - → water moves from moist soil (lower negative potential) to dry soil.

4.2 Movement of water vapour in soil

Vapour flow occurs only in relatively dry soil where vapour pressure differences are significant. There are two types of vapour flow.

- Mass flow:
  - water vapour flows in a mass along with other soil gases
    - → as atmospheric pressure decreases, gases expand and escape the soil
    - → as atmospheric pressure increases, gases contract and enter the soil.
- Diffusion flow:
  - diffusion is the property by which two gases readily mix when in contact
    - → water evaporates from moist / warm soil and the vapour diffuses into the adjacent dry / cool soil
    - it is due to a difference in temperature.

5 Availability of soil water to a plant at different limits of soil water content

Soil water is available to plants at different limits of soil water content. Soil water content describes how much water a soil can contain at different limits.

- Saturation point:
  - all soil pores are filled with water
  - also called maximum moisture holding capacity of the soil
  - occurs after rainfall.
    - Saturation capacity can be expressed as centimetre of water per metre of soil depth.

- Field water capacity:
  - soil water content after soil has been saturated and drained freely for 1–2 days
  - free drainage occurs by force of gravity
  - remaining water is held with a force greater than that of gravity.
- Temporary wilting point:
  - due to higher transpiration on hot windy days
  - plants recover during cooler part of the day
  - does not require any addition of water.
- Permanent wilting point:
  - soil moisture percentage at which plants cannot obtain enough moisture to continue growing (i.e. when they die)
  - plant roots take up available water or water vapour
    - → dry out without additional water
    - → remaining water is tightly retained and plant roots cannot extract it.
  - depends on
    - rate of water usage by the plant
    - depth of the root zone
    - water holding capacity of the soil.

6 Capillary and gravitational movement of water in soil

Capillary action and the gravitational movement of water are two forces that have an effect on soil water.

- Capillary action allows water to flow up plant stems.
- Gravitation movement of water allows water to move downwards through the soil.

7 Effective soil water management

Soil water management is based on the manipulation of the soil water balance.

7.1 Soil water balance

- Soil water balance (SWB) reflects all quantities of water added, removed or stored in a given volume of soil during a given period of time.
- The term water balance, when applied to a crop or soil system, describes what happens to precipitation and the various components of water flow in and around the soil profile:
  - precipitation (P) – rainfall, and/or irrigation – is the major water input to the crop or soil system
  - P affects surface runoff water (R), crop evapotranspiration (ET), deep percolation (DP) and changes in soil water storage (S):
    - $P = R + ET + DP + S$
- Understanding SWB helps farmers manage soil water more effectively.

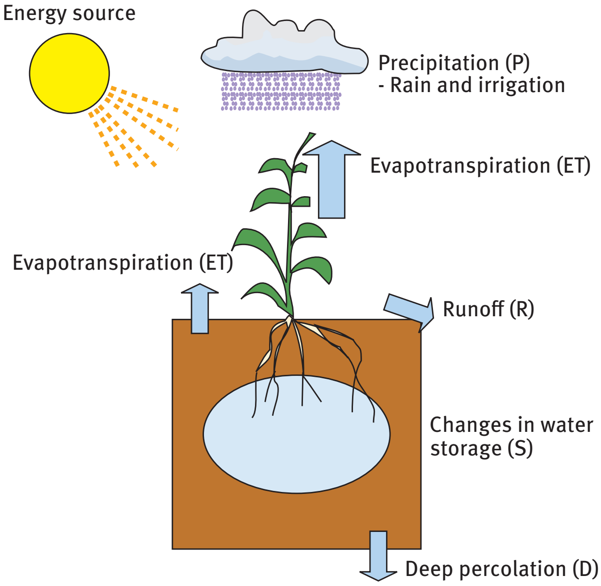


FIGURE 4 The water balance cycle

7.2 Components to consider in management strategies

- In the above water balance formula, only transpiration can promote crop growth and yield:
  - therefore: transpiration must be kept high to maximise yield
    - → all the other components except P result in a loss of water
    - → they must be managed effectively.

Table 6 Components to consider in water management strategies

Evaporation	driven by energy of the sun striking soil surface, speed in which moist air is removed (wind), moisture content of soil	restrict solar energy reaching soil surface: cover with stubble mulch; do not irrigate frequently; use deeper irrigations at longer intervals
Interception	extent to which a crop holds water in its canopy; directly related to size and density of crop canopy	use deeper irrigations at longer intervals
Runoff	occurs when precipitation rate exceeds water infiltration rate; infiltration rate depends on soil structure, texture and water content	improve soil structure by adding organic compost; apply water more efficiently based on soil texture; adjust irrigation time and duration
Drainage	uncontrolled drainage below root depth wastes water; can flush out excess salt from roots	soil moisture content must be near to field capacity to make water available to plants; reduce soil moisture content during rainy season (prevent runoff)

7.3 Effective management strategies

- Firstly do the following:
  - check how much water you have (in storage or have access to)
  - understand your crop water needs
  - have access to a nearby weather station
  - know the organic matter content, soil depth, structure, texture, and water holding capacity of the soil on your farm.
- Then undertake the following strategies:
  - regularly review your volume of water (stored and available)
  - design and monitor an irrigation programme
  - use only amount of water required and monitor usage with rain gauges
  - irrigate later in the day and not during windy conditions
  - application rate of water should not exceed infiltration rate of soil.

Unit 6

Soil temperature

1 The main factors influencing soil temperature and their measurement

Soil obtains its energy from solar radiation.

Table 7 Main factors influencing soil temperature and their measurement

Moisture content	
• influenced by rate at which soil warms up and cools off: moist soils warm more slowly than dry soils • condensation increases temperature • rainfall decreases temperature • specific heat capacity and thermal conductivity influences temperature • presence of water has a strong influence on temperature: water has high heat capacity so it takes less heat to raise soil temperature in dry soil	• use soil moisture sensors • soil moisture content is highly variable • aircraft and satellites use remote sensing technology to enhance the variation • measures uppermost layers of soil and provides data on energy variations
Soil colour	
• dark soils absorb more energy from the sun and heat more quickly • cultivated soil has a greater temperature	• soil thermometer can be used • measurements should be done on a summer afternoon for accurate results
Direction of slope	
• solar radiation that reaches the land surface at an angle is scattered over a wider area • South Africa is in the southern hemisphere so northern facing mountain slopes are warmer	• use of lines of latitude to simulate changes in direction of exposure and degree of slope
Soil cover	
• vegetation and cloud cover intercepts direct sunlight • cloud cover also insulates soil from temperature changes	• compare temperature under a shady tree with bare soil • compare temperature between rows of healthy crop close to reproductive stage with nearby bare soil

2 Effects of soil temperature on physical, chemical and biological processes in soils

- Soil temperature influences:
  - nutrient cycling
  - microbial processes
  - plant growth rates
  - root functions
  - water storage.

- Two main categories:
  - chemical and physical processes
  - biological processes.

2.1 Chemical and physical processes affected by soil temperature

- Chemical and physical processes affect decomposition and mineralisation of organic matter
  - → thus affect nutrient availability.
- Soils with high temperatures experience accelerated rates of mineral weathering.
- Rates and depth of evaporation increase with soil temperature.
- Increased viscosity at low soil temperatures decreases:
  - the rate of nutrient transport to the roots
  - water uptake rate of the roots
  - water transport rate within the plant.

2.2 Biological processes affected by soil temperature

- Biological processes affect growth and physiology of plant root systems
  - → thus affect nutrient uptake
  - → amount and duration of root growth, root morphology, and root spatial distributions
  - → rates of ion uptake, root respiration, cell membrane permeability, and transport in xylem.

3 Methods to manipulate soil temperature for better production

- Tillage and shaping of fields:
  - slope angle and direction affect soil temperature
  - modify soil thermal properties by specific tillage practices, e.g.
    - ridging and shaping.
- Mulching and vegetation:
  - used for water conservation and soil temperature manipulation e.g.
    - straw, weed or trash, gravel, plastic, paper, aluminium foil.
- Shading and row spacing
  - artificial shading, e.g.
    - net or transparent plastics
  - row spacing and plant population.

Unit 7

Soil morphology

1 The terminology: soil profile, soil horizon and profile hole

The weathering of rocks into smaller pieces to form soil is a key process that directs soil formation. The outcome is a complete soil profile with various soil horizons.

- Several factors influence soil formation and the development of a soil profile:
  - Parent material: unconsolidated material that provides most of soil horizon character.
  - Climate: rainfall and temperature influence the rate of weathering.
  - Topography: arrangement of physical features (e.g. slope) that influences the vegetation and soil type of a location.
  - Time: soil formation is extremely slow → so a younger soil profile reflects the parent material more closely.
  - Organisms: type and number of organisms are important
    - → influenced by plants.

2 The development and description of master horizons

South Africa uses the South African Binomial System of Soil classification:

- Master soil horizons: O, A, E, G, B, C, and R.
- Subdivisions of the major horizons occur in some soil profiles.
  - Some locations do not contain all soil horizons.

Table 8 Master horizons of soil classification

O-horizon	• organic horizon • contains undecomposed organic debris or decomposed organic materials and humus
A-horizon	• surface horizon or topsoil • contains inorganic matter mixed with leached mineral
E-horizon	• subsurface horizon • eluviated zone that contains little or no organic matter
B-horizon	• subsoil • illuviated zone that contains materials leached from upper horizons
G-horizon	• usually wet and clayey texture, mottling may be present
C-horizon	• slightly weathered parent material
R-horizon	• unaltered parent material

3 Soil profiles

- Adult soil:
  - significantly developed soil profile
  - B-horizon contains clay silicate, or oxides (aluminium, manganese and iron)
  - yellowish, reddish or dark in colour (except if parent material is high in white calcium carbonate)
  - influenced by climate, vegetation and drainage.
- Young soil:
  - minimal horizonation
  - A-horizon forms directly above R-horizon
  - parent material is the strongest influence.
- Wet or waterlogged soils:
  - poorly drained
  - rubber-like consistency
  - shrinks, hardens and cracks into cubes when drying out.
- Eroded soils:
  - topsoil has been removed by wind, water or gravitational creep
  - B-horizon is often the top layer
  - unable to sustain crop life.

4 A practical identification of topsoil and subsoil horizons

- Topsoil characteristics:
  - it is the topmost layer
  - does not contain rocks
  - high proportion of organic matter
  - good drainage.
- Subsoil characteristics:
  - just beneath the topsoil
  - low in organic matter
  - lighter in colour and stickier
  - adults soils are rich in oxides
  - more compact
  - highest nutrient content.

Unit 8

Soil classification

- Soil classification = grouping soil with similar properties.
- Distinguishing properties indicate type of horizons present and degree of development.

1 The binomial soil classification system in South Africa

There are two main categories or levels of soil classes:

- Soil forms:
  - an upper or general level
    - defined by a unique vertical sequence of horizons.
  - There are 73 soil forms.
- Soil families:
  - a lower and more specific level
    - they share properties of the form
    - they are differentiated within the form based on other properties.
  - There are 404 soil families.
- Steps involved in binomial soil classification system:
  - demarcate master horizons
  - identify diagnostic horizons (subsections of master horizons)
  - name a soil form
  - identify distinguishing family marks
  - identify soil family
  - determine texture class of A-horizon and add it to the soil family name, e.g.
    - sandy loam, loam.

2 Diagnostic horizons of topsoil and subsoil horizons

Topsoil and subsoil horizons may be divided into further subsections:

- five for topsoil and 14 for subsoil.
  - These are differentiated based on various soil properties.

Table 9 Diagnostic topsoil horizons	
Organic O	high organic matter content (>20%), black to dark brown colour, low bulk density, 20–30 cm depth; formed in wet areas
Humic A	dark-coloured, moderate organic carbon content, low base status, well-drained
Vertic A	dark coloured, high clay content, swell-shrink properties, visible slickensides; found in sub-humid or semi-arid areas, or under grasslands
Melanic A	dark-coloured when dry, strong structure that is not hard when dry, no slickensides
Orthic A	low in organic matter, thin layer, sometimes light coloured, very common

Table 10 Diagnostic subsoil horizons	
E horizon	• position: second in sequence of diagnostic horizons; • grayish and lighter colour than horizons above and below it, elluvial horizon low in clay and oxides, sandy, low chemical reactivity
G horizon	• position: below a vertic-A, melanic-A, orthic A or E-horizons; • grey or bleached, saturated with water
Red apedal B	• red colour, weakly structured, no alluvial or Aeolian stratifications
Yellow-brown apedal B	• analogue of the red apedal B, but yellow or brown instead of red
Red structured B	• position: below orthic A-horizon; • red and uniform colour, better structure than red apedal B
Soft plinthic B	• reddish brown, yellowish brown or black mottled colour, grey colours due to gleying in the horizon or just below it, contains sesquioxides
Hard plinthic B	• position: below orthic-A, yellow-brown apedal B or E horizons; • indurated zone containing iron and manganese
Prismacutanic B	• position: below orthic A- or E-horizon; • abrupt transition with overlying horizon with respect to at least two of texture, structure and consistence; prismatic or columnar structure; colour either does not indicate wetness or vertical faces have continuous coatings of uniform, dark colour
Pedocutanic B	• position: below topsoil or E-horizon, or via a stone-line; • moderate to strongly developed sub-angular or angular blocky structure in the moist state, enriched with clay
Lithocutanic B	• created by *in situ* weathering of rock under topsoil, variegated zone
Neocutanic B	• composed of unconsolidated material
Neocarbonate B	• same as red apedal, yellow-brown apedal or neocutanic B-horizons except for calcium and/or magnesium carbonate
Podzol B	• enriched in organic matter and sesquioxides; no textural differentiation; • e.g. sandy parent materials under fynbos vegetation
Podzol with placic pan	• position: lower 100mm of podzol B-horizon; • freely drained or gleyed

3 The benefits of soil classification in agriculture

- Organise and facilitate knowledge about soils.
- Understand the relationship among different soils.
- Establish groups or classes of soils for practical purposes.
- Predict the behaviour of different soils.
- Identify the best uses of soils.
- Estimate agricultural productivity potential.
- Transfer information to similar soils in other locations.

Unit 9

Soil colloids and soil acidity

1 Soil colloids

- They are very small particles of either organic or inorganic matter:
  - determine physical and chemical properties
  - carry an electrostatic charge
    - = which is pH dependent.

1.1 Description and characteristics of inorganic soil colloids

- Inorganic colloids
  - → account for the majority of soil colloids.
- There are three main types:
  - Phyllosilicate clay minerals
  - Non-crystalline silicate clays
  - Oxides.

1.1.1 Phyllosilicate clay minerals

- Derived from silica → contain aluminium, magnesium and hydroxide.
  - responsible for cracks in dry soil (due to mineral shrinkage)
  - responsible for nutrient retention
  - protects soil from weathering, e.g.
    - 1:1 type (kaolinite = most important clay mineral)
    - 2:1 type (montmorillonite).

1.1.2 Non-crystalline silicate clays

- Formed from volcanic ash deposits.
  - amorphous
  - receptive and fertile minerals, e.g.
    - allophone and imogolite.

1.1.3 Oxides

- Also known as sesquioxides.
  - → responsible for nutrient retention, e.g.
    - iron and aluminium oxide clays
    - hydrous oxides.

1.2 Differences between inorganic and organic colloids

Comparison of inorganic and organic colloids is shown in Table 11 on the next page.

Table 11 Comparison of inorganic and organic colloids	
Inorganic colloids	**Organic colloids (also called humus)**
soils and clays (dispersed colloid) + water (dispersing substance)	minerals from prehistoric plants (dispersed solid) + water (dispersing substance)
net positive charge	net negative charge (but contains + and – charged species)
	increase water and nutrient retention

1.3 Cation adsorption and cation exchange in soil

Cation exchange is the exchange of a cation in the soil solution for another cation on the colloid surface.

- Acidic / acid-forming cations: e.g.
  - hydrogen (H^+), aluminium (Al^{3+})
    - neither are plant nutrients.
- Basic / alkaline-forming cations: e.g.
  - calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+) and sodium (Na^+)
    - main positively charged crop nutrients.
- Clay particles (–) attract nutrients and non-nutrients (+).
- Organic matter (– and +) attracts cations (+) and anions (–).
  - → prevents leaching of essential nutrients.
  - Cation exchange capacity (CEC) is the ability of soil to exchange cations with a soil solution.
- Expressed in centi mol per kg (cmols (+) kg^{-1}).
- Can be altered by addition of organic matter and liming of a soil, e.g.
  - in acidic soils, Al^{3+} replaces Ca^{2+}.

2 Soil acidity

- Most agricultural crops give better yields on soils that are not too acid or too alkaline.
- Many South African soils are acidic and must be treated.
- The pH scale is used to measure acidity or alkalinity, where pH = $-\log [H^+]$.

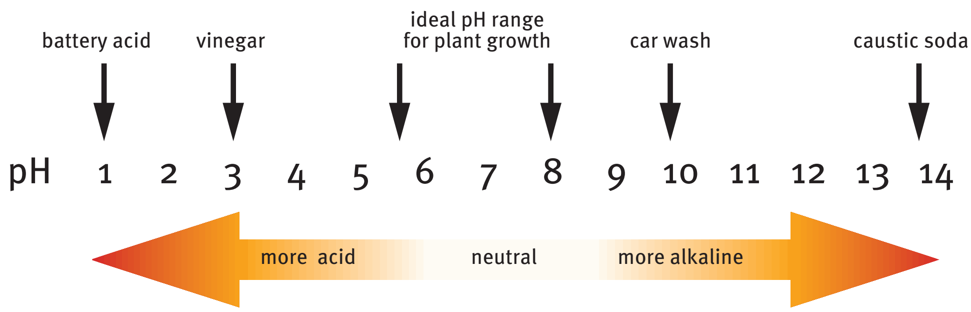


FIGURE 5 The pH scale

2.1 The concepts: soil acidity, active acidity and reserve acidity

2.1.1 Soil acidity

In humid regions, rainfall exceeds evapotranspiration.

- Soils become acidic when basic cations (Ca^{2+}, Na^{+}, Mg^{2+} and K^{+}) are leached from the soil by rainwater:
  - basic cations are replaced by Al^{3+}
    - → which is hydrolysed to form aluminium hydroxide ($Al(OH)_3$) solids and hydrogen (H^{+}) ions in solution.
  - Ca^{2+} is normally the predominant exchangeable cation in soils.
    - In highly weathered soils, Al^{3+} may become the dominant exchangeable cation.

2.1.2 Active acidity

Active acidity

- = the concentration of H^{+} ions in soil and water mixture.
  - Measured using a pH meter.
  - Can be neutralised by application of lime to soil.

2.1.3 Reserve acidity

Reserve acidity :

- = concentration of H^{+} ions attached to clay and organic matter and not dissolved in solution.
  - Measured as buffer pH in a buffer solution.
  - Estimates the resistance of soil to pH change.

2.2 Factors influencing or causing the soil acidification process

Soil acidification

- = a natural phenomenon that occurs after leaching due to heavy rain or the uptake of plant nutrients by the crop.
  - Causes of soil acidity:
    - application of sulphur (forms sulphuric acid)
    - atmospheric pollutants such as sulphur dioxide
    - weathering of acidic parent material
    - use of nitrogenous fertilisers and leaching of nitrate from ammonium-based fertilisers
    - loss of exchangeable bases from the soil due to leaching and erosion
    - decay of organic matter (produces organic acids).

2.3 The effects of soil acidity on crop production

Soil pH affects plant nutrient availability. Optimum pH range is typically 6–7,5.

- The main effects of soil acidity on crop production are:
  - toxic organic compounds are broken down by micro-organisms
  - activity of bacteria responsible for nitrogen fixation decreases
    - → thus lower production of the main plant nutrient nitrogen
  - availability of aluminium and manganese increases
    - → which can be toxic and restrict uptake of nutrients calcium and magnesium
  - phosphorus (an essential plant nutrient) forms insoluble compounds with aluminium and iron and thus becomes unavailable.

2.4 Methods of preventing or controlling soil acidification

- Apply lime ($CaCO_3$), called liming the soil, to neutralise active acidity:
  - CO_3^{2-} reacts with H^+ ions (from H_2O)
  - eliminates toxic Al^{3+} and H^+
  - produces CO_2 gas.
- Apply fertilisers to improve soil fertility.
- Avoid acidifying fertilisers.
- Plant acid-tolerant perennial species.

Unit 10

Soil alkalinity and soil salinity

1 The concept: soil alkalinity (predominant cations)

Soil alkalinity refers to how alkaline a soil is.

- Alkaline soils have the following properties:
  - pH level above 7,0
  - contain large amounts of calcium, sodium and magnesium (released by weathering)
  - less soluble than acidic soil
  - iron, manganese, and phosphorus levels are too low for plant growth
  - water and essential nutrients cannot penetrate the soil easily
    - found in arid and semi-arid regions.

2 The concepts: saline soils and sodic soils

2.1 Saline soils

- Contain an excess of soluble salts, e.g.
  - sodium chloride (common table salt) and calcium sulphate (gypsum).
- 'Chemical drought' occurs:
  - water moves out of the roots via osmosis when salt concentration in the soil solution exceeds the salt concentration inside the roots –
    - high soil electrical conductivity
    - rain washes out chlorine, while the sodium remains leading to sodic soils.

2.2 Sodic soils

- These are chlorine-washed soils that contains excess sodium:
  - defined as a non-saline soil, i.e. contain low total salt levels
    - → result in poor crop production and soil structure
    - → cause clay soil particles to disperse and form hard, impenetrable crusts.

3 Characteristics of saline or white brack soils

Defining characteristic = contain sufficient neutral soluble salts to adversely affect crop growth:

- Salt precipitates on the soil surface. Usually: pH < 8,5
  - electrical conductivity > 4 dS/m
  - sodium adsorption ratio or exchangeable sodium percentage > 13
    - sodium and chloride present in large quantities
    - calcium and magnesium present in adequate quantities
    - contains large amounts of gypsum (calcium sulphate)
    - contains no soluble carbonates.
  - → Uneven growth of crops.

Salinity can be measured. To measure:

- saturate soil with distilled water
- leave to settle overnight
- measure the water with an EC meter
- Expressed as EC (electrical conductivity) in deci-siemens per metre (dS/m)
  - defined by EC > 4 dS/m.

4 Factors causing brackishness, soil alkalinity or saltiness

- These factors cause brackishness, soil alkalinity or saltiness:
  - salty irrigation water
  - soil parent material
  - poorly drained soils
  - inorganic or synthetic fertilisers
  - dairy and beef animal manure
  - compost made from animal manure
  - field slope and drainage.

5 The effects of alkaline or brack on crop productivity

Alkaline levels regulate the availability of vital nutrients and affect the ability of crops to absorb nutrients.

- If alkaline levels are too high:
  - crops may wilt or die (even if soil moisture content appears adequate)
  - salts at the root zone make extraction of water by roots difficult.

6 Methods to prevent or control soil alkalinity

- Monitor soil pH (take several soil samples in your field).
- Test irrigation water.
- Apply sulphur or gypsum.
- Do not over use compost and animal manure.
- Irrigate to leach salts in drier areas.
- Cover soil with mulch during summer months.
- Do not over lime soil.

7 Reclamation of alkaline or brackish soils

Alkaline or brackish soil usually has low nitrogen content and a reduced availability of plant nutrients. These can be addressed as follows:

- Identify the cause of alkalinity.
- Establish drainage with good quality water.
- Add organic matter to facilitate drainage.
- Add gypsum to reduce the pH.
- Adopt a ridges and furrow system of planting.

Alkaline soils that contain a high proportion of calcium carbonate are called calcareous soils.

- Use these ways to reclaim calcareous soils:
  - add sulphuric acid to leaching excess calcium carbonate
  - add sulphur to form sulphuric acid in situ
  - choose a salt-tolerant crop, e.g. barley.

Unit 11

Soil organic matter: Living organic matter

Micro-organisms and macro-organisms make up the living organic matter of the soil.

- Micro-organisms are microscopic.
- Macro-organisms can be seen with the naked eye.
  - they live mostly in the surface layers of the topsoil
  - they break down non-living organic matter in the soil for re-use by plants.

1 Importance and role of soil micro- and macro-organisms

The major role of soil organisms is to maintain the balance of the soil ecosystem and to provide plants with nutrients.

- Importance and role of soil micro-organisms:
  - decompose dead plants and animals, and animal dung
  - free nutrient elements from organic material for use by other organisms
  - fix atmospheric nitrogen into soil
  - improve soil structure
  - help to form soil.
- importance and role of soil macro-organisms:
  - decompose dead organic matter so that micro-organisms can decompose it further → provide food for other animals.

2 Main groups of soil micro-organisms

2.1 Bacteria

Bacteria are vital in recycling nutrients.

- Many are anaerobic → so they release methane instead of CO_2.
- Can be classified as autotrophic or heterotrophic:
  - autotrophic bacteria: use carbon for food
    - → do this by extracting CO_2 from air and using sunlight or nitrogen and sulphur for energy.
  - heterotrophic bacteria: decompose dead organic matter, recycle nutrients and release CO_2 into the air
- Bacteria involved in decomposition of organic matter can be classified according to the temperatures at which they grow best, i.e.
  - psychcrophilic, mesophilic and thermophilic (order of increased temperature preference)
- Photosynthetic bacteria:
  - use sunlight for energy, e.g. blue-green or cyanobacteria.
  - some are nitrogen fixers, e.g. Azotobacter.
- Nitrifying and denitrifying bacteria:
  - → convert nitrogen compounds into different forms.

2.2 Other micro-organisms

2.2.1 Fungi

- They produce long thin branches (hyphae):
  - → form a network (mycelium) which infiltrates the tissue of plants or animals.

One group is called *mycorrhizae*:
- exhibit symbiosis with almost all plant roots
- aid nutrient exchange
- increase disease and drought resistance.

2.2.2 Algae

- They are single-celled organisms that contain chlorophyll:
  - → allows them to photosynthesise.
- They are dependent on high levels of moisture.
- Some fix nitrogen from the air into the soil in the form of ammonia.

2.2.3 Protozoa

- They are single-celled organisms that live in moist soil:
  - metabolise by photosynthesis
  - prey on bacteria, fungi and nematodes.

3 Main groups of soil macro-organisms

3.1 Annelids

- Example of annelid = earthworms:
  - swallow and digest dead organic matter
  - excrete digested products in casts or dung in the lower subsoil
    - micro-organisms break down the semi-digested products.

3.2 Molluscs

- Examples of mollusc = snails and slugs (species called gastropods):
  - eat live plants and dead plant matter
  - assist in the breakdown of organic matter.

3.3 Arthropods

- Examples of arthropods = flies (insects), woodlice (isopods), mites (arachnids), centipedes (myriapods):
  - creatures with jointed legs or segmented bodies
  - eat dead organic matter and decompose into smaller pieces for micro-organisms
  - feed on plant-eating soil organisms
  - dung beetles and termites are found in dry soils.

3.4 Nematode worms

- Nematode worms = very small.
  - millions found in the upper layers of the soil
  - eat and decompose rotting flesh of plant matter.

4 Requirements for soil micro- and macro-organisms

Table 11 Requirements for soil micro- and macro-organisms

	Micro-organisms	Macro-organisms
Moisture	water required for their metabolism, soil must contain 50–80% moisture	moist soil because many can dry out easily
Temperature	optimal range is 25–30 °C	
Light	required by photosynthetic organisms	protection from sunlight
pH	optimal range is 6–8	
Air	mostly aerobic organisms	
Food	main nutrients = carbon, nitrogen minor nutrients = calcium, phosphorus, potassium	dead organic matter

5 The carbon cycle and conversion by soil micro-organisms

- Six main steps in the cycle:
  - Step 1: plants extract CO_2 from the air during photosynthesis.
  - Step 2: plants make sugars, starches and cellulose.
  - Step 3: plant products are ingested by herbivores.
  - Step 4: micro-organisms decompose dung or dead bodies of herbivores.
  - Step 5: micro-organisms release CO_2 into the air.
  - Step 6: CO_2 is used by plants.
- Plants and animals also release CO_2 during respiration.

6 The nitrogen cycle and conversion by soil micro-organisms

- Ammonifying organisms: protein / urea → NH_4^+:
  - bacteria and fungi decompose proteins or urea from plant and animal matter
  - ammonium is released into the soil
  - ammonification or mineralisation: chemical compounds in organic matter are made available to plants for nutrition
  - immobilisation: organic matter decomposes and is absorbed by micro-organisms, therefore becoming unavailable to plants.

- Nitrifying bacteria, *Nitrosomas*: $NH_4+ \rightarrow NO_2$ (i.e. converts ammonium to nitrites):
  - process called nitrification
  - nitrites are toxic to plants, but are rapidly converted to nitrates.
- Nitrifying bacteria, *Nitrobacter*: $NO_2 \rightarrow NO_3$ (i.e. converts nitrites to nitrates):
  - nitrates can be used by plants.
- Nitrogen-fixing organisms:
  - absorb and fix nitrogen from the air into plants or the environment
  - use an enzyme called nitrogenase
  - → called nitrogen assimilation
  - symbiotic nitrogen fixers: bacteria found in root nodules of legume plants, e.g.
    - *Rhizobium*
  - non-symbiotic fixers: free-living micro-organisms, e.g.
    - *Azobacter*
- Denitrification bacteria: $N_2 \rightarrow NO$ (i.e. converts nitrogen to nitrous oxide):
  - process called volatilisation.

7 The phosphorus cycle

- Three main steps in the cycle:
  - Step 1: plants absorb phosphorus from soil WHEREAS animals obtain phosphorus by eating plants.
  - Step 2: plant and animal matter are decomposed by micro-organisms.
  - Step 3: micro-organisms release phosphorus into the soil (i.e. mineralisation).
- Most phosphorus is unavailable as it is insoluble or bound to soil particles.
- Micro-organisms release some of this insoluble phosphorus (i.e. solubilisation).

8 The process of symbiosis

- Symbiosis = co-operation between two different organisms which benefits both organisms.
- Symbiotic relationships occur between plants and soil micro-organisms.
  - *Mycorrhizae* as an example:
    - fungi species that attach to plant roots
    - plant benefits by increased absorption of phosphorus
    - fungus obtains carbon and other growth requirements from the plant.
  - *Rhizobium* bacteria as an example:
    - penetrates the roots and forms nodules in the tissues
    - plant receives nitrogen extracted from the air
    - bacteria receives water and nutrients from the host plant
    - symbiosis is reduced by nitrogen fertilisation, high soil acidity and temperatures.

Unit 12

Soil organic matter: Non-living organic matter

1 Definitions of fresh organic matter and humus

Fresh organic matter:

- = Dead remains of living plants and animals.
  - Components decompose at different rates.
  - To accelerate decomposition you should:
    - provide aeration and moisture
    - ensure the correct pH
    - correct the carbon:nitrogen ratio
    - add nitrogen-containing compounds
- Fresh organic matter → not suitable for use as compost.

Humus:

- = Final product of decomposition of fresh organic matter:
  - dark and crumbly
  - smells like soil.

2 Effects of organic matter on soils

- Physical effects:
  - improves soil structure of soil (by causing aggregation of particles)
  - improves drainage of clay soils
  - binds sandy soil, which lessens damage by water and wind erosion
  - improves aeration
  - humus increases soil temperature which favours plant growth.
- Chemical effects:
  - provides basic nutrients
  - prevents leaching of nutrients
  - produces organic acids which aid weathering.
- Biological effects:
  - creates favourable conditions for micro- and macro-organisms
  - organisms promote aeration and nutrient recycling.

3 Factors that affect the balance of organic matter in soils

The factors that affect the balance of organic matter in soils are summarised in Table 13 on the next page.

Table 13 Factors that affect the balance of organic matter in soils		
	Gains	**Losses**
Nature	• falling leaves and dead grass • animal dung deposits • dead roots	• microbial decomposition • wind and water erosion • high moisture and temperature

Agriculture	• compost or organic fertilisers
	• shallow tillage methods
		• tillage and cropping methods:
		  • increase wind and water erosion
		  • bury and putrefy crop residue
		• compaction by heavy equipment

3.1 Impact of decomposition of organic matter on global warming

- Decomposition by aerobic micro-organisms → release of carbon dioxide (CO_2).
- Decomposition by anaerobic micro-organisms → release of methane (CH_4).
- Methane contributes much more to global warming then carbon dioxide.
- Burying organic matter in landfills contributes to global warming.
- Composting kitchen waste is preferable and returns organic matter to soil.

4 Effects of the decline in organic matter on soil degradation

- Although inorganic fertilisers add nutrients to soil they do not improve soil quality:
  - soil becomes drier
  - more compact
  - less well aerated
  - nutrients are leached.

5 Making a compost heap

- Select a site.
- Dig a trench and fork the base.
- Line the base with sticks or branches.
- Layer the heap:
  - first carbon-containing browns
  - then nitrogen-containing greens
  - use more brown than green matter
  - should be 750 cm wide and 250 cm high
  - repeat layering monthly for three months
- Keep moist.

It is ready when you have dark, flaky, sweet-smelling humus.

Topic 2

Topic questions

- Answer the questions below.
- Give yourself one hour.
- Check your answers afterwards and do corrections.

1 Name and describe the 3 main groups of soil particles with respect to their size. (6)
2 Describe three factors that influence the development and stability of soil structure. (6)
3 Soil colour is influenced by the amount of organic matter, the presence of various compounds, drainage and leaching. Explain three of these factors with examples and colours. (6)
4 Name the three main soil gases and state which one is the most important for plant growth and development. (4)
5 Answer the following questions about soil moisture.
  a Name three types of soil water. (3)
  b Ascribe each of these properties to one of the 3 types of soil water.
    i found in soil macro pores
    ii held on particle surface by adhesion forces
    iii found in soil micro pores
    iv not available to plants because held tightly by roots
    v held against pull of gravity. (5)
  c Fill in the missing word: Soil water content is a function of water supply and water _______. (1)
  d Name four factors that contribute to the missing word provided in (c) above. (4)
6 One of the main factors influencing soil temperature is soil cover.
  a Explain (3)
  b State one way in which this can be measured. (1)
7 Briefly compare topsoil and subsoil. (4)
8 Name the system used to classify soils and list three benefits of soil classification in agriculture. (4)
9 Explain the term 'soil colloid' and give two examples. (4)
10 Explain the difference between active acidity and reserve acidity. (2)
11 State four methods to prevent or control soil alkalinity. (4)
12 Describe the phosphorus cycle and include the terms mineralisation and solubilisation in your answer. (6)
13 Explain the symbiotic relationship between *Rhizobium* bacteria and plants. (3)
14 Explain how the decomposition of organic matter can influence global warming. (4)

Total: 70

Topic 3

Plant studies

Overview

TOPIC 3 Page 78
Plant studies

UNIT 1 Page 80 – Plant nutrition and photosynthesis
- Photosynthesis and respiration
- Pigment and photosynthesis
- Light and dark phases of photosynthesis
- Food storage in plants
- Rate of photosynthesis

UNIT 2 Page 84 – Water and nutrients
- The importance and functions of water in plants
- The movement of water from the soil to the roots of plants
- Osmosis and diffusion in plant cells
- Movement of water in plants and into the atmosphere
- Adaptation of plants to reduce transpiration rate
- Movement of the products of photosynthesis

UNIT 3 Page 87 – Mineral nutrition
- An introduction to macro- and micro-elements
- The different macro-elements
- The different micro-elements

UNIT 4 Page 91 – Plant nutrient uptake and analysis
- Types of plant nutrient or mineral uptake
- Forms in which nutrients or minerals are available to plants
- Factors affecting the availability of nutrients to plants
- Importance of nutrient element analysis in crop production
- Methods to determine nutritional status of soil

UNIT 5 Page 94 – Organic and inorganic fertilisers
- An introduction to fertilisers
- The main inorganic fertilisers and their impact on the environment
- Agricultural lime
- The use of gypsum

UNIT 6 Page 98 – Organic fertilisers and fertilisation practices
- Main types of organic fertilisers
- The concept: green manure
- Description of farm manure
- Description of compost
- Fertilisation practices

UNIT 7 Page 101 – Plant reproduction: Sexual reproduction
- Sexual reproduction in plants
- Fertilisation process in plants
- Seeds and fruit setting
- Seed germination

Topic 3

Plant studies

Overview

TOPIC 3 Page 78
Plant studies

UNIT 8 Page 108
Plant reproduction: Asexual reproduction

- Types of asexual methods of reproduction
- Oculation and grafting
- Advantages and disadvantages of asexual plant propagation methods

UNIT 9 Page 115
Plant improvement and biotechnology

- Plant improvement
- Biotechnology

UNIT 10 Page 118
Weed management control

- Weeds and herbicides
- The impact of weeds on agriculture
- Features of weeds that make them successful
- Agents of weed dispersion or transmission
- Methods of weed control

UNIT 11 Page 123
Plant diseases and pest control

- Plant diseases and their control
- Pesticides, plant pests and their control
- Integrated pest management (IPM)
- Insect control in stored seed and grass
- Plant protection and the state

Unit 1

Plant nutrition and photosynthesis

1 Photosynthesis and respiration

1.1 Photosynthesis

- Converts light energy into the chemical energy of sugars and other organic compounds, i.e.
  - $CO_2 + H_2O$ + energy sun → carbohydrates + O_2
    - chemical energy is stored in the form of glucose (a carbohydrate)
    - secondary products: other carbohydrates, lipids, proteins.
- Photosynthesis process occurs mainly within the leaves:
  - CO_2 is obtained through stomata
  - H_2O is obtained through the roots
  - sunlight is absorbed by chlorophyll located in chloroplasts – site of photosynthesis
  - O_2 is released through stomata.
- Importance of photosynthesis:
  - production and renewal of almost all the atmospheric oxygen
  - provision of food for all plants and animals
  - production of fossil fuels (coal, natural gas and oil) from plant and animal remains
  - reduction of CO_2 in the atmosphere.
- Energy produced is used in respiration.

1.2 Respiration

- Plants and animals break down energy-rich organic compounds into simple inorganic compounds
  - = release large amounts of energy for cellular work necessary for growth and reproduction, i.e.
    - carbohydrates + O_2 → CO_2 + H_2O + chemical energy.

Table 1 The differences between photosynthesis and respiration

Photosynthesis	Respiration
• produces food • stores energy • consumes H_2O • consumes CO_2 • releases O_2 • light-dependent	• consumes food • releases energy • produces H_2O • produces CO_2 • consumes O_2 • light-independent

2 Pigment and photosynthesis

- Pigments absorb light energy and provide energy. Main groups of pigments =
  - chlorophylls (provide green colour)
  - and carotenoids (provide yellow, orange or red colour).
- Chlorophyll pigments:
  - found in chloroplasts
  - trap energy from sun which supplies energy for photosynthesis
  - helps plants to form products needed for growth during photosynthesis
  - composed of central magnesium atom surrounded by several nitrogen-containing hydrocarbon rings with long hydrocarbon tails.

3 Light and dark phases of photosynthesis

Photosynthesis takes place in two phases: the light (or light-dependent) phase and the dark (light-independent) phase.

- Light phase:
  - occurs in the thylakoid membranes of the chloroplast
  - light energy → energy carried by electrons
  - energy in the electrons is used to make ATP (energy carrying compound) and NADPH which are used for the next main step
  - oxygen is a by-product.
- Dark phase (or Calvin cycle):
  - occurs in the stroma of the chloroplast
  - controlled by enzymes (therefore affected by temperature)
  - CO_2 is first incorporated into RuBP (ribulose biphosphate)
  - hydrogen and electrons from NADPH are added to form GP3 or PGAL (carbohydrate)
  - PGAL is used to make glucose and other carbohydrates for the plant.

4 Food storage in plants

- Plants store excess energy, nutrients or water in storage organs for future growth:
  - insoluble products take up less space
  - excess products are made insoluble by dehydration and hydrolysis reactions
  - temporary storage of starch occurs in leaf cells during the day.
- Food storage organs often grow underground as they are protected from herbivores:
  - storage organs =
    - roots / tubers / bulbs (e.g. carrots, radish)
    - stems (e.g. potato, sugarcane)
    - leaves (e.g. onion, lettuce)
    - seeds (e.g. peas, maize)
    - fruit (e.g. tomatoes, pecan nuts).

5 Rate of photosynthesis

It is the rate of O_2 production per unit mass (or area) of green plant tissues or per unit weight of total chlorophyll.

5.1 Factors affecting the rate of photosynthesis

5.1.1 Temperature

- Temperature = directly proportional to rate of photosynthesis and respiration:
  - photosynthesis reaches a maximum rate, which varies with different plant species
  - optimum temperature = temperature at which growth is the fastest
  - lower lethal temperature = temperature below which cells are killed.
- Farmers should choose plants according to area, season and time.

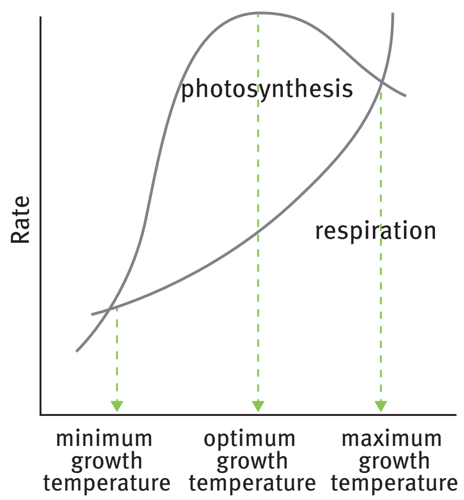


FIGURE 1 Rate of photosynthesis and respiration vs. temperature

5.1.2 Light

- Light = directly proportional to rate of photosynthesis (until optimum light intensity reached):
  - plant species differ in their optimum intensities
  - few crop plants grow well in shade
    - exception = sweet potatoes.

5.1.3 Carbon dioxide

- Carbon dioxide = directly proportional to rate of photosynthesis:
  - light and water must also be available.

5.1.4 Water

- Water → required for photosynthesis and transpiration:
  - shortage of water → causes growth to slow down or stop.

5.2 Manipulation of plants conditions to increase photosynthetic rate

- Temperature:
  - ensure enzymes have an optimal temperature range.
- Nutrients:
  - ensure that plants have optimum nutrients.
- Light:
  - increase light intensity under which crops grow
  - manipulate light colour in growing environment (chlorophyll absorbs red and blue light and reflects green, orange, and yellow light)
  - increase exposure time to light.
- CO_2 concentration:
  - increase CO_2 availability by adding $KHCO_3$ or $NaHCO_3$ to the water.
- Water:
  - insufficient water
    - → the plant's stomata will shut
    - → deprive plant of CO_2.

Unit 2

Water and nutrients

1 The importance and functions of water in plants

- Seed germination: mature seeds are dry and need water for metabolism and growth.
- Plant growth: cell division and expansion require water:
  - → lack of water minimises growth of new shoots and leaves, thus less sugar available for fruit growth
- Nutrient transport: mineral nutrients dissolve in soil water and are absorbed through roots.
- Photosynthesis: process whereby plants produce their food → requires water.
- Stomata: water content of guard cells determines whether they open or close stomata.
- Plant structure: water pressure in cells (turgor pressure) helps maintain their shape.
- Plant habitats: watery environments support aquatic plants, e.g. sea, rivers.

2 The movement of water from the soil to the roots of plants

- Roots draw up water and nutrients from the soil.
- Root hairs provide a large surface area for absorption.
- Water molecules containing mineral salts pass from the soil through the thin cell walls of the roots into the plant by osmosis:
  - mineral concentration is higher inside root cells than in the soil
    - → this creates root pressure (type of osmotic pressure)
    - this pressure forces water up, out of the root.

3 Osmosis and diffusion in plant cells

- Osmosis:
  - passage of water through a semi-permeable membrane
  - driven by osmotic pressure, i.e. tendency of pure solvent to move through semi-permeable membrane into solution with solute to which membrane is impermeable.
- Diffusion:
  - molecules spread from an area of high concentration to one of low concentration until an equilibrium is reached

Both processes involve movement of molecules down a concentration gradient (i.e. high to low) and do not require an external force.

4 Movement of water in plants and into the atmosphere

4.1 Movement of water from the roots to the stems and leaves

4.1.1 Osmotic flow and root pressure

- Water enters the roots by osmosis:
  - flow of water, called osmotic flow, is driven by a concentration gradient
  - water diffuses from root hairs to the xylem of the root, where sap is more concentrated than soil water
  - pushes existing water up the plant = called root pressure
    - → water moves up through the xylem of the root and stem.
  - BUT root pressure is not strong enough to move water very high up
    - → use transpiration pull.

4.1.2 Transpiration pull

- Driven by transpiration rate, facilitated by cohesion of hydrogen bonded water molecules:
  - water is lost through the stomata of leaves by transpiration
  - pulls up entire column of water into the petiole (leaf stalk) and plant leaves
  - uses capillary action (or capillarity).

4.2 Movement of water from the leaf to the air

4.2.1 Transpiration

- Transpiration = the evaporation of water from surface of plant leaves:
  - the sun warms water inside leaves and it changes to water vapour
  - vapour diffuses through the stomata (controlled by guard cells)
  - → allows mass flow of plant nutrition and water from roots to shoot.

4.2.2 Guttation

- Guttation = loss of water in liquid form from an uninjured leaf or stem:
  - occurs when pressure builds up in leaves at night due to lack of transpiration.

5 Adaptation of plants to reduce transpiration rate

5.1 Stomata (main adaptation)

- Stomata = tiny passages that allow exchange of gases between plant and atmosphere:
  - surrounded by guard cells that control whether stomata open or close
  - function of guard cells depends on their water pressure (turgor pressure) –
    - if full of water, stoma open (allow diffusion of CO_2)
    - BUT if they lose water, then stoma close.

- Stomata maintain a fine balance to ensure efficient photosynthesis but prevent dehydration, e.g.
  - usually open during daylight, respond to temperature and wind.

5.2 Special plant adaptations

- Xerophytes, e.g. succulents
  - during the day stomata close to retain water
  - at night, stomata open when water loss by transpiration is lower and CO_2 enters and is stored for use during daylight
  - leaves rolled inwards to conceal stomata.

5.3 Leaf adaptations

- Fewer or sunken stomata.
- Tiny or needle-shaped leaves reduce surface area.
- Thickness and size differ depending on whether in shade or sunlight.
- Shiny or waxy surfaces, covered in fine hairs, thick cuticles.

6 Movement of the products of photosynthesis

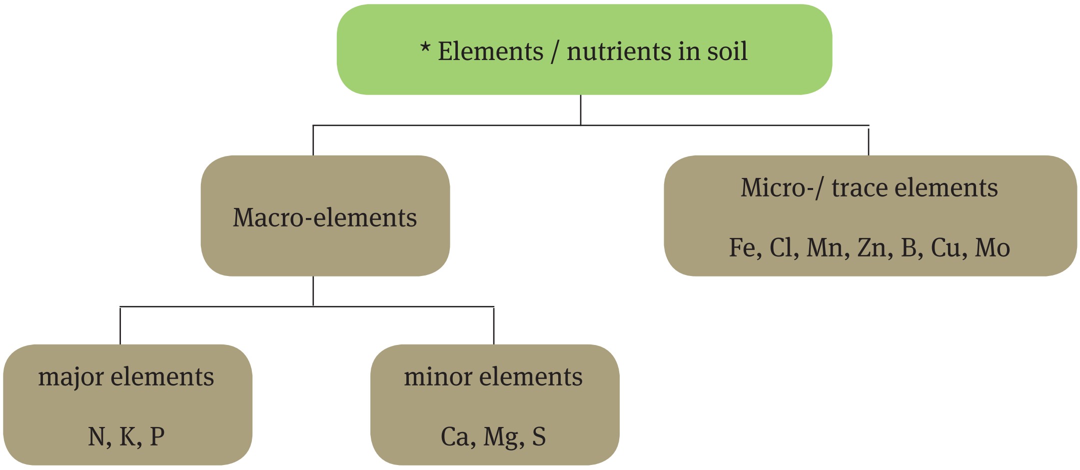
- Photosynthesis products are called photosynthates, e.g.
  - sugars, amino acids, fatty acids.
- Photosynthates = moved from where they are made (the source) to where needed (the sink) via the phloem:
  - pressure gradient between source and sink drives sap along the phloem tubes.
  - Source: cells load photosynthates into the phloem
    - → water moves in from xylem ducts by osmosis
    - → sap pushed along the phloem (called translocation).
  - Sink: photosynthates transported out the phloem
    - → sugars consumed or converted into starch.

Unit 3

Mineral nutrition

1 An introduction to macro- and micro-elements

This schematic shows the different types of element found in soil with examples of each.



* Other essential elements for normal growth: C, H, O – found in air and water

- Macro-elements: required for plants to thrive → used in relatively large amounts (the same definition applies to major elements).
- Micro-elements: not needed as much as macro-elements → used in smaller amounts (the same definition applies to minor elements).
- Form(s) in which elements are taken up by plants:
  - Major elements: N as NH_4^+, NO_3^-; K as K^+; P as $H_2PO_4^-$, HPO_4^{2-}
  - Minor elements: Ca as Ca^{2+}, Mg as Mg^{2+}, S as SO_4^{2-}
  - Micro-elements: Fe as Fe^{2+}, Fe^{3+}; Cl as Cl^-; Mn as Mn^{2+}; Zn as Zn^{2+}; B as $H_3BO_3^-$, Cu as Cu^{2+} and Cu^{3+}; Mo as MoO_4^{2-}.

2 The different macro-elements

Table 2 Major macro-elements

Nitrogen (N)	Phosphorus (P)	Potassium (K)
Uses		
• constituent of proteins, nucleic acids, hormones, co-enzymes and chlorophyll; • promotes vegetative growth (by changing carbohydrates to proteins)	• constituent of proteins, nucleotides, phospholipids, and ATP; • thus: promotes cell division, shortens growth period, improves fertility and seed production, improves nutrient value and disease-resistance of crops, improves keeping properties of fruit, vegetables and cereals	• regulates flow of soil water; • catalyses reactions for: enzyme activation, protein synthesis, starch synthesis and translocation, nitrate translocation, control of stomata; • efficient photosynthesis thus: improved yield and disease-resistance of crops; • development of root system

Table 2 Major macro-elements		
Nitrogen (N)	**Phosphorus (P)**	**Potassium (K)**
	Forms	
• major form: NO_3^- in soil water; • NH_4^+ also in soil water; • urea converted to NH_4^+ and used as foliar feed	• inorganic: $H_2PO_4^-$ (major form) • organic: absorbed as phytin, phospholipids and nucleic acids (not usually natural)	• K^+ ions from soil water
	Symptoms of deficiency	
• stunted growth; • yellowing of older leaves; • leaves become brown or die (severe)	• purple, discoloured leaves; • reduced: growth, flower, seed and fruit production, nutrient value, keeping quality	• leaf scorch
	Symptoms of toxicity	
• result of excess NH_4^+; • crops and cereals become excessively succulent; • poor quality fruit; • falling or scorched leaves	• early ripening / excess crops; • small fruit spoil quickly; • scorched leaf tips; • leaves become yellow	• acidic and sour citrus fruit; • scorched leaf tips

Table 3 Minor macro-elements		
Magnesium (Mg)	**Calcium (Ca)**	**Sulphur (S)**
	Uses	
• constituent of chlorophyll; • activates enzymes for carbohydrate and protein metabolism; • with sulphur, increases rate of lipid synthesis	• stabilise membrane structure; • makes cell walls rigid; • required for activation of some enzymes; • development of growth tips and roots	• constituent of two amino acids and some vitamins; • activation of certain enzymes
	Forms	
• Mg^{2+} ions in soil water; • $MgSO_4$ (Epsom salts) and dolomitic lime supplements	• Ca^{2+} in soil water; • bonemeal, lime and gypsum contain Ca (applied to soil)	• SO_4^{2-} ions in soil water
	Symptoms of deficiency	
• chlorosis	• leaves chlorotic and curled; • stunted plant; • poorly developed roots; • poor nutrient uptake	• slender plants; • yellowing leaves; • decreased growth rate
	Symptoms of toxicity	
• never seen under natural conditions	• rarely seen; • insoluble phosphate salts form, thus P deficiency	• unlikely; • scorched edge in older leaves

3 The different micro-elements

Table 4 Properties of the trace element, iron (Fe)		
Uses	**Forms**	**Deficiency and toxicity**
• component of electron transport proteins; • needed for chlorophyll formation	• soluble iron salts in soil water (e.g. $FeSO_4$); • iron chelate in foliar spray	Deficiency: • occurs on calcareous soils - insoluble iron salts precipitate at high pH; • susceptibility varies between plants; • starts in young leaves which show interveinal chlorosis; Toxicity: • none in natural conditions

Table 5 Properties of the trace element, manganese (Mn)		
Uses	**Forms**	**Deficiency and toxicity**
• required for photosynthesis; • co-factor in respiration and N metabolism	• Mn^{2+} in soil water; • Mn^{2+} in foliar spray	Deficiency: • young leaves are chlorotic, woody stems; brown necrotic spots in middle of legume seeds; Toxicity: • only due to poor fertilisation practices

Table 6 Properties of the trace element, copper (Co)		
Uses	**Forms**	**Deficiency and toxicity**
• constituent of electron transport proteins, enzymes that catalyse respiration reactions	• Cu^{2+} in soil water; • $CuSO_4$ solutions as foliar spray	Deficiency: • similar to chlorosis; • young maize leaves yellow, stunted; • reduced growth in apples; Toxicity: • rare in plants

Table 7 Properties of the trace element, zinc (Zn)		
Uses	**Forms**	**Deficiency and toxicity**
• activation of various enzymes (main function); • synthesis of a precursor of auxins (plant hormones)	• Zn^{2+} ions in soil water; • Zn^{2+} as a foliar spray	Deficiency: • maize: chlorosis, reduced growth, brownish-purple stripes on stem; • fruit trees: lower leaves are small, light, curled edges; Toxicity: • severe stunting, interveinal chlorosis

Table 8 Properties of the trace element, molybdenum (Mo)		
Uses	**Forms**	**Deficiency and toxicity**
• component of enzyme that converts nitrates to nitrites; • essential for nitrogen fixation by bacteria	• MoO_4^{2-} in soil water; • sodium molybdate as foliar spray	Deficiency: • interveinal chlorosis; • cabbage family: tall, slender plants Toxicity: • rare unless excessive Mo spraying

Table 9 Properties of the trace element, boron (B)		
Uses	**Forms**	**Deficiency and toxicity**
• aids sugar translocation during carbohydrate metabolism; • influences nucleic acid cell content at growth tips of roots and stems	• H_3BO_3 in soil water; • borax as a supplement	Deficiency: • apples and tomatoes: internal cork; • root crops: brown or black heart; • celery: stem-crack occurs; • multiple small new stems form; Toxicity: • N and B most common toxicity due to poor fertilisation practices; • stunted plants

Table 10 Properties of the trace element, cobalt (Co)		
Uses	**Forms**	**Deficiency and toxicity**
• role as essential micro-nutrient has not been established	none	Deficiency: • none in plants, grazing stock show evidence of wasting disease or pining Toxicity: • rare in grazing fields; • tomatoes: chlorosis, very dark green or deformed leaves

Unit 4

Plant nutrient uptake and analysis

1 Types of plant nutrient or mineral uptake

1.1 Passive ion uptake

- Nutrient elements diffuse from soil water into the root down the concentration gradient:
  - requires no energy
    - i.e. = passive
  - rate depends on steepness of concentration gradient.

1.2 Active ion uptake

- Absorbs nutrient elements from soil water against concentration gradient:
  - requires energy
    - i.e. = active
  - carried out by transport carrier molecules that supply this energy (i.e. ATP)
    - → ATP binds the nutrient and transports it one-way across the membrane.

2 Forms in which nutrients or minerals are available to plants

Table 11 Nutrient forms of phosphorus, potassium and nitrogen

Phosphorus (P)	Potassium (K)	Nitrogen (N)
Organic: Ca^{2+} bound as mono-, di- (available) or tricalcium phosphates (unavailable); SA has little but available from nucleic acids, phospholipids, phytin **Inorganic:** bound in iron or aluminium compounds – called fixed phosphates (unavailable)	total K content high but most unavailable to plants; equilibrium between different types of potassium **Soluble K:** in salts KCl and K_2SO_4 (available) **Fixed K:** fixed by some clay minerals (available) **Adsorbed K:** adsorbed to negative charge on clay particle (available) **K in rock minerals:** unavailable but reserve (after soil-forming processes)	**Gas:** unavailable directly except in legume family that uses *Rhizobium* nitrogen-fixing bacteria **Organic:** main N source; from manure, compost, fertilisers (available after decomposition by microbes) **Ammonium (NH_4^+):** end product of protein decomposition (available); adsorption to clay colloids prevents leaching **Nitrates (NO_3^-):** major form absorbed (available); does not adsorb to soil colloids, thus some leaching

3 Factors affecting the availability of nutrients to plants

- Soil pH.
- Presence of other nutrients.
- Leaching: leads to draining of mineral salts from the topsoil to subsoil where unavailable.
- Crop removal: clean clearing, deforestation or cutting down of harvested crops.
- Oxidation and reduction: changes state of mineral salts, thus salts may be washed away.
- Burning: reduces plant nutrients.
- Erosion: removes soil nutrients.

Table 12 Factors affecting availability of P, K and N to plants

Phosphorus (P)	Potassium (K)	Nitrogen (N)
Soil pH: determines form of P thus availability; $H_2PO_4^-$ is preferred ionic form **moisture content:** determines amount that can dissolve in soil water **Activity of micro-organisms in organic matter:** use inorganic P (decrease availability); produce organic acids and decay products (increase availability) **Other elements in the soil:** excess calcium forms are unavailable $Ca_3(PO_4)_2$	**Alternative dying out and wetting of soil:** clay minerals fix potassium when soil dries out **Other elements in the soil:** excess calcium causes K exchange on clay surfaces, increasing K content of soil water (available but susceptible to leaching) **Type of clay mineral:** some clay minerals have high adsorption capacity, thus low potassium availability	**Application of organic matter:** improves nitrogen content; initially ammonium and nitrates used by microbes (i.e. nitrogen negative period); microbes multiply and die, releasing nitrogen back into soil **Soil air:** aerobic bacteria that decompose organic matter need well aerated soil **Moisture content:** aerobic soil microbes need water to function, but excess water prevents them receiving O_2 **Soil type and soil pH:** influence microbe activity **Other factors detrimental to soil microbes:** high salinity, disinfectants and poisonous substances

4 Importance of nutrient element analysis in crop production

- Well managed nutrient levels help achieve profitable yields:
  - → farmers should conduct soil nutrient element analysis to determine additional nutrients required for optimum crop production.

Common terms used to describe nutrient levels:

- deficient: low concentration that severely limits yield
- insufficient: level below that required for optimum yields, symptoms seldom evident
- sufficient: adequate levels for optimum crop growth
- excessive: level high enough to cause shortage of another nutrient
- toxic: levels high enough to reduce plant growth or cause death of plants

5 Methods to determine nutritional status of soil

5.1 Soil sample analysis

- Soil sample analysis = usually done before planting:
  - contact analytical laboratory for questionnaires and packets
  - keep samples for each land unit, and topsoil (10) and subsoil (5) separate
  - draw representative sample from mixed sub-samples
  - place in clean bag (plastic, cloth or hessian), identify and deliver with questionnaire.

5.2 Plant or leaf sample analysis

- Plant or leaf sample analysis = done when crop is already growing:
  - leaf sample taken to laboratory where it is washed, dried and stored
  - representative sample taken at a certain time of the year
  - pick 10–20 young, mature healthy leaves (at least 10 undamaged) before 10:00
  - do not wash, place in clean plastic bag and deliver to laboratory immediately.

Unit 5

Organic and inorganic fertilisers

1 An introduction to fertilisers

- Fertiliser = organic or inorganic material of natural or synthetic origin (other than liming materials) that is added to soil to supply plant nutrients:
  - six macro-nutrients: N, P, K, Ca, Mg, and S
  - seven micro-nutrients: B, Cl, Cu, Fe, Mn, Mo, and Zn.
- Organic fertilisers = composed of decayed organic matter
  - → broken down into humus by micro-organisms and soil animals.
- Inorganic fertilisers = chemical preparations consisting of inorganic salts applied to soil or directly to plants
  - → referred to as artificial or commercial fertilisers.

2 The main inorganic fertilisers and their impact on the environment

2.1 Nitrogenous fertilisers

They usually contain the words 'ammonium' or 'nitrate' or 'urea' in their names.

Table 13 Main types of nitrogenous fertilisers

Urea, $CO(NH_2)_2$	**Limestone ammonium nitrate (LAN), $CaCO_3NH_4NO_3$**	**Ammonium sulphate, $(NH_4)_2SO_4$**
contains highest nitrogen content of 46%; released in the form of NH_4^+ by hydrolysis	mixture of $CaCO_3$ and NH_4NO_3; nitrogen supplied by NO_3^- and NH_4^+ (80% of LAN)	contains 21% nitrogen as NH_4^+, and 24% sulphur as SO_4^{2-}
consists of regular, round, white granules that are water soluble; NH_4^+ adsorbed to soil colloids and released slowly, not readily leached	consists of large, irregular, grey-white granules that are water soluble; NH_4^+ adsorbed to clay colloids, not readily leached except when oxidised to NO_3^-; NO_3^- immediately available but easily leached	
uses: replenish nitrogen, as foliar spray, in irrigation water	uses: replenish nitrogen at planting time and as a top-dressing, and on acid, sandy soils ($CaCO_3$ increases pH)	uses: common as fertiliser: sulphate reduces pH, release of NH_4^+ forms acid which also lowers pH

2.2 Phosphorus fertilisers

2.2.1 Rock phosphate (or Langfos)

- Raw phosphate found in basic slag and rock phosphate.
  - Basic slag
    - → contains 9,5% phosphorus, fine dark grey powder, readily available, no leaching, good residual effect, must be ploughed deep into soil before seeding and planting.
  - Rock phosphate
    - → contains 12% phosphorus, fine yellow powder, not readily available, no leaching, slow uptake, cheap, must be ploughed deep into soil before seeding and planting, used in acid soil to supplement phosphorus.

2.2.2 Superphosphate (monocalcium phosphate, $Ca(H_2PO_4)_2$)

- Most popular fertiliser for supplying readily available phosphate:
  - whitish-grey granular fertiliser
    - contains 11,3% phosphorus
    - readily soluble and available
    - usually contain 50% gypsum (to prevent consequent sulphur deficiency)
    - soon precipitates with calcium, not easily leached, less available to plants
    - used to supplement phosphorus at or before planting.

2.3 Potassium fertilisers

They typically contain the words 'potash' or 'potassium' in their names.

Table 14 Types of potassium fertilisers

Potassium chloride, KCl	Potassium sulphate, K_2SO_4
• contains 50% potassium	• contains 40% potassium
	• uses: for crops which do not tolerate KCl, supplement K where KCl unsuitable due to high chloride soil content
• white salt	• white salt
• water soluble, immediately available, adsorbed to soil colloids thus not leached	• water soluble, immediately available, adsorbed to soil colloids thus not leached

2.4 Mixed or compound fertilisers

- Mixture of nitrogen (N), phosphorous (P) and potassium (K):
  - also contain other minerals, e.g.
    - sulphur (S).
- Each type is designated by a number, e.g.
  - 2:3:2 (24) means the ratio of N to P to K is 2:3:2 and 24 kg out of 100 kg are minerals.

Calculation of the percentage plant nutrient in mixed fertilisers

Example: Calculate the percentage of nitrogen in the fertiliser mixture 2:3:2 (24).

Answer:

- The total quantity of all three nutrients together in 100 kg of the mixture is 24 kg.
- The sum of the parts of each nutrient is 2 + 3 + 2 = 7.
- Mass of N in 100 kg mixture = $\frac{2}{7}$ of 24 = 6,8 kg or 6,8%

2.5 Impact of inorganic fertilisers on the environment

- Environment negatively affected when fossil fuels are burned during their production:
  - release substances that contribute to acid rain and greenhouse effect
  - cause water contamination
  - does not add any organic material into the soil, thus organic material is depleted by soil micro-organisms
  - contain sulphuric acid and hydrochloric acid which increase soil acidity, thus decreasing nutrient availability and killing *Rhizobium*, a nitrogen-fixing bacteria.

3 Agricultural lime

- Two forms of agricultural lime:
  - calcitic lime: finely ground limestone, 80–90% $CaCO_3$, < 14% $MgCO_3$
  - dolomitic lime: finely ground limestone, 80% $CaCO_3$, > 14% $MgCO_3$.
- Application of lime:
  - need for lime application is determined by pH
  - soil characteristics determine quantity required
  - apply three months before planting and before rainy season
  - should be ploughed in deeply.
- Benefits of lime:
  - physical effect → improves soil structure
  - chemical effect → raises pH thus nutrient availability
  - biological effect → increases activity of soil microbes due to pH change.

4 The use of gypsum

Gypsum is calcium sulphate ($CaSO_4$) bonded to two molecules of water.

- Has many agricultural uses based on the fact that gypsum provides calcium ions:
  - improves soil structure
    - → provides calcium which flocculates clays in soil
    - → decreases swelling and cracking in certain clayey soils
  - helps prevent soil erosion

  - → makes soils more water permeable
- prevents waterlogging of soil
  - → improves soil infiltration rate and hydraulic conductivity
- corrects subsoil acidity
  - → prevents surface crusting and decreases the effects of toxic soluble aluminium
  - → of particular value as it reaches the subsoil which lime does not
- helps reclaim sodic soils
  - → supplies calcium which replaces sodium held on clay colloids, thus allowing sodium to be leached
  - → also decreases pH to values conducive to growth of most crops
- makes use of low quality irrigation water possible
  - → reclaimed water is useable if gypsum and water-soluble polymers are added
  - → sodium build-up in lower horizons is possible
- decreases heavy-metal toxicity
  - → calcium prevents excess uptake of many heavy metals and prevents adverse effects if they reach high levels
- decreases toxic effect of sodium chloride salinity
  - → calcium inhibits sodium uptake
- helps to keep clay off tuber and root crops
- decreases loss of fertiliser nitrogen to air
  - → calcium decreases loss of nitrogen from ammonium by volatilisation
  - → calcium also improves nitrogen uptake in young plants
- improves crop quality
  - → calcium ensures good fruit quality.

Unit 6

Organic fertilisers and fertilisation practices

1 Main types of organic fertilisers

- Plant-based organic fertilisers = kelp meal fertiliser, cottonseed meal, alfalfa meal, peat moss.
- Animal by-products = blood meal, bone meal, fish emulsion.
- Manure = farm manure, green manure (decomposing crop residue).

Compost → offers steady and slow release of all of the nutrients required by plants

Table 15 Impact of organic fertilisers on the environment

Positive effects	Negative effects
• provides minerals and improves structure; • helps soil to hold water; • helps extra water to drain from soil; • cools soil in summer and warms it in winter; • stops soil from becoming hard, compacted; • binds soil	• release nutrients into their surroundings (streams, rivers, estuaries); • overuse can dry out plants

2 The concept: Green manure

- Green manure = type of cover crop grown to add nutrients and organic matter to the soil, e.g.
  - legumes (used for their ability to fix nitrogen using bacteria).
- Characteristics of green manure crops:
  - easily obtained seed, grow rapidly, deep root system, strong feeder, high fibre content.
- Cover crop is still in an immature succulent stage. Can be achieved in two ways:
  - addition of green cuttings such as lawn clippings (small scale)
  - addition of natural weeds or especially sown crops (large scale).
- Application of green manure:
  - planted in the rainy seasons
  - should be ploughed in at a mature stage but before they seed
  - main crop should be planted immediately after green crop has decomposed.
- Benefits of green manure:
  - addition of organic matter improves soil structure (by forming soil aggregates)
  - increases nitrogen content of soil
  - through decomposition it releases nutrients held within the green manure
  - decreases water and nutrient loss (leaching) from soil
  - prevents soil erosion
  - assists in weed control and reduction of insect pests and diseases.

3 Description of farm manure

Farm manure = organic matter used as organic fertiliser in agriculture.

- Consists of dung or faeces and urine of domestic animals, material used for bedding (straw, peat, muck, leaves, sawdust, shavings) and vegetable refuse.
  - Animal manure = excreta (dung or faeces) of domestic farm animals:
    - rich in nitrogen, smaller amounts of all other minerals
    - slowly available to plants and not leached easily
    - valuable by-product of livestock farming
    - better to use dry manure to prevent scorching leaves.
  - Liquid manure = useful way to give minerals to plants while they are growing:
    - → immediately available to plants, but lost by leaching.
    - To prepare → fill cloth sack with animal manure and hang in a drum of water for 1 week.
    - Care needs to be taken not to get the liquid manure on the leaves or stems as it can burn them.

Factors affecting composition of farm manure

- type and age of animal from which manure obtained
- type of ration fed to animals
- type and amount of bedding incorporated
- storage and handling of manure.

4 Description of compost

Compost = organic matter that has been decomposed and recycled as a fertiliser and soil amendment.

- Contains all 14 minerals, but contains less nitrogen than manure.
- Preparation and requirements for compost production:
  - large amounts of organic material from remains of crops, clearing of weeds, pruned branches and leaves, by-products of food processing
  - source of nitrogen should be added
  - agricultural lime should be added
  - composting material must be packed in layers
  - heap must be kept moist, but not too wet.
- Beneficial effects of compost:
  - physical effects
    - → maintains and increases the organic content of soil
  - chemical effects
    - → contains almost all plant nutrients, but some may be in insufficient quantities
  - biological effects
    - → soil bacteria are added to soil.

- Organic products used as nutrient supplements:
  - spent mushroom compost, bone-meal, hoof and horn meal, dried blood meal, fishmeal, seaweed extract, ash.

5 Fertilisation practices

5.1 Soil applications

With soil applications, it is important to consider the water solubility of the fertiliser.

- Band placing:
  - fertiliser can be placed in a 'band' close enough to supply young plants with nutrients efficiently, but not cause salt burns to roots
  - common method of applying nitrogen and potassium fertilisers.
- Broadcasting:
  - uniform distribution of fertiliser over planting area (top-dressing)
  - usually worked or ploughed into the ground (base-dressing)
  - used for crops that cover the land.
    - Fertilisers that dissolve slowly require deep incorporation.

5.2 Foliar application

- Application of soluble fertiliser as fine spray or mist onto leaves with maximal coverage:
  - add dispersants and apply during active growth periods of crops
  - nutrients are readily available to plants
  - suitable for most soluble fertilisers.

5.3 Fertiliser application through irrigation

- Applied by means of irrigation water or specially designed implements:
  - irrigation systems can be used → microjet or drip irrigation are best
  - sprinkler irrigation can be used but → take care not to burn foliage.

5.4 Aerial application of fertiliser

- Also known as aerial topdressing:
  - involves aircraft that apply granular fertilisers (aircraft hire is costly)
  - fast and economical, and suitable for areas that may not be accessible
  - not suitable during windy periods.

5.5 Top-dressing and plant mixtures

- Can accompany band placing.
- Method replaces leached nitrogen while crop is growing:
  - → put nitrogen fertiliser onto wet soil around plants
    - = economical and effective.

Unit 7

Plant reproduction: Sexual reproduction

1 Sexual reproduction in plants

Sexual reproduction in plants = the reproduction of flowering plants by producing seeds → seeds formed after pollen from male part fertilises egg from female part of flower.

1.1 Functions and structures of the main parts of a flower

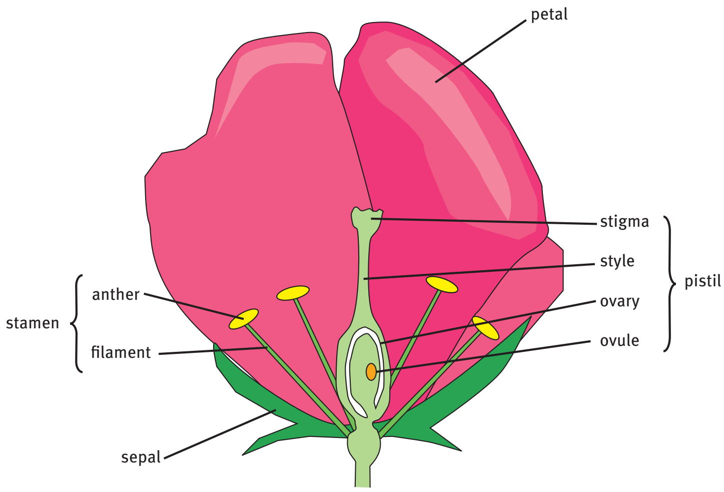


FIGURE 2 The main parts of a flower

- Female reproductive organ:
  - → called the pistil –
    - stigma is hairy and/or sticky to trap polled
    - ovary produces eggs or ovules.
- Male reproductive organ:
  - → called the stamen
    - anther produces pollen.
- Non-sexual parts:
  - → petals (collectively referred to as the corolla) and sepals (collectively referred to as the calyx)
    - they support the sexual parts
    - calyx protects the ovary
    - corolla attracts insects to the flower.

1.2 Pollination

- Pollination = process by which pollen is transferred in plants, enabling fertilisation and sexual reproduction:
  - pollen carried from anther to stigma
  - pollen grain grows downwards towards the ovary and fertilises an ovule
  - ovary forms the fruit, fertilised ovules develop into seeds.

Self- and cross-pollination

- Self-pollination: when pollen that reaches the stigma comes from the same plant; occurs in plants where petals cover the stigma.
- Cross-pollination: when pollen comes from a different plant of the same species; sometimes take place between species in the same genus. Cross-pollination is necessary to set fruit in two types of plants:
  - protandrous plants: male and females parts in same flower, but pollen shed before stigma ready to receive it
  - protogynous plants: pollen shed when stigma is old and can no longer receive it.

- Main agents of pollination:
  - insects: e.g. fruit and vegetable plants
    - flowers attract insects by producing nectar, strong smell and bright petals
    - some plants have specific pollinators.
  - small animals: e.g. birds, bats and mice (minor role in cross-pollination)
    - birds feed on nectar, flowers have strong smell and bright petals
  - wind: e.g. cereal plants
    - no nectar, strong scent or bright petals
    - male and female organs hang out of flowers.

1.3 The structure of a matured pollen grain and a receptive stigma

1.3.1 Matured pollen grain

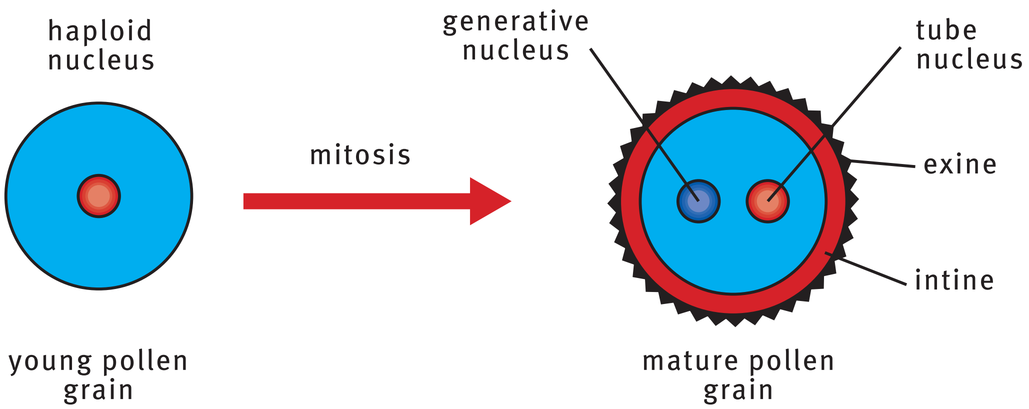


FIGURE 3 Structure of a mature pollen grain

- contains a tube nucleus and a generative nucleus
- generative nucleus divides to produce two sperm.

1.3.2 Receptive stigma

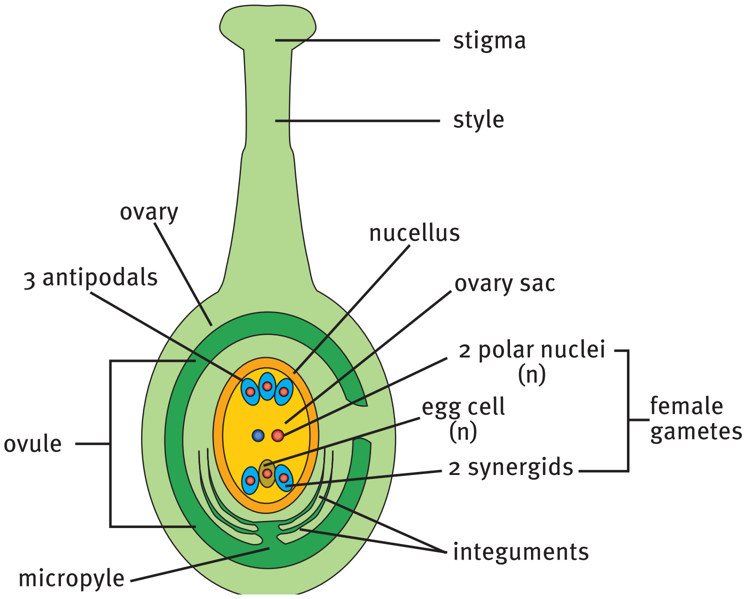


FIGURE 4 Structure of a receptive stigma

- micropyle: opening in the ovule walls for pollen to enter
- nucellus: provides nutrition of ovule growth.

1.4 The germination of a ripe pollen grain on a receptive stigma until fertilisation

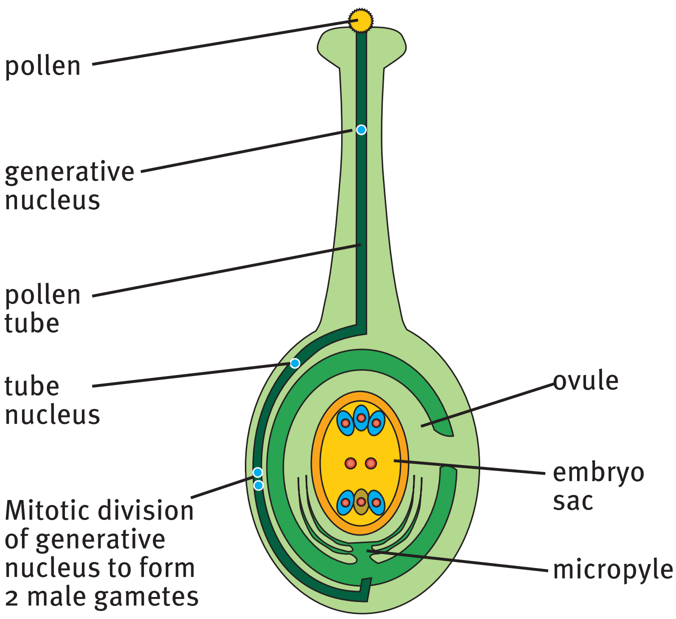


FIGURE 5 Germination of ripe pollen grain on receptive stigma until fertilisation

- Pollen grain lands on stigma and germinates, forming a pollen tube.
- Tube nucleus controls its growth.
- Generative nucleus travels down tube and undergoes mitosis.
- Tube moves through micropyle into the ovule to begin fertilisation.

2 Fertilisation process in plants

2.1 Fertilisation and double fertilisation

- Fertilisation = union of haploid male and female gametes to form a zygote:
  - pollen tube enters ovule via micropyle
  - → two male gamete nuclei are released into embryo sac
    - one fuses with egg nucleus → diploid zygote (2n)
    - one fuses with two polar nuclei → triploid endosperm nucleus (3n)
    - tube nucleus disintegrates.
- Endosperm = nutrient-rich tissue that nourishes developing embryo.
  - Referred to as double fertilisation because two sperm fuse with female gametes.

2.2.1 Development of a fertilised ovule to form a seed or fruit

- After fertilisation, zygote divides and differentiates into seed embryo:
  - as embryo matures, integuments (outer layers of ovule) harden into seed coat
  - ovule ripens to become a seed
  - ovary ripens around the seed to form the fruit.

2.2.2 The concept: parthenorcarpy

Parthenocarpy = fruit production without fertilisation of ovules, resulting in seedless fruit:

- Stimulative parthenocarpy: requires stimulation such as pollination.
- Vegetative parthenocarpy: no stimulation required:
  - occurs naturally, e.g.
    - wild parsnip
  - can be induced artificially if desired, e.g.
    - seedless grapes.

2.2.3 The concept: ablactation

Natural tendency of fruit trees to shed some of their immature fruits is called ablactation. Happens when:

- Crop is too large = strain the tree's resources and result in smaller fruits
    - → tree sheds fruit.
- Climatic conditions, like excessive heat
    - → tree will shed fruit (all of which use up moisture) to lessen the number of fruit that must use up resources.
- Also due to:
  - soil factors, like the availability of moisture and nutrients.
  - biological factors, like the presence of insects.
  - management factors, like the spraying of trees with chemicals.

3 Seeds and fruit setting

3.1 The concepts: fruit setting and seed germination

3.1.1 Fruit setting

- Fruit = plant structure that contains its seeds = mature or ripened ovary of a flower:
  - → setting occurs once flower petals fall and ovary has been stimulated to grow into a fruit.
- Mature fruit consists of:
  - exocarp (skin), mesocarp (fleshy tissue), endocarp (forms boundary around seeds)
    - → influenced by water shortage, pests, diseases, nutrient deficiency, heat and wind.

3.1.2 Seed germination

- Seed = small embryonic plant enclosed in covering or seed coat:
  - → occurs with fertilisation and depends fruit set.

3.2 Development of seeds or fruits from a fertilised flower

- Ovules develop into seeds → ovary ripens to form a fruit:
  - maturing seeds release a hormone
    - → stimulates ovary wall to develop into a fruit
  - other parts of the flower (petals, sepals and stamens) may fuse and ripen with the ovary to form the fruit –
    - upper part of seed → becomes main area of growth
    - lower part of seed → produces stalk which absorbs and manufactures nutrients.

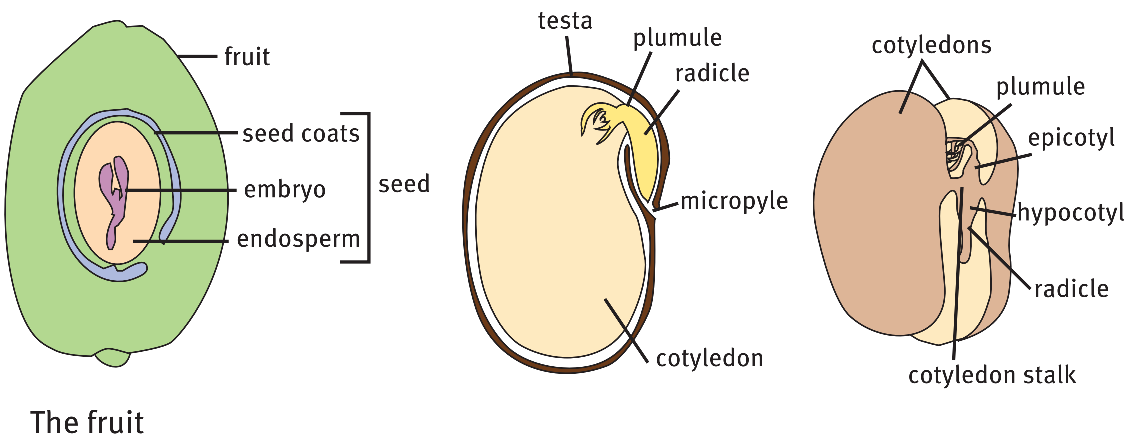


Figure 6 Seed structure within a fruit (a) the fruit showing the seed inside; (b) a longitudinal section of the seed; (c) diagram of a seed structure

3.3 Types of fruits according to their development

- Simple and compound fruits:
  - develop from single ripened ovary from a single flower
  - ovary may be simple (one pistil or carpel), e.g.
    - legume, nut
  - OR ovary may be compound (two or more fused carpels), e.g.
    - beans, mustard family.
- Aggregate fruits:
  - develop from separate ovaries fused together in a single flower
  - → called syncarps, e.g.
    - strawberries, blackberries.
- Multiple fruits:
  - ovaries develop separately into fruitlets
  - → cluster together and develop into single fruit with central core when mature, e.g.
    - pineapple, mealie.
- Accessory fruits:
  - fleshy fruits that contain other plant tissues in addition to the ovary, e.g.
    - entirely fleshy fruit (banana), the pome (apple), the pepo (cucumber), hesperidium (orange), drupe (peach), most aggregate and multiple fruits.

4 Seed germination

4.1 The process of seed germination

- Process 1: Imbibition
  - phase I: seed absorbs water
  - phase II: little absorption, increased enzyme activation and synthesis
  - phase III: further water uptake, seed coat ruptures, radical emerges.
- Process 2: Respiration – when seed absorbs water, it also respires (anaerobic but later aerobic).
- Process 3: Activation of enzyme systems – food reserves are activated.
- Process 4: Radicle emergence and seedling growth – radicles move downward and form the root, shoot (plumule) emerges and grows upward.

4.2 The concepts: seed dormancy and scarification

4.2.1 Seed dormancy

Seed dormancy = period of metabolic inactivity that precedes germination:

- germination will not occur even under favourable conditions
- dormancy period is broken by 'after-ripening'
- gives seeds better chance of survival.

4.2.2 Scarification

Scarification = methods used to bring seeds out of dormancy:

- → breaching of natural seed coat by mechanical, thermal or microbial methods
- → mimics natural processes that weaken the seed coat before germination.

4.3 The basic requirements for seed germination

- Water: seeds need water to germinate, soak overnight in water to improve germination.
- Air: air in soil required for germination.
- Suitable temperature: most seeds germinate best at approximately 25 °C:
  - Cool-requiring seeds: ≤25 °C, e.g. lettuce
    - some seeds need period of cold before germination, e.g. apple.
  - Warm-requiring seeds: ≥15 °C, e.g. tomato.
  - Cool and warm tolerant seeds: 5 °C–30 °C, e.g. carrot.
- Light: fresh seeds (not stored) require light, e.g. lettuce, many flowering plants
  - → put thin covering layer of soil over seeds.

Unit 8

Plant reproduction: Asexual reproduction

Asexual reproduction in plants is the reproduction from pieces of the parent plant other than the seeds.

1 Types of asexual methods of reproduction

1.1 Separation and division of stems and roots

- Plants can produce stems or roots that store food.
- After growing season, shoots die down → remain dormant in soil until next season.

There are four main types of specialised stems and roots:

- Bulbs:
  - = grown mainly for their flowers (except onions)
  - small, underground stems covered in fleshy leaves that store food
  - new green leaves and flower stalk emerge from bulb in growing season
  - buds grow on stems between leaves, e.g.
    - onion family (grown from seeds), lily, tulip.
  - To propagate:
    - → dig up, separate and plant bulbs immediately that have died down after growing season.
- Tubers:
  - = swollen ends of undergrounds stems
  - buds on tubers grow into new plants, which produce new tubers, e.g.
    - potato, yams and Jerusalem artichoke.
  - To propagate:
    - → planting whole tubers (preferable) or pieces of tubers (with at least one bud).
- Rhizomes:
  - = underground stems with buds at joins of scale-like leaves
  - new plants grow from buds to form clump of plants, e.g.
    - banana, strelitzia, many grasses.
  - To propagate:
    - → separate new plants off clump (each needs piece of rhizome stem and some roots) or divide rhizome (each piece must have two or more buds).
- Stolons (or runners):
  - = stems that grow at soil surface or just below ground (usually)
  - form adventitious roots at nodes, and new plants arise from buds at plant base
  - after formation of new plant, stolon usually dies away, e.g.
    - strawberry, many grasses.
  - To propagate:
    - → dig up new plants, cut them off the runner and transplant.

1.2 Cuttings

- Cuttings are pieces of stems, leaves or roots from which new plants grow:
  - stem cuttings develop roots
  - root cuttings develop shoots
  - leaf cuttings develop both shoots and roots.

1.2.1 Stem cuttings

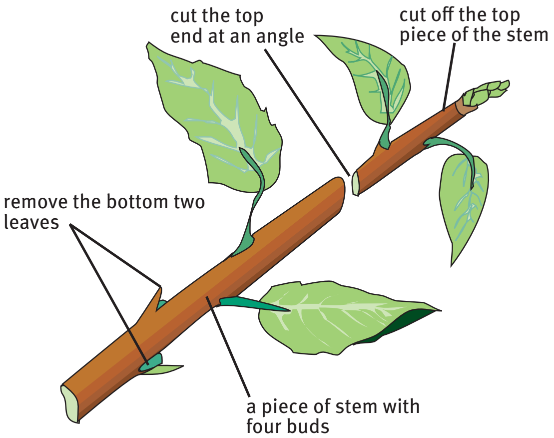


Figure 7 Taking a stem cutting

- Choose a healthy, productive plant.
- Do not plant upside down (i.e. angled end must be at the top).
- Dip bottom end into rooting hormone powder or liquid to improve rooting:
  - roots grow from the part in the soil, new stems grow from buds above the soil.
- Keep soil moist and keep in the shade until growing well.

1.2.2 Leaf cuttings

- Can consist of leaf alone, leaf attached to leaf stalk, or leaf attached to small piece of stem by leaf stalk (latter is actually a stem cutting):
  - shoot growth comes from bud between leaf and stem.

1.2.3 Root cuttings

- Usually taken in winter when plants not growing actively, e.g.
  - guava, apple, oriental poppy, white poplar, rose, blackberry.
- To propagate:
  - → plant cuttings horizontally in well-drained soil.

2 Oculation and grafting

- Oculation or budding = joining stem of one plant with buds from another so that they grow together as one plant.
- Grafting = joining stems of two different plants so that they grow together as one plant.
  - → Can only bud or graft together plants of the same genus.

- Scion = part of new plant that grows into the stem and branches.
- Rootstock = part of new plant that grows into the roots:
  - can be either cultivar (grown from cuttings or layering) or seedling rootstocks
  - cultivar preferred as characteristics are same as parent plant (i.e. known).
- Cambium = thin layer between bark and wood of stem:
  - it is the reason for success of oculation and grafting
  - can continue to grow after stem has been cut off
  - two cambium layers must be placed next to each other.

2.1 Successful oculation and types of oculation

- Only bud onto young plants or smaller branches of large plants.
- Can topwork young trees by grafting buds onto small branches of upper part of trees.
- Grafting buds can ensure stronger join and less wind damage:
  - = good method for small amount of scion wood.
- Time of the year is important:
  - bark must separate easily from wood of rootstock
  - buds must be dormant
  - rootstock must be growing actively.
    - → Late summer is best time.

2.1.1 T-budding

- Place bud 20 to 40 cm above soil.
- Bark must be smooth and protected from sun and wind.

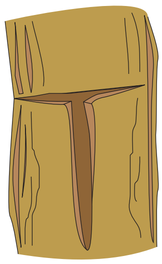


FIGURE 8 T-budding

2.1.2 Inverted T-budding

- Same as T-budding except T is inverted.
- Used to prevent rainwater or excess sap from running behind or into join.

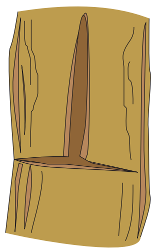


FIGURE 9 Inverted T-budding

2.1.3 Patch budding

- More difficult than T-budding.
- Used on plants with thick bark.
- Bark of bud wood and rootstock must easily separate from wood.

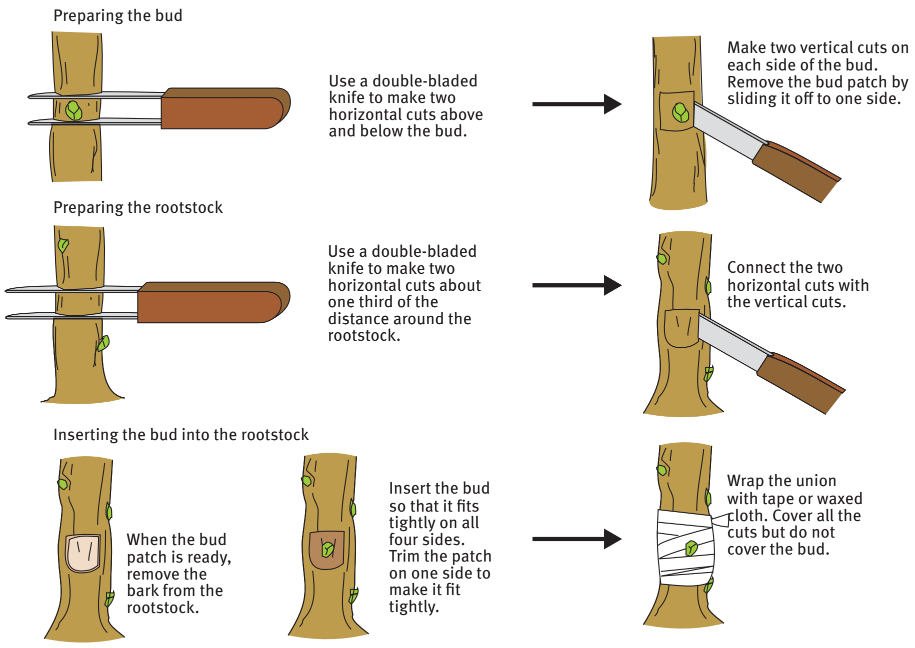


FIGURE 10 Patch budding

2.1.4 Chip budding

- Use if bark of rootstock does not separate from its wood.
- No protective flaps.

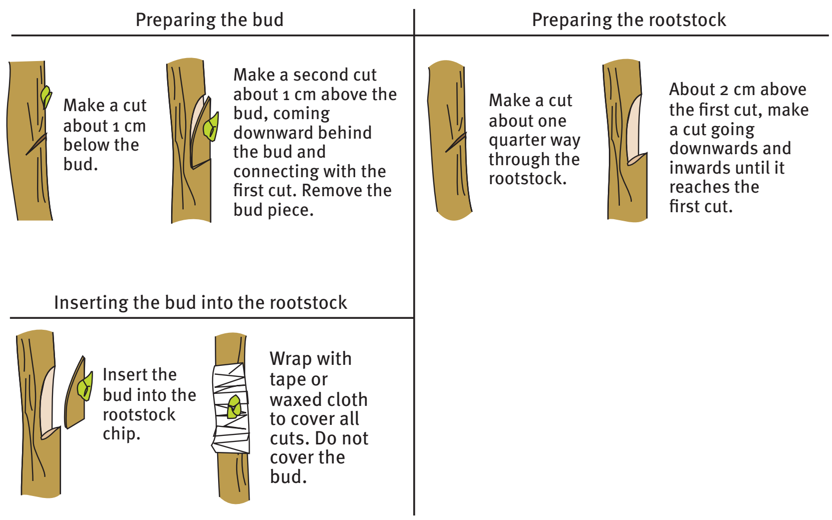


FIGURE 11 Chip budding

2.2 Types of grafting

Grafting = technique whereby vascular tissues from two plants are joined together:

- vascular joining is called inosculation.

2.2.1 Whip or tongue grafting

- Used to graft thin stems.
- Do in winter when plants are not growing.

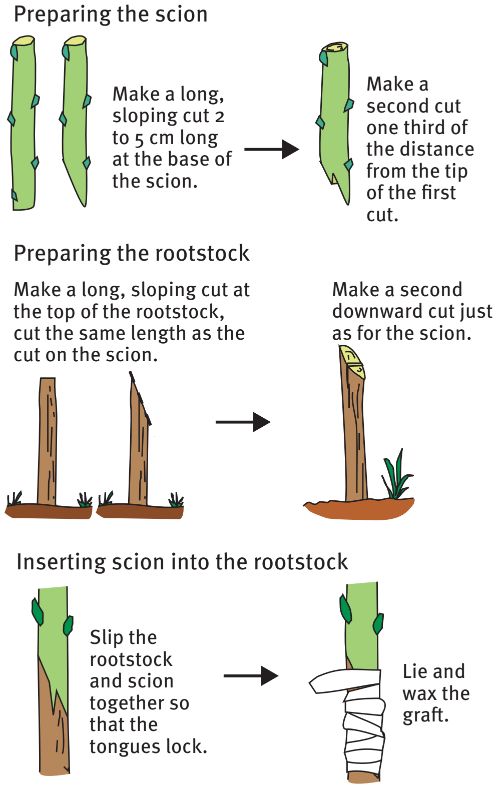


FIGURE 12 Whip or tongue budding

2.2.2 Cleft grafting

- Used for mango and avocado trees.
- Do in winter.

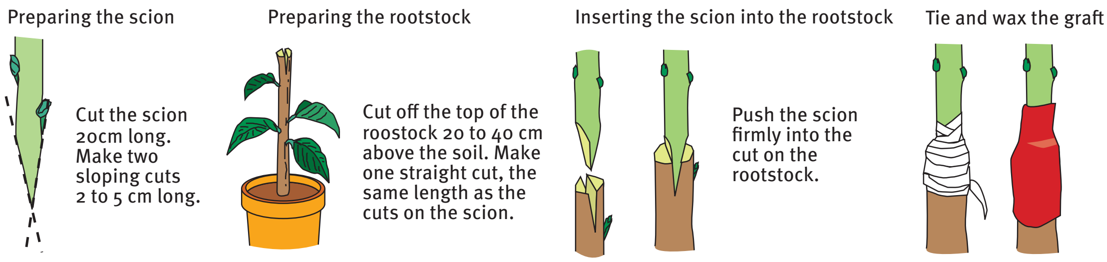


FIGURE 13 Cleft grafting

2.2.3 Wedge grafting

- Use for topworking trees.

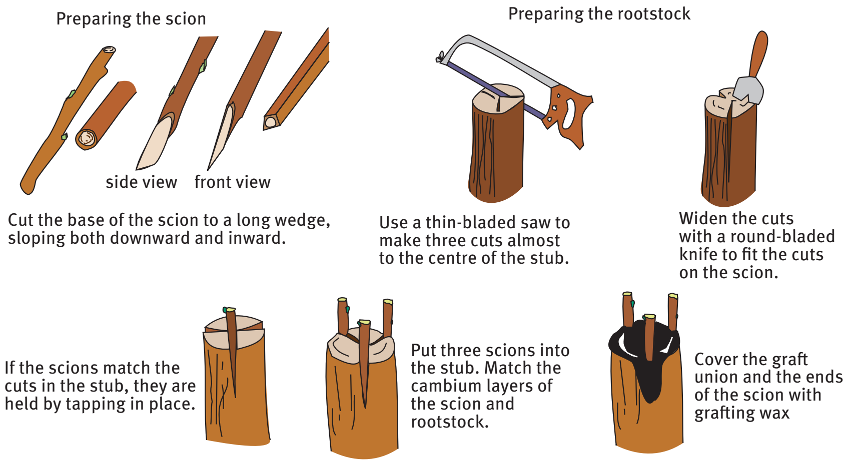


FIGURE 14 Wedge grafting

2.2.4 Approach grafting

- Use for trees that are difficult to graft, e.g.
  - mango and macadamia.
- Best time is during active plant growth.

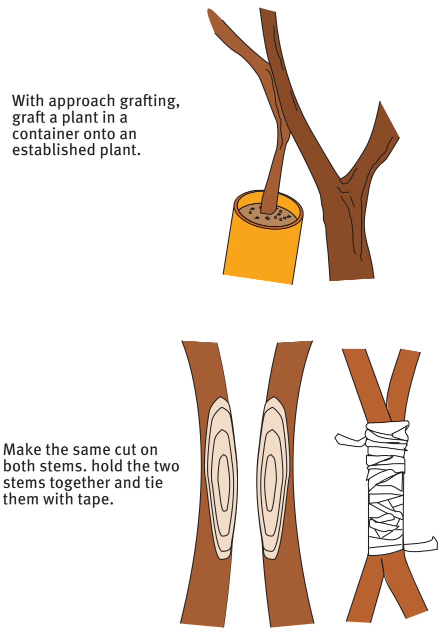


FIGURE 15 Approach grafting

3 Advantages and disadvantages of asexual plant propagation methods

3.1 Advantages

- Fast growth.
- Same as parent plant so all plant characteristics known and good characteristics retained.
- Bear fruit in the first year.
- Can be used to grow plants that do not produce seeds, e.g.
    - pineapples and bananas.

3.2 Disadvantages

- Plants may not grow in the same way as seed-propagated plants e.g.
    - indigenous trees have deep taproot to reach groundwater during dry periods, but trees grown vegetatively develop fibrous root system which does not help survive droughts.

Unit 9

Plant improvement and biotechnology

1 Plant improvement

1.1 Selection

Selection = process of improving cultivars by collecting seeds from the best plants:

- adapted to climate of the area
- resistant to pests and diseases found in those areas.

1.2 Hybridisation (hybrid seeds)

Hybridisation = form of crossbreeding or controlled cross-pollination in plants.

- Take pollen from flowers of one cultivar and place on stigmas of flowers of second cultivar (anthers of second cultivar have been removed to prevent self-pollination):
    - → hybrid plants usually better than both the parent cultivars.
- Use seeds of hybrid to plant next crop.
- May be used to produce disease-resistant plants.

1.3 Gene mutation

Gene mutation = exposure of seeds to chemicals or radiation to change seed DNA and generate mutants with desirable traits, thereby improving plant production.

- Sometimes called mutagenic plants or mutagenic seeds.
- Methods: exposure to gamma rays, protons, neutrons, alpha and beta particles.
- Wheat, barley, rice, potatoes, soybeans, onions = bred genetically.
- Genetic breeding has produced plants with these properties:
    - higher-yielding
    - resistant to pests, diseases and drought
    - adapted to environments and growing conditions of a region
    - improved qualities, e.g.
        - larger seeds, new colours, and sweeter fruits.

2 Biotechnology

Plant improvement methods are often imprecise or yield results slowly. Therefore → use biotechnology.

- Biotechnology = any technique that uses living organisms (or substances from these organisms) to make or modify a product for a practical purpose.
- Agricultural biotechnology = understanding and manipulating genetic make-up of organisms for use in production or processing of agricultural products:
    - → research into genome structure and genetic mechanisms that determine important traits is very promising.

2.1 Genetically modified plants and their characteristics

- Created by genetic engineering, i.e. movement of genetic material between organisms to change characteristics.
- Also called transgenic organisms.
- New characteristics include:
  - plants that are resistant to diseases, pests and stress
  - fruits and vegetables that stay fresh for longer
  - plants that possess healthy fats and oils and increased nutritive value
  - soybeans with a higher expression of naturally occurring anti-cancer proteins
  - higher value-added feed for livestock
  - higher fibre extraction rates in paper and pulp industry (lignin modification in trees)
  - biodegradable plastics, prophylactic and therapeutic vaccines.

2.1.1 GM crops in South Africa

- Examples = maize and cotton (insect resistant and herbicide tolerant), soybean (herbicide tolerant).
- GM crops: 51% yellow maize, 62% white maize, 80% soybean and 90% cotton.
  - Most popular: Bt insect resistant maize
    - *Bacillus thuringiensis* (Bt) is a bacterium toxic to certain insects
    - GM plant known as Bt cotton or Bt maize.
  - Second most widely used: Roundup Ready (RR) herbicide-tolerant maize
    - stalk borer resistance built into the seeds
    - less sensitive to harmful effects of herbicides.
- Stacked traits Bt+RR sales commenced in 2007.
- Field trials of drought-resistant maize varieties underway.

2.2 Advantages and disadvantages of genetic modified crops or plants

2.2.1 Advantages

- Environmental:
  - → fewer harmful chemicals washed into soil (farmers can use less pesticide on insect resistant plants).
- Health:
  - → produce healthier food (farmers use less pesticide on insect resistant plants).
- Economic:
  - → lower production costs (less susceptible to viruses and insects, hardier crops, reduced need for pesticides and/or herbicides).
- Yields:
  - → more consistent yields (less susceptible to disease, insects and herbicides); higher yields (improved seeds).

2.2.2 Disadvantages

- Environmental:
  - → indiscriminate use of weed killers on herbicide resistant crops (as they are less susceptible to these chemicals).
- Health:
  - → long-term effects have not been established.
- Economic:
  - → too costly for small-scale farmers (GM seeds include a 'technology fee')
  - → some traits do not benefit small-scale or subsistence farmers (e.g. herbicide resistance – if they cannot afford herbicides)
  - → seeds cannot be retained for breeding (due to patent).

Unit 10

Weed management control

1 Weeds and herbicides

- Weeds:
  - = plants not planted by farmer that compete with planted crop for space, sunlight, nutrients
  - → can be herbs, ground covers or creepers; annuals or perennials.
- Herbicides:
  - = chemicals that kill or interfere with growth of specific weed targets –
    - → act by altering metabolic processes but leave planted crop relatively unharmed
    - decompose rapidly in soil via microbial decomposition and hydrolysis.
- Common weeds:
  - Common blackjack (*Bidens pilosa*):
    - → seeds stick in clothing and animal hair and germinate in dense mats
    - → spreads fungus disease to potatoes, tomatoes, and cotton; easily controlled with post-emergence herbicides.
  - Common thorn apple (*Datura stramonium*):
    - = tall, aggressive growing, poisonous annual
    - → poisonous seeds found in thorny pods, contaminate maize grain.
- Morning glory (*Ipomoea* species):
  - = aggressive fast-growing creepers that smother or strangle crops
    - → trumpet-like flowers of various colours
    - → seeds germinate and grow rapidly, contaminate grain crops.
  - Creeping sorrel (*Oxalis* species):
  - = small plant with underground bulb or stolon
    - → difficult to remove as parts remain in the soil and regrow
    - contains oxalic acid which poisons livestock.
- Parasitic weeds = feed directly off other plants:
  - → e.g. dodder (*Cuscuta campestris*):
    - = yellow thread-like stems and seeds, lacks chlorophyll so cannot produce own food
    - → seeds germinate or it regenerates from pieces of stem
    - → reduces production or kills host plant (e.g. lucerne)
    - → must be physically removed and burned since herbicides ineffective.
  - → e.g. witchweed (*Striga asiatica*)
    - = indigenous semi-parasite of grass, maize and tobacco roots
    - → seeds (500 000 per plant) germinate near plants that secrete strigol
    - → well fertilised host plants can survive, beans can cause 'suicide germination'.

2 The impact of weeds on agriculture

- Can grow on poor, exposed soil that other plants cannot.
- → Sometimes referred to as pioneers:
  - prevent soil erosion and improve soil condition for later growth of other plants
  - compete with planted crops for resources and may affect their growth and health
  - seeds germinate more quickly and young plants grow rapidly
  - source of plants pests which spread to crop seedlings
  - encourage insects which damage crops
  - contaminate final product and interfere with crop harvesting.
- Alien or exotic weeds:
  - do not have natural predators in South Africa and can become invaders, e.g.
    - *Lantana* (South American bush spread by birds)
    - black wattles
    - *Sesbania* (grows along watercourses and drains natural springs)
    - bankrupt bush or *Seriphium plumosum* (dominate livestock grazing or pasture, make it unpalatable).

3 Features of weeds that make them successful

3.1 Adaptive features of weeds

- Hairs on stem or leaves → protects from herbivores, reduces water loss.
- Waxy or small leaves → reduces water loss.
- Multiple flowers or fruit → many seeds mean higher reproduction rate.
- Strong root system → grow in high erosion areas and nutritionally poor soil, maximise water uptake, roots not loosened easily.
- Root nodules containing nitrogen-fixing bacteria → allow growth in low nitrogen soils.
- Rhizomes → deep roots ensure spread easily and quickly, removal difficult.

3.2 Properties that allow weeds to grow more easily than crop plants

- Produce large seed quantities → germinate rapidly.
- Rapid growth → deprived crop seedlings of sunlight.
- Aggressive growth → choke plants or smothering crop seedlings.
- Spread efficiently → by wind, birds or animals.
- Resist harsh weather conditions (such as drought or cold).
- Produce growth-inhibiting substances (e.g. bankrupt bush).

4 Agents of weed dispersion or transmission

- Animals:
  - seeds pass through digestive tract (birds and mammalian herbivores) and are deposited in faeces
  - ants carry seeds to nests, discarded with other refuse
  - seeds or seedpods cling to animal fur and human clothing and then drop off.
- Machines:
  - seeds present in soil are exposed to light and air by ploughs during cultivation
  - farm vehicles transfer seeds stuck in their tyre treads.
- Wind and water:
  - wind spreads seeds that are tiny, have tufts of hair, and are 'winged'
  - plants break off at stem base and scatter seeds like a tumbleweed
  - seeds of wetland species float and are carried downstream (or blown by wind).
- Mechanical ejection:
  - release mechanism of mature seedpods, i.e. seedpods burst open and propel seeds away from plant, e.g.
    - *Oxalis stricta*.
- Other dispersion methods:
  - crop seeds or compost contaminated with weed seed.

5 Methods of weed control

5.1 Mechanical weed control

- Hand weeding:
  - → used when rows of plants are close together.
- Cultivation:
  - → remove weeds by hand using tools (e.g. hoes) within a month of appearance
  - do on hot dry days when weeds will die.
- Mulching:
  - → mulch between vegetable or crops rows will suppress and smother weeds.
- Solarising:
  - → black plastic laid on ground will absorb heat and kill underlying weeds.

5.2 Chemical (herbicide) weed control

5.2.1 Selectivity

- Herbicide selectivity = susceptibility or tolerance of different plants to herbicide:
  - → non-selective: kill most plants and could also kill the planted crop
  - → selective: at correct dose they kill weed but not crop.

5.2.2 Method of action

- = way in which herbicide acts on weeds:
  - → contact: only affects parts of plant onto which applied (usually the leaves)
  - → systemic: absorbed through roots and spread into whole weed by translocation.

5.2.3 Time of application

- = stage of weed development at which applied:
  - → pre-emergence: applied before weeds emerge, absorbed by developing root or shoot
  - → post-emergence: applied after weeds have emerged.

5.2.4 Application of herbicides

- Use correct herbicide and strictly according to instructions.
- Excessive use can lead to herbicide resistance.
- Available in various formulations:
  - powder, granules or liquid concentrate (diluted in water and spray)
  - granules for scattering in soil
  - gel for applying on stems or stumps
  - oils for diluting in diesel.
- Example = phosphorous herbicide group:
  - used post-emergence, non-selective, act systemically, inhibit amino acid formation
    - e.g. triazines and ureas, acetanelides, phenoxy compounds.

5.3 Biological weed control

- Uses natural organisms to control weeds → insect predators or fungal diseases.
  - example in South Africa:
    - cochineal bug (*Dactylopius ceylonicus*) eradicated prickly pear cacti (*Opuntia ficus-indica*) → bug was bred in laboratories and used to suck sap from leaves → spread by birds that visited prickly pears for fruit.
  - Pest must be highly specific to prevent spread to other plants.
- Advantages:
  - → environmentally friendly, self-sustaining, cost effective.
- Disadvantages:
  - → slow, unpredictable, relatively expensive.

5.4 Integrated weed control

- Integrated weed control = management approach to weed control focused on prevention rather than eradication.
  - Advantages:
    - → cost effective, labour effective, reduces reliance on chemical control.

- Principles of integrated weed control:
  - cultural methods → good seedbed preparation to minimise weed problems
  - optimal herbicide use → only when weeds susceptible, correct product for weed type, only if weather suitable, apply evenly
  - crop rotation → rotate or alternate to provide competition for weeds
  - total farm hygiene → managing weeds on farm as a whole.
- Other weed removal options:
  - = animals to graze non-poisonous weeds, burning of weeds, smother crops (e.g. lucerne).

Unit 11

Plant diseases and pest control

1 Plant diseases and their control

- Diseases caused in plants by pathogenic micro-organisms, e.g. viruses, bacteria and fungi:
  - → micro-organisms are adapted to invading plant tissues.

1.1 Type of plant diseases caused by micro-organisms

1.1.1 Viral diseases

- Symptoms:
  - = spotting, mottling, twisting, distortion, wilting, or death of leaves; bark of trees are less commonly affected.
- Methods of transmission:
  - = seeds –
    - → spread through pollen during fertilisation and then through seeds
  - = vegetative –
    - → subdivision by vegetative reproduction (bulbs, cuttings or runners)
  - = mechanical –
    - → by means of infected sap (by infected pruning or cutting tools)
  - = pests –
    - → sucking insects and nematodes transmit when piercing plant cells
- Mechanism:
  - → inhibit growth and prevent production, e.g.
    - mosaic virus (tobacco plants, tomatoes and maize), greening virus (citrus plants).

1.1.2 Bacterial diseases

Plant bacteria found in soil, on living plants, or on plant debris.

- Symptoms:
  - = rot, wilt, galls, spots, canker (similar to fungi).
- Transmission:
  - → infected seeds, wind, contact with infected plants.
- Mechanism:
  - → kills young plants, deforms leaves, rots leaves or stems, spoils fruit, e.g.
    - bacterial wilt of potatoes (caused by *Pseudomonas solanacearum*)
    - crown gall of tobacco (caused by *Agrobacterium tumifasciens*).

1.1.3 Fungal diseases

- Symptoms:
  - = characteristic pattern and discolouration of leaves.

- Transmission:
  - → fungi spores that are spread in soil or by wind or water.
- Favourable conditions:
  - = moisture, low light intensity, high humidity (during overcrowding), e.g.
    - damping off (horticultural crops)
    - downy mildew (vines)
    - powdery mildew (wheat, onions).

1.2 The control of plant diseases

1.2.1 Bacterial and viral plant diseases

- No treatment, so must prevent or control:
  - measures include –
    - → eradicate infected plants
    - → use clean seed, plant stock, and tools
    - → control plant pests
    - → do not smoke when handling plants
    - → ensure good soil condition and use disease-resistant cultivars
    - → rotate crops, use intercropping, and sow with recommended spacing.

1.2.2 Fungal plant diseases

- Use same methods as for bacterial and viral diseases:
  - fungicides:
    - → available for some diseases, use correct product and apply correctly, some seeds are pre-treated with fungicides.
  - watering early in the morning and avoid overcrowding of plants.

2 Pesticides, plant pests and their control

- Pesticides = substance used to prevent, destroy or repel pests.
- Pesticide formulations = chemical, biological, antimicrobial.
- Pests = invertebrate animals that feed on various plant parts, e.g.
  - arthropods (insects, mites), worms, molluscs (snails, slugs).

2.1 Plant pests

- Insects:
  - = six-legged arthropods or jointed-legged animals, e.g.
    - various bugs (aphids, leaf hoppers and scale insects)
    - grasshoppers
    - caterpillars (larval forms of butterflies and moths)
    - beetles
    - flies, ants and termites.
  - Some are beneficial because
    - → they eat pests or help pollinate crops and fruit trees.

- Mites:
  - = arthropods with eight legs –
    - → live in plant debris and feed on dead organic matter
  - Some are parasites
    - → damage crops.
- Molluscs:
  - = soft un-segmented bodies, some have protective shell
    - → most troublesome during wet seasons
    - → eat live plant material.
- Nematodes:
  - = tiny parasites found in soil and plant material
    - → found in huge numbers (up to 40 000 in roots of one potato plant).

2.2 Type of damage caused by pests on plants

- Damage on visible parts of plant (leaves, fruit, flower buds, stems, barks or roots) or seeds:
  - → prevents plant nutrition or reproduction.
- Sucking pests:
  - suck sap from plants
    - → affected parts dry out, deform and become mottled
  - found on undersides of leaves, e.g.
    - leaf suckers (aphids, thrips)
    - stem suckers (scale insects)
    - fruit suckers (moths, scale insects, mites, thrips).
- Chewing and stinging pests:
  - eat various parts of plants, causing damage or scarring, e.g.
    - leaf damage (grasshoppers, caterpillars)
    - flower damage on fruit trees (CMR beetles → prevents fruiting)
    - fruit damage (fruit flies → lay eggs in developing fruit or vegetable)
    - seedling damage (cutworms)
    - stem or root damage (termites, woodborers)
    - stored grain or seed damage (beetles, weevils, grain moth larvae).
- Eelworms:
  - = tiny nematode worms occurring in very large numbers in soil
  - → parasitic eelworms infest plant roots (e.g. tomatoes and potatoes)
  - → only controlled by soil fumigation.

2.3 The control of plant pests

2.3.1 Chemicals (pesticides)

- Pesticides = registered chemicals for use against pests:
  - also poisonous to animals and humans so use with care
  - trained operators required when using large quantities.

- Precautions when using pesticides:
  - use correct product, correct amount and at correct stage
  - ensure correct interval between application and harvesting
  - follow safety directions
  - do not dispose of into water sources.
- Methods of applying pesticides:
  - leaves → reapply, especially after rain
  - fruit → apply at certain stages, e.g.
    - to prevent fruit fly attacks
  - vegetables → apply post-emergence
  - stored grain and seeds → apply directly or into storage containers
  - soil → apply in granular form or as a fumigant.

2.3.2 Biological methods of pest control

- Involve the use of natural organisms to control pests:
  - predators → animals that eat plant pests, e.g.
    - ladybird larvae eat aphids
  - parasitoids → parasites that breed in the body of pests and then eat them from the inside, e.g.
    - very small wasps
  - transgenic plants → genetically modified, disease resistant plants, e.g.
    - BT maize (poisons bollworm that feed on maize).

3 Integrated pest management (IPM)

IPM is a pest management system that uses:

- good cultivation practices based on an ecological approach
- chemical and biological pest control methods.

IPM is based on five main principles.

1. Monitoring and record-keeping:
   - regular observation of crops, accurate pest identification, recording of pest behaviour and reproductive cycles.
2. Acceptable pest levels:
   - establish acceptable pest levels called action thresholds.
3. Preventive cultural practices:
   - select best varieties for local conditions, maintain healthy crops, quarantine plants, use of cultural techniques, e.g.
     - removal of diseased plants.
4. Mechanical and biological controls:
   - mechanical methods are first options, e.g.
     - handpicking, using traps; biological control via conservation of natural predators or their introduction.

5 Responsible pesticide use:
- only used as required and at specific times in pest lifecycle.

3.1 Benefits of integrated pest management

- Reduced exposure to hazardous chemicals → human and environmental, thus reduced cost of pesticide application.
- Environmental improvements to farms → enhance long-term sustainability.
- May be only solution to long-term pest problems.

3.2 Steps to follow in implementing integrated pest management

1 Proper identification of pests:
- → ensures effective action is taken.

2 Learn pest and host lifecycle and biology:
- → helps determine likely time of outbreak
- → can remove conditions needed to survive.

3 Monitor the environment for pest population:
- → ensures timely action is taken
- determine distribution and if population is increasing or decreasing.

4 Establish action threshold:
- → point at which cost of pest damage exceeds cost of pest control.

5 Choose an appropriate combination of management tactics:
- → mechanical, cultural, biological, and chemical controls.

6 Evaluate results:
- → Desired effect? Satisfactory prevention or management? Satisfactory method? Unintended side effects and their future prevention? Future plans?

4 Insect control in stored seed and grass

4.1 Conditions that influence insect damage to stored seeds or grains

- Length of storage: = six weeks requires protection from possible damage.
- Moisture content: store when dry (high moisture → increased temperature → reduce efficacy of grain protectants → insects multiply)
  - therefore: aerate containers to cool seed and grain.

4.2 Lifecycle of some pests or insects of stored agricultural products

Take action when pests or insects reach the stage at which they can cause damage and/or be most easily eradicated.

Table 16 Common pests in South Africa that damage stored seed and grain				
Pests	**Crops / products**	**Lifecycle**	**Optimal conditions**	**Larvae development**
Maize weevil (*Sitophilus zeamais*)	maize crops	~5 weeks (30 °C, 70% RH)	27–31 °C › 60% RH	in individual grain, eat from inside out, reproduce and release larvae
Flat grain beetle (*Cryptolestis*)	grain, cereal products	22–24 days (32–35 °C, 75% RH)	25 °C 75% RH	
Tropical warehouse moth (*Ephestia cautella*)	rice, wheat, maize, beans, cotton seeds, cereals	45–55 days (28 ºC, 70% RH)		
Lesser grain borer (*Rhyzopertha dominica*)	cereals, seeds, dried fruit, almost all grains	1–2 months (25 days if ideal conditions)	32 °C 12% RH	in loose grain, bore into damaged kernels, adults chew their way out

4.3 Various methods of controlling insects in stored seeds or grain

- The goal for control methods = relatively insect-free, no insecticides or fumigants
- Methods:
  - clean old grain, grain debris and ensure it is dry
  - spray empty bins with insecticide
  - aerate grain to cool it
  - regular measurement of grain temperature and sampling for insects.
  - → Pesticides can be used if required, e.g.
    - Super Guard (dust formulation)
    - K-Obiol (surface spray and fog)
    - aluminium phosphide fumigants (toxic, restricted use).

5 Plant protection and the state

- Plant protection = control of plant pests in agriculture.
- Various organisations provide advice and information, and conduct research:
  - Plant Protection Research Institute (PPRI) of the Agricultural Research Council
  - The Directorate of Plant Health and Quality, National Department of Agriculture.
- Role of the state in plant protection:
  - prevent importation of diseased plants and pests
  - impose control measures for disease or pest threat.

Topic 3

Topic questions

- Answer the questions below.
- Give yourself one hour.
- Check your answers afterwards and do corrections.

1 Which chemical reaction best describes the process of respiration? (1)

a $CO_2 + H_2O$ + energy sun → carbohydrates + O_2

b carbohydrates + O_2 → $CO_2 + H_2O$ + chemical energy

2 Describe the importance of photosynthesis. (4)

3 List three minor macro-elements found in soil. (3)

4 Pair up the statements in the two columns which describe the major macro-elements found in soil. (6)

a major form of this element in soil is NO_3^-	i can be absorbed from phospholipids
b $H_2PO_4^-$ is the major form of this element in soil	ii constituent of proteins and nucleic acid
c toxic levels of this element produce acidic and sour citrus fruit	iii regulates flow of soil water

5 Briefly describe leaf sample analysis as a method of determining the nutritional status of soil. (4)

6 Name two factors that affect the availability of nitrogen in soil. (2)

7 Provide a word or term to match each of the following descriptions.

a A chemical preparation consisting of inorganic salts that is applied to soil or plants.

b A type of cover crop grown to add nutrients and organic matter to soil.

c A type of fruit production that results in seedless fruit.

d A management approach to weed control focused on prevention rather than eradication.

Topic questions

e The most successful genetically modified plant used in agriculture in South Africa.

f The male reproductive part of plants that produces pollen.

g A period of metabolic inactivity that precedes germination.

h The hairy/sticky female part of a plant that traps pollen. 8 x 2 = (16)

8 A farmer applies the fertiliser 3:2:1(22) to the soil. Calculate the percentage of potassium in the mixture. Show your calculation. (3)

9 Provide the common name for $CaCO_3NH_4NO_3$, a nitrogenous fertiliser. (1)

10 Which fertiliser contains the highest percentage of potassium: KCl or K_2SO_4? (1)

11 Name three beneficial effects of compost. (3)

12 Describe broadcasting in the context of fertilisation practices. (3)

13 Briefly describe the process of pollination and how it leads to the formation of a fruit. (4)

14 Explain what is meant by asexual reproduction in plants. (1)

15 Name four main types of specialised roots and stems. (4)

16 State the parts of two plants that are joined in the process of :
a oculation
b grafting. (2)

17 Explain briefly how hybrid plants are bred. (2)

18 Name two common parasitic weeds. (2)

19 Briefly describe how birds and machines disperse weeds. (5)

Topic questions

20 Which statement is incorrect?

a Pesticides

i are used to prevent and repel pests.

ii can be disposed of into water sources.

iii can be formulated as antimicrobials.

b Viral diseases

i may be spread by pests.

ii inhibit growth and prevent production of plants.

iii do not usually affect plant leaves.

c IPM principles

i include early and accurate identification of pests.

ii include the use of pesticides before mechanical methods.

iii require the establishment of action thresholds. 3 x 1 = (3)

Total: 70

Topic 4

Optimal resource utilisation

Overview

TOPIC 4 Page 132
Optimal resource utilisation

UNIT 1 Page 133
Soil surveying and planning

- The concept: soil survey
- The soil survey process in agriculture
- The concept: precision farming
- Ultramodern technologies used in precision farming

UNIT 2 Page 138
Water use and irrigation

- The concepts: irrigation and irrigation schedule
- Main sources of water for irrigation
- Criteria to determine water quality for irrigation
- Irrigation systems
- Reasons for and advantages of irrigation scheduling
- How to determine the moisture content of soils

UNIT 3 Page 145
Soil drainage, cultivation and crop rotation

- The term: soil drainage
- Primary and secondary soil cultivation: aims and differences
- Different types of soil cultivation systems
- The concept: crop rotation

UNIT 4 Page 150
Greenhouses, hydroponics and aquaculture

- The concept: greenhouse
- The concept: hydroponic production systems
- The concept: aquaculture

Unit 1

Soil surveying and planning

1 The concept: soil survey

- Soils surveying: process of determining characteristics and quality of soil in an area so that authorities or farmers can develop an appropriate land-use plan
- Main characteristics to consider:
  - soil texture
  - soil depth
  - rockiness of soil
  - amount of soil erosion
  - slope.

Soil texture

- Fine and medium texture soils (clay, clay loam and sandy loams) retain water and nutrients better than sandy soils
  - → thus have higher agricultural potential.
- Clay soils hold more moisture than sandy soils
  - → thus respond more slowly to changes in air temperature during spring and autumn.

Soil depth

- Defined as height of soil layer above the rock layer
  - measured with soil auger.
- Most crops require soil depth of at least 90 cm with good drainage.
- some vegetable crops grow in shallow (50 cm), well-drained soil.

Soil rockiness

- Refers to size and abundance of rocks or stones in an area –
- measured with rockiness index:
  - → volume of rocks as % of total soil volume.
- High stone content or rockiness leads to poor water retention of the soil
  - → affects ease and cost of cultivation.

Soil erosion

- Transport of soil by natural forces (mainly water and wind)
  - → removes nutrient-rich lighter soil fractions and damages soil fertility.
- Types of soil erosion:
  - rill erosion – rills are small furrows caused by surface runoff on bare soil, often begins on paths used by people
  - donga erosion – dongas or gullies form when smaller rills become deeper and wider
  - sheet erosion – removal of thin top layer evenly over a large area, caused by strong winds or heavy rain in an area with little or no vegetation.

- Signs of soil erosion:
  - dust storms
  - streams, rivers and dams carrying muddy water
  - dams that are silted up and filled with mud
  - new soil deposits
  - deep footpaths
  - plants with uncovered roots
  - pedestals
  - bare ground with poor plant growth.

Slope

- Affects soil erodibility, thus used to determine land-use class numbers (1–7).
- Steepness indicated on contour maps by closeness of contour lines.
- Aspect of the slope:
  - direction to which slope faces → affects vegetation, wildlife and parasites that may occur there
    - N-facing and W-facing usually hotter and dryer than S-facing and E-facing slopes, respectively.
- Waterways usually occur at the bottom of slopes:
- → soil in and around these differ.

2 The soil survey process in agriculture

The soil survey process in agriculture is made up of the following steps:

- Statement of objectives
- Background study:
  - find out what area was used for; get information from aerial photographs, orthophoto maps (satellite photos made into maps), previous survey reports; gather on-site information (e.g. erosion and slope)
- Fieldwork:
  - = detailed study of the area and main soil characteristics (texture, depth, rockiness, erosion – amount and likelihood of, slope) including their measurement
- Soil sample analysis:
  - usually done in a soil laboratory
- Interpretation and implementation of information:
  - determine land-use class (1–7)
  - develop a soil map
    - = shows distribution of soil types and/or soil properties in area of interest:
    - used for land evaluation, spatial planning, agricultural extension, environmental protection and similar projects.

Developing a soil map

- Obtain outline map of area –
  - 1:10 000 orthophoto map or traced outline of map is best.
- Make observations about land (e.g. signs of erosion and type)
- Auger the soil
- Find soil texture
- Find soil depth
- Use codes to indicate information on map
  - S: soil type, D: soil depth, N/S etc., R: rockiness, E: erosion as follows:
    - S1 . D3
    - N. R1 . E2

Table 1 Features of land in each land-use class

Land-use class number	Best use for that land-use class	Rockiness	Soil type	Soil depth	Erosion	Slope
1	Annual cropping	R1	S2–4	D1	E1	A
2	Cropping with cover crop	R1	S2–4	D2	E2	B
3	Cover crop and trees with some cropping	R1	S1–5	D3	E2	C
4	Permanent pasture	R2	S1–5	D3	E3	D
5	Veld	R3	S1–5	D4	E3	E
6	Forestry	R3	S2–4	D4	E3	F
7	Wildlife	R4	Sw Xw	D4	E4	F

Table 2 Explanation of codes in Table 4.1

Soil texture	Soil depth	Rockiness	Erosion	Slope
S1 sandy	D1 greater than 90 cm	R1 less than 10% rock	E1 no signs of erosion	A D–3°
S2 sandy loam	D2 50–90 cm	R2 10–20% rock	E2 shallow rills and/or deep paths	B 3–8°
S3 loam	D3 25–50 cm	R3 20–50% rock	E3 deep rills or sheet erosion	C 8–15°
S4 clay loam	D4 less than 25 cm	R4 more than 50% rock	E4 dongas	D 15–25°
S5 clay				E 25–35°
Sw waterlogged				F more than 35°
Xw waterway				

3 The concept: precision farming

- Modern method of crop farming management, uses traditional soil survey and ultramodern techniques.
- Basic principles:
  - → to manage small areas within fields (and not whole field as single unit)
  - → farm with most productive crop
    - = to get best return (profit or yield) per hectare of land.
- Basic aims:
  - → minimise inputs
  - → maximise yields
  - → use sustainable practices (e.g. pest, water and nutrient management).
- Method:
  - → collect detailed information on climate, geography, soil, specific crop needs, and weather
  - information analysed by sophisticated computer software programs:
- Provides precise data on subfields on a farm:
  - optimum sowing densities
  - fertiliser estimates and other input needs
  - irrigation needs
  - accurate crop yield predictions.
- Advantages:
  - optimal production
  - less damage to the environment
  - sustainability of production
  - healthier food, and traceability of foods produced and consumed.

4 Ultramodern technologies used in precision farming

Geographic Positioning Systems (GPS)

- Satellite network that orbits Earth and provides precise satellite and time location information to ground receivers:
  - → obtain precise co-ordinates of any location in a field.

Geographic Information Systems (GIS)

- Computer software database system:
  - → used to input, store, retrieve, analyse and display information in map-like format
    - = analyses inputs and
    - determines water and fertilisation management system.

Remote Sensing Systems

- Use of aerial photography or satellite imagery to measure various aspects of soil or crop in specific places, combined with other information gained in GIS
- information obtained includes:
  - vegetation indexing (measuring type and amount)
  - soil drainage maps
  - colour infrared aerial photographs (information on soil type and soil moisture)
  - crop health monitoring (infrared photography used to detect or measure plant stress and crop evaporation or transpiration rates).

Google Earth

- Website that provides satellite imagery
  - + can be integrated with GIS
    - → enhances planning of fields, crops and other structures (dams, roads and buildings).

Yield monitors

- Crop yield measuring devices located in harvesting machinery:
  - store crop yield at every specific sit,
  - correlate with GPS co-ordinates and integrate in GIS.

Variable Rate Fertilisation (VRT)

- Fertiliser field application equipment controlled by integrated information on GIS:
  - → delivers exact amount of fertiliser needed at every identified site.
  - Ensures:
    - optimum production
  - Reduces:
    - wastage and environmental effects of fertiliser.

Unit 2

Water use and irrigation

1 The concepts: irrigation and irrigation schedule

- Irrigation used to supplement rainfall in drier parts of South Africa:
  - → allows farmers to grow crops with high water requirement and during the dry season.
- Definitions:
  - irrigation
    - = moving or supply of water from water source to site of growing crops to improve its production
  - irrigation schedule
    - = plan developed by a farmer showing when and how much water to supply to a particular crop to ensure optimal production.

2 Main source of water for irrigation

Groundwater

- This is rainwater that has seeped into soil and moved down to rock layer below.
- Natural sources:
  - spring: occurs when layer of rock has thin soil layer thus water seeps or flows out onto the soil surface
  - vlei: occurs in low-lying areas where groundwater may rise to the surface during high rainfall periods.
- Constructed sources:
  - well: shallow holes dug to access groundwater above layer of rock, provides limited water supply
  - borehole: narrow and deep hole which penetrates upper layers of rock, supplies significant amounts of water.

Surface water

- Occurs when rainwater runs over soil surface instead of seeping into soil:
  - forms streams → flow into rivers → flow into constructed dams, lakes or the sea.
- Dams store surplus water during rainy season.
- Irrigation water can be drawn directly from large rivers, lakes or dams.

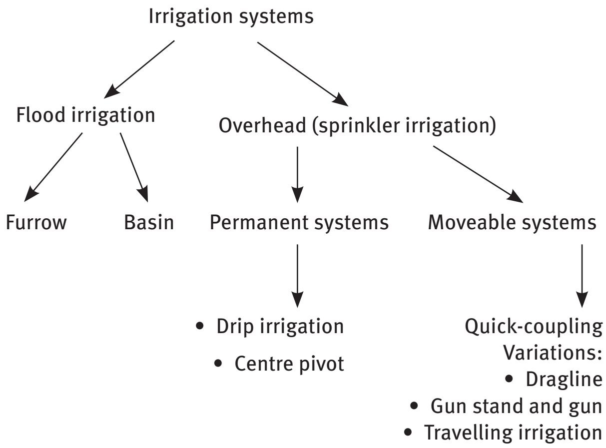
3 Criteria to determine water quality for irrigation

- First determine if sufficient water is available.
- Then consider if water quality is suitable for irrigation:
  - → rainwater is clean, pure and contains no salts; groundwater may contain salts and/or pollutants.

- Sample water and analyse at a laboratory:
  - salinity: total amount of dissolved salts
  - sodicity: amount of sodium containing salts
  - toxic chemicals: e.g. boron, manganese or iron
  - turbidity: amount of suspended soil particles in water (can block irrigation systems, wear out pump impellers)
  - pollutants:
    - biological – faecal bacteria from sewerage (e.g. Escherichia coli)
    - chemical – phosphates and nitrates (city waste water and runoff from fertilised lands), and pesticides (in runoff).

4 Irrigation systems

- Step 1: find suitable water source
- Step 2: move water to land to be irrigated
- Step 3: spread water evenly over area



Different irrigation systems

4.1 Flood irrigation

- Water is released into the ground and led down a slope to where it is needed
  - water led via furrows or basins.

Furrow irrigation

- Construct furrows for water to flow down (using hoe or plough, animal- or tractor drawn)
  - crops planted on ridges of soil between furrows
  - only use on gentle slopes (< 5% gradient) to avoid excessive erosion.
- Main canal/furrow is along contour at top of slope (made of soil, stone, brick or concrete)
  - source water is fed into main canal
  - openings at intervals along main canal allow water to run down the irrigation (or secondary) furrows, one at a time.

- When one furrow is flooded, soil is pushed back to close furrow and open canal above next furrow.
- Horizontal drainage stream at bottom of slope removes excess water and leads it into a tank (can be pumped back to main canal).

Basin irrigation

- requires flat or gently sloping land (< 5% gradient)
- soil walls divide field into a number of basins
- starting from a main canal, water is led from basin to basin
- each basin must be flat
- e.g. around fruit trees, rice (grows well in shallow water).

Table 3 Advantages of flood irrigation systems

	Furrow irrigation	Basin irrigation
No power needed (depends on position of water source)	√	√
No expensive equipment needed	√	√
Easy to set up and manage	√	√
Even spread of water	√	√

Table 4 Disadvantages of flood irrigation systems

	Furrow irrigation	Basin irrigation
Requires a lot of water	√	√
Difficult to control delivery of water	√	√
Difficult to set up and manage	√	√
Uneven spread of water	√	√
Erosion may occur (gradient >5%)	√	√

4.2 Sprinkler or overhead irrigation

- Delivers water like rain onto the crop.
- Two main types: permanent systems and moveable systems.

4.2.1 Permanent systems

- has permanent laterals and sprinklers
- uses valves to irrigate different blocks at a time
- disadvantages: expensive and inflexible in their use
- advantages: low labour requirements, less sensitivity to wind, no soil or crop damage occurs due to movement of pipes.

Drip irrigation/micro-irrigation

- relatively permanent system (pipes remain in situ for growing season or longer)
- plastic mother line/mainline runs from water source along one edge of field to be irrigated
- narrow plastic pipes branch off at intervals and run along length of each plant row

- type of crop determines spacing between branched pipes
- along the branch pipe, opposite each plant, there are holes, drippers or small sprinklers.

Centre (circular) pivot irrigation

- lightweight aluminium mainline and electrical power cable is laid underground
- mainline leads from source of water and power to centre of circular field
- mainline ends in a valve which is connected to centre pivot
- centre pivot: raised single aluminium irrigation line on wheels with valve at fulcrum (centre) and sprinklers at regular intervals along its length; turns slowly on wheels controlled by gears.

Table 5 Advantages of permanent overhead irrigation systems

	Drip irrigation	Centre pivot irrigation
Water is spread evenly	√	√
Easy to control water delivery	√	√
No runoff, thus no erosion or water wastage	√	√
Can be used on sloping ground	√	√
Weeds are less problematic (ground between plants does not receive water)	√	√

Table 6 Disadvantages of permanent overhead irrigation systems

Drip irrigation	Centre pivot irrigation
• fairly expensive	• high initial capital outlay (centre pivot equipment)
• maintenance is labour intensive	• high running costs (pump and equipment maintenance)
	• well-trained operator needed
	• not suitable for all crops (i.e. those whose leaves should not be watered)
	• not suitable for windy days
	• water loss due to evaporation before water reaches the ground

4.2.2 Moveable systems

- Used to reduce the initial cost outlay.
- Usually need more management and labour during irrigation season.

Quick-coupling straight-line system

- Construction:
  - main line laid and buried across centre of field (plastic or aluminium)
  - branch/sprinkler lines attached to valves/hydrants at intervals along mainline, at right angles
  - quick-coupling 6 m branch lines (lightweight aluminium) are laid above ground, linked with quick-coupling clamps to any length required
  - narrow, perpendicular riser pipes are positioned at intervals along branch lines with sprinkler nozzles fitted at the top.

- Functioning:
  - water is pumped from water source to main line
  - several branch lines can be attached to mainline (depending on amount of water, pump strength, field length)
  - several sprinklers may be used (depending on amount of available water, pressure-build in piping by pump)
  - water pressure causes water to shoot out of sprinklers which makes them turn.
- Advantages:
  - most economical and basic sprinkler irrigation system
  - no runoff, thus no erosion and water wastage
  - water is spread evenly
  - easy to control water delivery
  - can be used on sloping ground
  - less labour intensive than flood irrigation.
- Disadvantages:
  - high initial capital outlay (equipment) compared with flood irrigation, but cheaper than permanent or centre pivots
  - high running costs (pump and equipment maintenance)
  - labour intensive (two people needed to move branch lines to new part of field)
  - not suitable for all crops (i.e. those whose leaves should not be watered)
  - not suitable for windy days
  - water loss due to evaporation before water reaches the ground.

5 Reasons for and advantages of irrigation scheduling

- Determine correct amount of water for crops.
- Determine right time to supplement natural rainfall for each crop type.
- Ensure optimal crop production.
- Conserve scarce or costly resources (water, electricity).

5.1 Factors affecting an irrigation schedule

Soil type

- Sandy soils drain and dry out more quickly than clay soils:
  - SO → crops on sandy soils need to be irrigated more frequently than clay or clay loam soils.

Climate and weather

- Rainfall: irrigation may be required in addition to rainfall during certain periods.

Transpiration and evaporation

- Transpiration: plants grow more quickly at higher temperatures (roots suck up more water and nutrients from soil, moves up through plant by transpiration pull, and by evaporation of water through leaves, called transpiration).

- Evaporation: water in and on the soil can evaporate directly into the atmosphere.
- Evapotranspiration: total loss of water from soil by evaporation and from leaves by transpiration.

Factors that affect evapotranspiration

- temperature: evapotranspiration increases with temperature
- humidity: evapotranspiration increases as humidity decreases
- wind: evapotranspiration increases with wind
- crop type: root depth, leaf structure and size varies which affects need for water
- water-loving plants: fast growing, large leafy plants (e.g. sugar cane, spinach and lettuce)
- drought tolerant: smaller leaves, fewer stomata, waxy leaf covering on the leaves to reduce transpiration (e.g. onions, lavender)
- root depth: this varies according to plant types, classified according to root length as short (30–60 cm, e.g. celery), medium (60–120 cm, e.g. pumpkin), long (120–180 cm, e.g. sunflowers)

6 How to determine the moisture content of soils

- Determine root depth of crop (use reference table).
- Determine depth of wetness (use soil auger and tape measure).
- Irrigate again and recheck depth of wetness (first irrigation is over once roots are wet).
- Monitor depth of wetness regularly and irrigate again when soil is wet to half the root depth.

6.1 Methods to determine soil wetness

Class A evaporation pan

- Determines amount of evaporation from free water surface as an estimate of water lost by plants through evapotranspiration:
  - water lost by evapotranspiration is 50–90% of water lost from free water surface (because soil and plants retain water)
    - → by measuring the amount of water lost in the evaporation pan and the amount (say 75%) that is lost from the soil, evaporation can be calculated.

Tensiometer

- Measures soil tension or force with which water is held in soil by soil particles (in kilopascals, kPa):
  - consists of plastic body tube with ceramic cup at bottom end and vacuum gauge at top
    - → cup allows water to flow into or out of tensiometer when placed at root depth.

Neutron moisture meter (NMM)

- Consists of probe, cabling and a logger which records measurements:
  - make long narrow hole in soil with soil auger, fit with thin-walled aluminium tube (or thicker PVC tube)
  - probe inserted into tube which is in close contact with surrounding soil
    - → probe emits fast neutrons and measures the number deflected back to it, which is proportional to water in ~50 cm area around probe.
  - Probe must be calibrated for where it is to be used.

Unit 3

Soil drainage, cultivation and crop rotation

1 The term: soil drainage

- Soil drainage
  - = natural or artificial removal of surface and subsurface water from an area
    - either excess irrigation water or water that results from high water table.
- Factors to consider before draining soil:
  - effect on other water supply, e.g. dry up nearby water source
  - effect on local wild plants and animals: if they prefer waterlogged conditions, may not find another suitable home and die out; pest numbers may increase if they were previously eaten by local inhabitants.

1.1 Different types of soil drainage systems

A farmer should consider the following before draining an area:

- whether it will be surface or subsurface drainage
- type of drainage systems to be used
- where the water will be drained to
- what will be done with the excess water.

Surface drainage

- Open ditch drainage
  - uses slope of the land
  - furrows are dug down slope of land so that water can be drained to lower ground
  - sufficiently long and wide furrows needed to drain off all water.
- Ridge and furrow drainage
  - used on relatively flat ground (< 3^o gradient)
  - ridges and furrows along length of field with drainage ditch perpendicular to field
  - crops planted on ridges between furrows
  - water can be diverted into natural waterways, fish ponds, shallow crop basins.

Subsurface drainage

- Increases surface runoff → reduces amount of water going into soil.
- Increases drainage rate → lowers water table → increases dry soil depth above table.
- Two types of subsurface drains:
  - pipe drains – water seeps in through holes in pipes below soil surface, then drained away; suited to deep permeable soils, and heavy (clay) or poorly drained soils; backfill is a major cost but crucial to effectiveness; amount of backfill governed by soil type and permeability, depth of backfill, and trench width.
  - interceptor drains – installed across direction of water flow near interface between flat and sloping land; pipes laid at base of trench and back filled with permeable material which intercepts water flowing from upslope; water delivered to drainpipe which leads to outflow.

1.2 Factors to consider before installing a pipe drainage system

- Soil suitability:
  - determine the soil permeability (soil survey, preferably during winter) to estimate drain spacing and depth; sandy, loam, and some well-structured clay loam soils are suitable.
- Materials to use:
  - cost and ease of installation should be considered; plastic pipes are light and easy to work with, clay pipes are heavy and easily damaged; size of holes in pipe is also important.
- Material around pipe (backfill):
  - allow movement of water from surrounding soil to pipes.
- Installation method:
  - should be on grade and of high quality; use correct spacing of drainage lines (depends on soil permeability); install drainage lines with grade (slope).

2 Primary and secondary soil cultivation: aims and differences

- Soil cultivation or tillage:
  - practice to improve soil condition before establishing crops
  - must first analyse soil to determine best type of cultivation.
- Aims of soil cultivation:
  - killing and removal of weeds
  - mixing in of organic matter and fertiliser
  - burying or mixing crop residue.

Table 7 Comparison of primary and secondary cultivation

Primary cultivation	Secondary cultivation
• deeper and more thorough	• shallower
• produces rough textured soil	• produces smoother surface finish
• loosen soil and mix in fertiliser and/or plant material	• shape planting rows, prepare seed beds and provide weed control

Common implements used for soil cultivation

- Primary cultivation –
  - mouldboard plough:
    - single blade/share ploughs one furrow at a time, cuts soil and turns it over
  - disc plough:
    - breaks soil and cuts plants with blade/disc (2-20), pulled by tractor
  - subsoiler:
    - blade/tine cuts deeper than other types, does not remove covering plants, pulled by large tractor
  - digging forks and spades.

- Secondary cultivation –
  - harrow:
    - used to prepare seedbeds, eradicate weeds, flatten soil; drawn by draught animals or tractors; disk (two rows of small discs) and spiked harrows (triangular or zigzag shape with spikes) used to loosen soil
  - field cultivator:
    - used to prepare seedbeds and eradicate weeds; uses spring-mounted steel shanks to shatter soil clods
  - crumbler rollers and rakes
  - inter-row cultivation: e.g. inter-row cultivators, hoes
  - land forming: e.g. ridgers, hoes.

3 Different types of soil cultivation systems

Disadvantages of soil cultivation

- tractors and draught animals compact soil surface → leads to runoff and erosion
- leaves the soil bare, which leads to erosion
- plough pans (hard surfaces) can develop below the surface, which causes waterlogging and root rot/water shortage for plants.

No-tillage cultivation system

- used by some farmers due to disadvantages of cultivation
- no ploughing so soil is not loosened or turned over
- plant seeds between leaves and stems left from previous crop
- either make furrows with a hoe and plant by hand or use no-tillage planters
- weeds can be left growing on the soil; kill weeds by slashing or mowing and then leaving on surface, or using herbicides.

Intensive cultivation or tillage system

- leaves <15% crop residue
- involves multiple operations with implements (mouldboard and disc ploughs).

Conservation cultivation or tillage system

- consists of no or minimum till which leaves minimum of 30% crop residue
- slows water movement, which reduces amount of soil erosion
- keep plant stubble on land = prevents erosion, high soil temperatures, evaporation.

Strip cultivation system

- combines conventional tillage (soil drying, warming benefits) with advantages of no-till cultivation
- uses minimum tillage and only disturbs planting area
- labour intensive and uses special equipment.

Slash-and-burn cultivation system

- involves cutting and burning of forests or woodlands by hand to create fields
- slash is what has been cut down, remaining ash acts as soil fertiliser.

4 The concept: crop rotation

- Growing different crops in sequence in the same field over a number of years:
  - sub-divides field (into 4) and plant different family of crops on each piece of land
  - swap crop families and land sections every year
  - after four years, same crop is grown on original patch.
- Advantages:
  - helps soil fertility (different plants use different soil minerals), reduces plant pests (weeds and insects cannot establish themselves).
- Compare with crop monoculture (replant same crop species in same field every year):
  - increase in crop-specific pests and diseases
  - exploits soil root zone which depletes nutrients and decreases root development.

4.1 Factors to consider when planning a crop rotation programme

- Profitability:
  - select crops that are in demand; understand current market trends and production costs.
- Pest management:
  - Manage and control crop pests (weeds and insects); know what types of pests are prevalent and how to combat them; consider pests when designing layout of crop rotation land (barrier strips around crops can prevent spreading of weeds).
- Soil moisture and fertility:
  - plant suitable crops for soil type; analyse soil moisture and fertility
- Residue management:
  - low residue carryover (e.g. from peas) can lead to wind erosion concerns; high residue crops (e.g. wheat) can lead to excessive residue build-up, resulting in direct seeding problems the following season.
- Crop choice:
  - plant different families in different sections; consider functions and needs of different crop groups (e.g. nitrogen consumers vs. nitrogen fixers); important to include legumes and companion crops.
- Legumes:
  - root nodules contain *Rhizobium* bacteria which fixes nitrogen in the soil; leave roots in the soil after harvesting to add nitrogen to the soil.
- Companion crops:
- crops that can be grown together for their mutual benefit, e.g.
    - maize stem provides beans with climbing support and beans provide maize with nitrogen; practice called companion planting or intercropping.

Advantages

- assists with pest and weed control
- prevents soil from building up negative reactions to specific crops
- improved soil quality, better nutrient distribution, and increased biological activity
- variety of crops produced throughout the year
- decrease financial risk
- peak labour times can be reduced
- balance the production of crop residues.

Disadvantages

- requires more knowledge and greater management skills than monoculture
- skill required to choose rotations and recall which crop to plant next
- mechanisation is more difficult
- may not allow for maximum profitability (limited acreage of most profitable crop).

Unit 4

Greenhouses, hydroponics and aquaculture

1 The concept: greenhouse

- Lightweight structure enclosed by transparent covering in which plants are grown:
  - elements (e.g. temperature and moisture levels) are controlled to ensure optimum growing conditions for particular plant or crop
  - expensive to construct and manage
  - used for high-value cash crops, e.g.
    - ornamental pot plants, flowers, tomatoes and cucumbers.

1.1 Use of greenhouses for production of high-value cash crops

Advantages

- crops protected from natural elements and large pests
- spoilage is minimised while output is maximised → improves profitability
- crops can be cultivated out of season due to temperature control
- extends growing season and allows farmers to produce out-of-season crops → increases profitability
- can grow crops that would not normally thrive in an area
- quality of crops improved.

Disadvantages

- high set-up cost for material and labour (e.g. bank loans with interest charges)
- high level of management competence required
- severe hail- and/or windstorms can result in costly damage
- costly and intensive pest and disease control measures required (optimum conditions often encourage small insects).

1.2 Materials that farmers use to construct greenhouses

Larger commercial greenhouses are usually tunnel-shaped with a frame made of plastic or aluminium piping. The frame is covered with transparent film plastics.

- Covers are made of cheap polyethylene (PE) or polyvinyl chloride (PVC) materials
- light transmission properties comparable to glass
- PE is UV protected, PVC will last up to five years
  - → can be used with light and cheap frames.
- Greenhouse tunnels have door at each end for convenience and ventilation
  - sophisticated greenhouses = greater control over conditions
    - heating → heating systems for use in cold climates
    - circulation → fans for air circulation.
    - ventilation → door, roof or eave vents or hinged flaps to aid ventilation
    - cooling → evaporative cooling apparatus, shading materials, paint on covering.

Greenhouses with computerised automatic environmental control apparatus = even greater control over conditions.

1.3 Factors to consider in the location of a greenhouse

- Environmental factors:
  - local climatic conditions:
    - hot areas will require cooling, cold areas need heating, occurrence of storms and hail determine building materials
  - availability of water:
    - crucial since impermeable plastic covering keeps out rain
  - sunlight:
    - needs full sun (especially morning sun when plants begin food production process), north/south orientation of long axis is best
  - drainage:
    - build where it is raised above surrounding area.
- Markets:
  - should be close to markets else transport costs become high.
- Power:
  - nearby electricity source needed (for sensors, computer equipment, automatic fans and vents, irrigation system).
- Labour:
  - need a nearby source of sufficient labour.
- Space:
  - sufficient space for storage area, ablutions for workers and work area.

2 The concept: hydroponic production systems

- This is a method of growing plants in tightly controlled greenhouses in a medium without soil:
  - plants grown in inert medium for anchorage of the roots
  - soluble nutrients in water flows through inert medium.

2.1 The benefits or advantages of hydroponic production systems

- crops can be grown where there is no soil, or the soil is too poor to support optimum production
- reduced or no soil preparation
- water efficient closed system (uses 5% water vs. normal farm)
- conserves nutrients (those not used are re-circulated)
- high yields due to optimum growing conditions
- uniform production
- high quality crops that require little washing
- can be used to improve nutritional value of vegetables
- reduced soil pollution with fertilisers and pesticides.

2.2 Inputs for hydroponic systems

Mediums

Mediums are required to support plants and provide aeration.

- Pumice and perlite:
  - imported and costly volcanic rock products
    - → pumice is lightweight
    - → perlite is lightweight and spongy, similar to vermiculite but holds more air and less water.
- Vermiculite:
  - superheated mineral (mica) = light, porous, holds a lot of water and nutrients.
- Expanded clay (or ex-clay):
  - baked-clay pellets = porous, lightweight, do not compact, reusable after washing.
- Plant fibres:
  - coir (or coco peat), wood fibre, peat moss, sawdust, straw bales.
- Inert soil materials:
  - sand, gravel and brick shards = provide good anchorage, but do not hold a lot of water or nutrients.

Nutrients

- Nutrient solutions contain specifically balanced soluble nutrients at specific concentrations for different crops BUT
  - pH of water must be controlled to ensure nutrient solubility and availability.

Containers

- Required to hold medium and nutrient mixture, e.g.
  - plastic or concrete plant containers, trenches lined with plastic.

2.3 Open and closed systems in hydroponic production

Open (run-to-waste) hydroponic system

- simplest hydroponic system
- also known as open static hydroponic system
- plants are grown in containers
- micro-tubes feed water and nutrients into containers daily.

Closed (or continuous flow) hydroponic system

- more sophisticated hydroponic system
- also known as recirculating trench hydroponic system
- plants grow in trenches with a slope of 1:100 from beginning to end
- elevated tank stores nutrient solution which flows through trench by gravity, past the roots to endpoint reservoir
- water is pumped back to elevated tank from endpoint.

Table 8 Advantages and disadvantages of open hydroponic production system	
Advantages	**Disadvantages**
• cheaper to erect	• requires more labour to operate
• requires less skill	• wastes more water and nutrients
• easier to control spread of disease	• more costly to maintain (nutrients are not recycled)

2.4 Production differences between hydroponic and open field systems

Hydroponic systems:

- more expensive to set up
- require a high level of technical expertise and management
- require less space to produce the same amount of crop
- higher production per hectare
- better security of production (climate controlled and fewer pests)
- higher quality product
- soil quality is not important (deficiencies rectified through nutrients in water solution)
- high costs thus only used for high-value cash crops.

3 The concept: aquaculture

Aquaculture is the controlled production of aquatic living organisms:

- practised in the sea (marine aquaculture) or in fresh water (fresh water aquaculture)
- produces wide variety of fish for human consumption
- supplies > 30% of seafood consumed worldwide:
  - > 90% produced in Asia
  - < 0,5% produced in Africa.

3.1 Common aquaculture farming species in South Africa

Freshwater aquaculture in South Africa

- Normally carried out in earthen ponds and dams, or raceways, or in recirculating systems:
  - = limited by supply of suitable water (inland rivers are often polluted)
    - In SA, takes place in Limpopo, Mpumalanga lowveld, northern KwaZulu-Natal, and more recently in the Western Cape.
  - Largest income source:
    - = ornamental fish industry, e.g. goldfish and koi carp.
  - Largest food producer:
    - = rainbow trout.
  - Other species:
    - = shrimp, African catfish and tilapia.

Marine aquaculture in South Africa

- Low production volumes but fast developing sector:
  - → normally farmed on raft or long lines, or in recirculating systems.
  - Major products:
    - = abalone (largest amount, mostly exported to the East), oysters
  - Largest food producer:
    - = mussels.
  - Other species:
    - = seaweed, spotted grunter, red roman, cob and yellow tail.

3.2 Structures for housing marine and freshwater species

Freshwater aquaculture structures

Fish farmed in freshwater

- = Brown trout (*Salmo trutta*), Rainbow trout (*O. mykiss*), common carp (*C. carpio*) and African catfish (*Cl. gariepinus*).

Structures used:

- Earthen ponds, dams or raceways:
  - earthen ponds and dams: constructed in streams and rivers or alongside them (avoids flooding, requiring pump)
  - raceway: water flows between series of ponds or dams built in river or stream.
- Recirculating systems:
  - only used away from natural water routes:
    - water pumped from source into fish dam, removed at other end, filtered and treated, pumped back to start for recirculation
    - expensive to construct, requires expertise and maintenance
    - used where water is not plentiful, reduces pollution of rivers.

Marine aquaculture structures

Fish farmed in marine structure

- = Cob, tilapia, white stumpnose, shellfish.

Structures used:

- Long-lines:
  - used in shallow seas, estuaries or lagoons:
    - consists of long, horizontal nylon ropes stretched across water surface, fixed with floats
    - vertical lines hang down from horizontal long-line at intervals; requires sea depth of 5–20 m (no pollution, lots of algal foods).
- Rafts:
  - floating structures constructed of wood, plastic and polystyrene:
    - act as walkways and floats for long-lines.

- Cages:
  - are attached under rafts and float in the water
  - → monoculture of fish (Cob and tilapia) are intensively fed and raised in these.
- Recirculating systems:
  - = similar to recirculating systems for fresh water agriculture
    - found close to the coast, pump and circulate seawater, raise sea fish (white stumpnose) or shellfish.

3.3 Description of fish culture systems

Intensive fish culture systems

Large numbers of fish or other aquatic animals are raised in confined spaces:

  - nutrients supplied as formulated feed (balanced diet)
  - water quality monitored and managed regularly.
- Open through flow system:
  - water brought from source (dam or river), enters and flows through fish-raising ponds or dams, leaves to enter river system and flow away
  - cheap to set up, less likely to cause disease in the fish.
- Closed recirculating system:
  - water enters fish-raising dam or pond, circulated through, collected and filtered and/or purified, reused in the dam
  - more costly to set up, can recirculate disease
  - suitable for areas with limited quality water supply, reduces pollution of rivers.

Extensive fish culture systems

Fish (or other species like shrimps) are farmed at low densities in natural still dams or ponds

  - either not fed at all or provided with some supplemental feeding
  - location must have favourable climate and unlimited space (rural areas)
  - monoculture aquaculture system:
  - only one species of fish or other aquatic species is kept.
- Unbalanced system:
  - some food wastage, water quality may be compromised as waste levels (detritus) build up.
- Polyculture aquaculture system:
  - includes integrated agriculture-aquaculture systems (IAA)
  - farm with more than one species to obtain optimal production and balanced environment
  - uses all available food resources in a pond or dam, and preserves water quality.
- Integrated Agriculture-Aquaculture systems (IAA):
  - intensive animal farming is combined with aquaculture (fish)
  - wasted food and excrement (manure) from farm animals used to feed fish.

3.4 Basic requirements for aquaculture farmers to achieve high yields

- Good location:
  - ensure location has a slope (so that water can flow without a pump) and suitable climate (growth slows down if it is too cold).
- Good water supply:
  - requires sufficient high quality water.
- Reliable power supply:
  - required for pumps, filters and/or heaters
    - → erratic electricity supply can slow growth or even kill fish.
- Good quality feed:
  - poor nutrition will slow growth and cause deficiency diseases.
- Good planning and support:
  - plan in conjunction with aquaculture experts, e.g.
    - University of Cape Town, Rhodes University, the Department of Agriculture.
- Relevant knowledge and skills:
  - farmers need –
    - knowledge of fish biology,
    - experience in aquaculture husbandry,
    - competence at harvesting and processing
    - marketing and sales skills.
- Good species:
  - choose correct species for prevailing climatic, managerial, nutritional and housing conditions
  - choose good strains.

3.5 Factor that limit the selection of aquaculture species

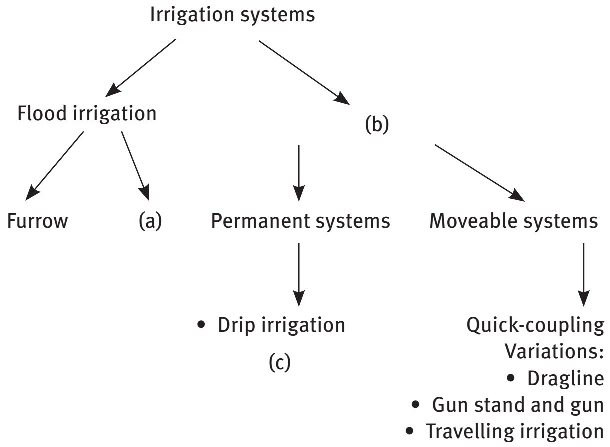
- geographic location (influences choice of species, climate, average temperature)
- water supply (amount and quality)
- available capital
- expertise and training
- availability of services (electricity, proximity to expertise and food supplies)
- market location (or airport for export produce).

Topic 4

Topic questions

- Answer the questions below.
- Give yourself one hour.
- Check your answers afterwards and do corrections.

1 Name five characteristics to consider in a soil survey. (5)
2 Define precision farming and state four advantages of this method. (6)
3 Name three sources of groundwater. (3)
4 Refer to the diagram below of different irrigation systems and fill in the missing words/phrases indicated by (a) – (c). (3)



5 Describe a quick-coupling straight-line irrigation system, with special reference to its construction. (5)
6 Provide three reasons for and advantages of an irrigation schedule. (3)
7 Name two types of surface drainage and describe briefly the one best suited to relatively flat land. (5)
8 Name two implements used in primary cultivation. (2)
9 Briefly describe the no-tillage method of cultivation. (4)
10 Name two types of crops that should be included in a crop rotation programme. (2)
11 Name five factors to consider when deciding the location for a greenhouse. (5)
12 Describe hydroponics and name the three major inputs required. (5)
13 Briefly discuss aquaculture in South Africa. Mention the two types of aquaculture, where they are carried out and state the largest income source of each type. (6)
14 Explain the main difference between intensive and extensive fish culture systems. (4)
15 Name two basic requirements for aquaculture farmers to achieve high yields. (2)

Topic questions

16 Provide the word or phrase that best describes the following statements:

- a The movement or supply of water from its source to the site of growing crops.
- b The removal of the thin top layer of soil evenly over a large area, caused by strong winds or heavy rain, in an area with little or no vegetation.
- c Method in which a field is subdivided and different crops are grown in sequence over a number of years.
- d Involves cutting and burning of forests and woodlands by hand to create fields for planting crops.
- e The controlled production of aquatic living organisms, mainly for human consumption.
- f A cheap, UV-protected material with good light transmitting properties that is used to construct greenhouses.
- g Crops that are typically grown in greenhouses due to their profitability.
- h The simplest hydroponic system in which plants are grown in containers fed by microtubes.
- i An instrument used to determine soil wetness which consists of a probe connected to a logger. (10 × 1 = 10)

Total: 70

Answers to Topic questions

Topic 1 Answers

1
   - a Molecule: can be broken down chemically into the elements of which they are composed. Example: carbon dioxide, water, sodium chloride, etc.
   - b Isotopes: atoms of the same element with different atomic weights. Example: chlorine.
   - c Valence electron: outermost electrons around an atom.

2 The atom has a small, positively charged core called the nucleus. The atom is electrically neutral and consists of: 1) electrons – negatively charged particles contained in a large outer volume called an electron cloud; 2) protons – positively charged particles concentrated in a small inner volume that contain most of the mass of the atom; 3) neutrons – electrically neutral and occur in the nucleus.

3
   - a alkali-earth metal
   - b fluorine / chlorine / bromine / iodine

4
   - a covalent bonding
   - b oxidation number
   - c chemical formula
   - d polar
   - e hydrogen bonding

5 b

6 Hydrogen bonds that hold water molecules together are quite strong. But covalent bonds between atoms in a water molecule are stronger. Thus hydrogen bonds often break and reform which provide water's ability to flow.

7
   - a carbon, oxygen
   - b 2 of Fe, Mn, B, Mo, Cu, Zn, Cl, Co

8 Plants use CO_2 and H_2O to build complex organic compounds. They are excreted by animals during respiration.

9
   - a alcohol
   - b aldehyde
   - c amide
   - d sugar

Answers to Topic questions

10

a CH_4

b methanogenesis

c most abundant

11 Propanol, primary

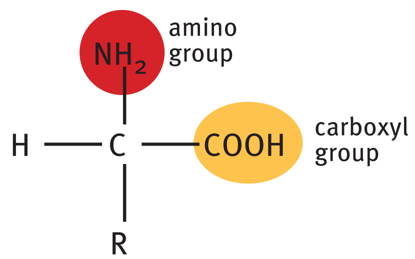
12

a A fatty acid is a long chain carboxylic acid. Saturated fatty acids contain only single C-C bonds, whereas unsaturated fatty acids contain 1 or more C-C double bonds.

b cis isomer

c Name any 4 of these: energy storage, waterproof coverings, main component of cell membranes, protection, function as hormones.

13



14 An amino acid that cannot be synthesised by the organism (usually humans) and must be supplied in the diet daily, typically from meat and dairy products.

15

- takes place mainly in the youngest plant tissues, i.e. meristematic tissues
- nitrogen is obtained from soil
- carbon is obtained from carbohydrates produced during photosynthesis
- N and C are contained in storage carbohydrates in seeds
- amino acids are formed in seeds and leaves (mainly in leaf chloroplasts)

16

a monosaccharides, glycosidic

b condensation / dehydration

c 6, fructose

d photosynthesis

e maltose

f energy

g walls

Total: 70

Answers to Topic questions

Topic 2 answers

1 Clay – smallest soil particles; Silt – in between size of clay and sand particles; Sand – largest soil particles
2 Name any 3 of: aggregate formation and stability, climate, tillage, electrostatic forces
3 Discuss any 3 of:
- amount of organic matter
  - usually topsoil (i.e. A-horizon) is dark or black
- presence of compounds and elements
  - iron oxides: yellowish-brown to reddish colour
  - manganese oxides: purplish-black soil colour
  - calcium carbonate: white
  - carbon compounds: black
- drainage
  - poor drainage results in light grey colour or rust-like spots (mottles)
  - referred to as bleached or washed out
- leaching
  - loss of iron compounds and coloured minerals results in light colour

4 oxygen, carbon dioxide, nitrogen (most important)
5
- a gravitational, capillary, hygroscopic
- b gravitational (i), capillary (iii, v), hygroscopic (ii, iv)
- c loss
- d any 4 of transpiration, evaporation, interception, runoff and drainage

6
- a Vegetation and cloud cover intercepts direct sunlight, and cloud cover can also insulate soil from temperature changes.
- b This can be measured by comparing temperatures under a tree with a bare soil OR the temperature between rows of healthy crops with nearby bare soil.

7 Topsoil: topmost layer, high proportion of organic matter
Subsoil: just beneath the topsoil, low in organic matter
8 Binomial classification system. List any 3 of:
- organise and facilitate knowledge about soils
- understand the relationship among different soils
- establish groups or classes of soils for practical purposes
- predict the behaviour of different soils
- identify the best uses of soils
- estimate agricultural productivity potential
- transfer information to similar soils in other locations

Answers to Topic questions

9 Soil colloids are very small particles of either organic or inorganic matter that are found in soil. They carry an electrostatic charge and determine the physical and chemical properties. Examples: any 2 of phyllosilicate clay minerals, non-crystalline silicate clays, oxides.

10 Active acidity is the concentration of H^+ ions in soil and water mixture; reserve acidity is the concentration of H^+ ions attached to clay and organic matter and not dissolved in solution.

11 List any 4 of

- monitor soil pH (take several soil samples in your field)
- test irrigation water
- apply sulphur or gypsum
- do not over use compost and animal manure
- irrigate to leach salts in drier areas
- cover soil with mulch during summer months
- do not over use lime soil

12

- step 1: plants absorb phosphorus from soil, animals obtain phosphorus by eating plants
- step 2: plant and animal matter are decomposed by micro-organisms
- step 3: micro-organisms release phosphorus into the soil (i.e. mineralisation)
- most phosphorus is unavailable as it is insoluble or bound to soil particles
- micro-organisms release some of this insoluble phosphorus (i.e. solubilisation)

13

- *Rhizobium* bacteria penetrates the roots and forms nodules in the tissues
- plants receive nitrogen extracted from the air
- bacteria receives water and nutrients from the host plant
- symbiosis is reduced by nitrogen fertilisation, high soil acidity and temperatures

14

- decomposition by aerobic micro-organisms → release of carbon dioxide (CO_2)
- decomposition by anaerobic micro-organisms → release of methane (CH_4)
- methane contributes much more to global warming than carbon dioxide
- burying organic matter in landfills contributes to global warming
- composting kitchen waste is preferable and returns organic matter to soil

Total: 70

Answers to Topic questions

Topic 3 Answers

1 b

2
- production and renewal of almost all the atmospheric oxygen
- provision of food for all plants and animals
- production of fossil fuels (coal, natural gas, oil) from plant and animal remains
- reduction of CO_2 in the atmosphere

3 Ca, Mg, S

4 1b, 2a, 3c

5
- done when crop is already growing
- leaf sample taken to laboratory where it is washed, dried and stored
- representative sample taken at a certain time of the year
- pick 10–20 young, mature healthy leaves (at least 10 undamaged) before 10:00am
- do not wash, place in clean plastic bag and deliver to laboratory immediately

6 List any 2 of: application of organic matter, soil air, moisture content, soil type and pH, factors that are detrimental to soil microbes

7 a) inorganic fertiliser; b) green manure; c) parthenocarpy; d) integrated weed control; e) Bt maize; f) anther; g) dormancy; h) stigma

8 Mass of K in 100kg mixture = [1 / (3+2+1)] of 22 = [1/6] of 22 = 3,7%

9 LAN or limestone ammonium nitrate

10 KCl

11
- physical effects – maintains and increases the organic content of soil
- chemical effects – contains almost all plant nutrients, but some may be in insufficient quantities
- biological effects – soil bacteria are added to soil

12
- uniform distribution of fertiliser over planting area
- usually worked into the ground
- used for crops that cover the land
- fertilisers that dissolve slowly require deep incorporation

13
- process by which pollen is transferred in plants, enabling fertilisation and sexual reproduction
- pollen carried from anther to stigma; pollen grain grows downwards towards the ovary and fertilises an ovule
- ovary forms the fruit, fertilised ovules develop into seeds

14 Asexual reproduction in plants is the reproduction from pieces of the parent plant other than the seeds.
15 bulbs, tubes, rhizomes, stolons/runners
16 a) stem and bud; b) two stems
17 Form of cross-pollination in which pollen from flower of one cultivar is placed on the stigma of a flower of a second cultivar to breed a hybrid plant that is better than both the parent cultivars.
18 dodder, witchweed
19 Birds: pass seeds through their digestive tract, which are deposited in their faeces
Machines: farm vehicles transfer seeds stuck in their tyre treads OR seeds present in soil are exposed to light and air by ploughs during cultivation (any one of these)
20 a) ii; b) iii; c) ii

Total: 70

Topic 4 Answers

1
- soil texture
- soil depth
- rockiness of soil
- amount of soil erosion
- slope

2 Precision farming:
- modern method of crop farming management, uses traditional soil survey and ultramodern techniques
- basic principle to manage small areas within fields and not whole field
- farm with most productive crop to get best return (profit or yield) per hectare of land

Advantages:
- optimal production
- less damage to the environment
- sustainability of production
- healthier food, and traceability of foods produced and consumed

3 Name any 3 of: spring, vlei, well, borehole

4
- a basin
- b overhead / sprinkler
- c centre pivot

Answers to Topic questions

5
- main line laid and buried across centre of field (plastic or aluminium)
- branch/sprinkler lines attached to valves/hydrants at intervals along mainline, at right angles
- quick-coupling 6 m branch lines (lightweight aluminium) are laid above ground, linked with quick-coupling clamps to any length required
- narrow, perpendicular riser pipes are positioned at intervals along branch lines with sprinkler nozzles fitted at the top

6 Name any 3 of:
- determine correct amount of water for crops
- determine right time to supplement natural rainfall for each crop type
- ensure optimal crop production
- conserve scarce or costly resources (water, electricity)

7 open ditch drainage, ridge and furrow drainage

Ridge and furrow drainage:
- ridges and furrows along constructed along the length of the field with a drainage ditch perpendicular to field
- crops planted on ridges between furrows
- water can be diverted into natural waterways, fish ponds, shallow crop basins

8 Name any 2 of: mouldboard plough, disc plough, subsoiler, digging forks, spades

9
- no ploughing so soil is not loosened or turned over
- plant seeds between leaves and stems left from previous crop
- either make furrows with a hoe and plant by hand or use no-tillage planters
- weeds: can be left growing on the soil; killed by slashing or mowing and then leaving on surface, or using herbicides

10 legume family, companion crops

11
- environmental factors (can also say: local climate, availability of water, sunlight or drainage)
- markets
- power
- labour
- space

12
- method of growing plants in tightly controlled greenhouses in a medium without soil; plants grown in inert medium for anchorage of the roots; soluble nutrients in water flows through inert medium
- Inputs: medium, nutrients, container.

Answers to Topic questions

13 freshwater aquaculture: carried out in earthen ponds and dams, raceways, recirculating systems; largest income source is ornamental fish industry (goldfish and koi carp)
marine aquaculture: carried out on raft or long lines, or in recirculating systems; major product is abalone

14 Intensive system:
- large numbers of fish or other aquatic animals are raised in confined spaces
- nutrients supplied as formulated feed (balanced diet)

Extensive system:
- fish (or other species like shrimps) are farmed at low densities in natural still dams or ponds
- either not fed at all or provided with some supplemental feeding

15 Name any 2 of:
- good location
- good water supply
- reliable power supply
- good quality feed
- good planning and support
- relevant knowledge and skills
- good species

16
a irrigation
b evapotranspiration
c crop rotation
d slash-and-burn cultivation
e aquaculture
f polyethylene / PE
g high-value cash crops
h open / run-to-waste hydroponic system
i neutron moisture meter / NMM

Total: 70

Exam Practice

AGRICULTURAL SCIENCES Paper 1

- TIME: 2.5 HOURS
- 150 marks

SECTION A

QUESTION 1

1.1 Various options are provided as possible answers to the following questions. Choose the most correct answer and write only the letter (a–d) next to the question number.

1.1.1 Components of the atom that contains most of its mass:
a) Neutrons
b) Electrons
c) Nucleus
d) Protons

1.1.2 An organic compound that contains a characteristic OH group:
a) Carboxylic acid
b) Alcohol
c) Amine
d) Phenol

1.1.3 The structural level of a protein responsible for the local arrangement:
a) Primary structure
b) Secondary structure
c) Tertiary structure
d) Quaternary structure

1.1.4 Carbohydrates serve the following functions in animals:
a) Act as storage food
b) Act as a hormone
c) Provide frictionless movement
d) All of the above

1.1.5 The most convenient laboratory method for soil analysis:
a) Hydrometer method
b) Sausage method
c) Feel method
d) Pipette method

1.1.6 This soil colour indicates the presence of iron compounds:
a) Grey
b) Red
c) Yellow
d) Light colour

1.1.7 The diagnostic topsoil horizon that is thin and low in organic matter:
a) Melanic A
b) Organic O
c) Orthic A
d) G horizon

1.1.8 An organism that converts nitrites to nitrates in soil:
- a) Nitrosomas
- b) Denitrification bacteria
- c) Nitrogen-fixing bacteria
- d) Nitrobacter (8 x 2 = 16)

1.2 The following statements are FALSE. Change the bold word(s) to make each statement TRUE. Write only the words next to the question number.
- 1.2.1 Chlorine is an example of a **noble gas**.
- 1.2.2 Soil air contains more **oxygen** than atmospheric air.
- 1.2.3 The **E-horizon** is the surface horizon which contains topsoil.
- 1.2.4 **Organic** soil colloids carry a net positive charge.
- 1.2.5 More **green** matter is required when making a compost heap. (5 x 2 = 10)

1.3 Write the agricultural word/ phrase for each of the following descriptions.
- 1.3.1 Type of bonding exhibited by sodium chloride
- 1.3.2 Process by which the principal component of natural gas is produced
- 1.3.3 A long chain carboxylic acid that contains two or more double bonds
- 1.3.4 Collection of soil aggregates bound together by natural processes
- 1.3.5 Force that enables water to travel up the stem of a plant
- 1.3.6 A process that does not require oxygen
- 1.3.7 Important components of cell membranes that possess a strongly polar character
- 1.3.8 A soil profile with minimal horizontation and a strong influence from parent material
- 1.3.9 Mass of soil per unit volume in its natural field state (9 x 1 = 9)

1.4 Choose a word/term from column B that matches a description in column A. Write only the letter (A-J) next to the question number. (5 x 2 = 10)

COLUMN A	COLUMN B
1.4.1 Example of a transport protein 1.4.2 Monosaccharide composed of 4 carbons 1.4.3 Used to manipulate soil temperature and improve crop production 1.4.4 Chlorine-washed soil that contains excess sodium 1.4.5 Fungus that attached to plant roots and enhances phosphorus absorption	A sodic soil B haemoglobin C tetrose D pentose E row spacing F mycorrhizae G soil thermometer H actin I *Rhizobium* J saline soil

TOTAL SECTION A: 45

QUESTION 2: BASIC AGRICULTURAL CHEMISTRY

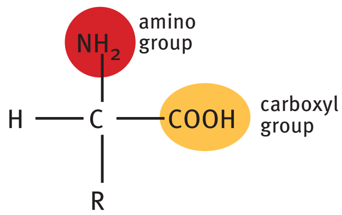
2.1 Water is necessary for life because water is the medium in which all of life's chemical reactions take place. It nourishes animals, human cells and every plant.
- 2.1.1 Explain the term valence electron. (2)
- 2.1.2 Use the number of valence electrons on oxygen and hydrogen to help you construct a Lewis structure of water. (3)
- 2.1.3 Name and define the type of bonding exhibited by water. (3)
- 2.1.4 The bonding referred to in (2.1.3) is responsible for one of the unique characteristics of water. Name this characteristic and describe briefly. (4)

2.1.5 Name 2 other properties of water that make it the ideal medium for living organisms. (4)

2.1.6 Choose the correct word to complete the following sentence: Water is a (polar/non-polar) molecule due to the presence of highly electronegative oxygen atoms. (1)

2.1.7 Explain what is meant by an electronegative atom. (2)

2.2 Amino acids are the basic building blocks of proteins. Their basic structure is shown in the figure below.



2.2.1 Explain the difference between essential and non-essential amino acids. (2)

2.2.2 List four essential amino acids. (4)

2.2.3 Proteins are made up of amino acids covalently linked by peptide bonds. Briefly explain how this bond formation occurs. (3)

2.2.4 The side chain, designated by the R group in the figure above, allows proteins to perform several important functions. Name 2 of these functions. (2)

2.3 The formation or synthesis of proteins in plants is vital to their survival. Discuss protein synthesis in plants. (5)

[35]

QUESTION 3: BASIC AGRICULTURAL CHEMISTY

3.1 The following table shows the basic groupings of organic compounds. Provide a word/phrase that corresponds with (a) – (d). (4)

Organic compound	Elements contained in compound	Main function
(a)	C, H, O, N, S, P	form structural parts of organisms; participate in cell signalling and recognition; act as molecules of immunity
Carbohydrates	C, H, O	major food and energy source
Lipids	C, H, O, N, S, P	(b)
(c)	C, H, O, N, P	storage of organism's ...(d)... information and its conversion into proteins

3.2 Saturated fatty acids play a vital role in nutrition and bodily functions but they should be consumed in moderation.

3.2.1 Name two food items that contain a high proportion of saturated fatty acids. (2)

3.2.2 Name two functions of saturated fatty acids that demonstrate their importance in bodily functions. (4)

3.3 Carbohydrates are essential for energy.

3.3.1 Provide a general formula for carbohydrates. (1)

3.3.2 Name the process that builds carbon atoms from carbon dioxide into monosaccharides. (2)

3.3.3 Name the type of bond that joins monosaccharides together to bond a disaccharide. (1)

3.3.4 Provide a chemical formula for the most well-known monosaccharide. (2)

3.3.5 Name the disaccharide that consists of two glucose units. (2)

SOIL SCIENCE

3.4 Soil texture is defined as the relative proportions of sand, silt, and clay particles in a mass of soil.

3.4.1 Name the tool that soil scientists and farmers use to classify soil textures. (2)

3.4.2 Name two ways in which soil textural classes may be determined. (4)

3.4.3 Knowledge of textural classes allows farmers to maximise productivity and minimise environmental harm. State 5 factors that are affected by soil texture. (5)

3.4.4 Name the smallest soil particle or separate. (2)

3.4.5 Provide two properties of soils containing a high percentage of this soil separate. (4)

[35]

QUESTION 4: SOIL SCIENCE

4.1 Soil structure refers to the arrangement of solid parts of the soil and the pore spaces between. The assembly of soil structure can be depicted by the flow diagram below.

single soil particles → (bound by .....(a)....) → **.....(b).....** → (bind together) → **peds or (c)** → (stack around each other) → **soil structure**

4.1.1 Provide the missing word/phrase indicated by (a), (b) and (c) in the diagram above. (3)

4.1.2 Soil structure is classified according to the three main criteria. Name these criteria. (6)

4.1.3 List four ways in which soil structure can be improved. (4)

4.2 There are three main types of soil water and some of their properties are summarised in the table below. Provide the word/phrase that corresponds to (a) – (e). (5)

Gravitational water	Capillary water	...... (c).... water
found in soil ......(a).......	found in soil ......(b).......	forms thin films around soil particles
moves through soil due to force of gravity	held against pull of gravity by cohesion and adhesion forces	held on particle surface by ...(d).... forces
not available to plants as it moves rapidly out of well-drained soil	available for plant growth	......(e)....... (available/ not available) to plants

4.3 Soil water balance reflects all quantities of water added, removed or stored in a given volume of soil during a given period of time. The change in soil water over time is given by the following expression: $\Delta Sm = Sm + P - T - E - I - R - D$

4.3.1 State the processes represented by the symbols T and I in the formula. (2)

4.3.2 Explain what leads to the process indicated by the letter "R". Indicate in your answer what the process designated by "R" is called. (2)

4.3.3 Briefly describe three strategies to limit the effect of process "E". Indicate in your answer what the process designated by "E" is called. (3)

4.4. Explain the main role of soil micro-organisms and macro-organisms. (2)

4.4.1 State the requirements of soil micro-organisms with regard to air. (1)

4.4.2 List three types of soil micro-organisms. (3)

4.4.3 The decomposition of organic matter by micro-organisms has a significant impact on global warming. Explain this statement. (4)

[35]

TOTAL SECTION B: 105

Exam Practice

AGRICULTURAL SCIENCES Paper 2

- TIME: 2.5 HOURS
- 150 marks

SECTION A

QUESTION 1

1.1 Various options are provided as possible answers to the following questions. Choose the most correct answer and write only the letter (a–d) next to the question number.

1.1.1 The process of photosynthesis:
a) produces food
b) releases energy
c) consumes oxygen
d) both (a) and (c).

1.1.2 Stomata:
a) are passages on leaves that allow the exchange of gases between plants and soil
b) are controlled by guard cells
c) are open during the day to prevent water loss in succulents
d) all of the above.

1.1.3 Which statement about potassium is incorrect?
a) It is available as soluble K in salts.
b) It is available in rock minerals.
c) It can be absorbed to a negative charge on clay particles.
d) It is fixed by clay minerals when soil dries out.

1.1.4 Oculation:
a) is a type of sexual reproduction in plants
b) requires budding onto young plants
c) is the joining of the stem of one plant with the stem of another
d) is the same as grafting.

1.1.5 Weeds:
a) can be selectively removed using herbicides
b) provide food to other plants
c) can be controlled with mulching
d) both (a) and (c).

1.1.6 Integrated pest management:
a) tries to establish acceptable pest levels
b) does not solve long-term pest problems
c) does not involve cultural practices
d) none of the above.

1.1.7 Signs of soil erosion include:
a) a bare ground with new plant growth
b) dams that are filled with mud
c) storms
d) shallow footpaths.

1.1.8 Constructed sources of groundwater are:
  a) springs and wells
  b) springs and vleis
  c) well and boreholes
  d) vleis and dams (8 x 2 = 16)

1.2 The following statements are FALSE. Change the bold word(s) to make each statement TRUE. Write only the word(s) next to the question number.
  1.2.1 **Osmosis** is the spread of molecules from an area of high concentration to one of low concentration until equilibrium is reached.
  1.2.2 Animal manure is slowly available to plants whereas **green** manure is immediately available.
  1.2.3 **Oysters** are the major product of the marine aquaculture sector in South Africa.
  1.2.4 Active **nutrient** uptake in plants is carried out by transport carrier molecules.
  1.2.5 Google Earth is a website that provides satellite imagery which can be used in **crop** farming. (5 x 2 = 10)

1.3 Write the agricultural word/phrase for each of the following descriptions.
  1.3.1 The yellowing of normally green leaves due to a lack of chlorophyll.
  1.3.2 An implement used to prepare seedbeds that is drawn by draught animals or tractors.
  1.3.3 A hydrated form of calcium sulphate that is used as fertiliser.
  1.3.4 The process of improving cultivars by collecting seeds from the best plants.
  1.3.5 The process of determining soil characteristics and the quality of soil in order to aid the development of a land-use plan.
  1.3.6 A form of flood irrigation that is suitable for growing fruit trees.
  1.3.7 This occurs when rainwater runs over the soil surface instead of seeping into the soil.
  1.3.8 Superheated mica that is used as a medium for hydroponics.
  1.3.9 A system that uses wasted food and excrement from animals to feed fish. (9 x 1 = 9)

1.4 Choose a word/term from column B that matches a description in column A. Write only the letter (A–J) next to the question number. (5 x 2 = 10)

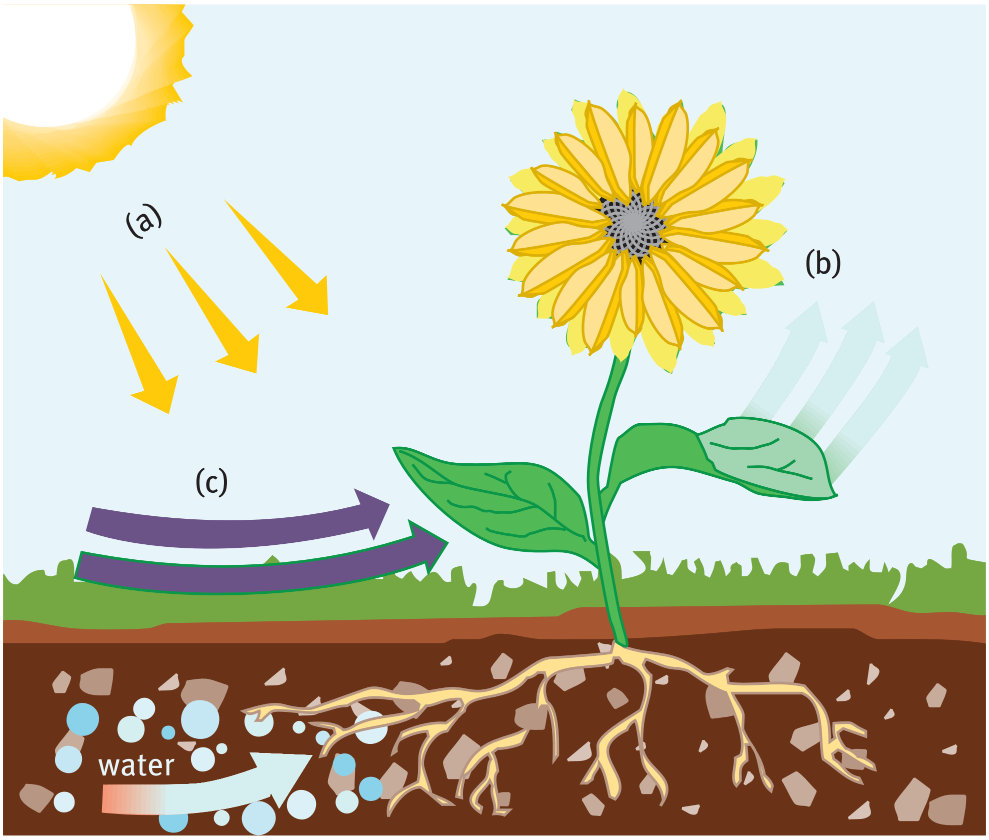
COLUMN A		COLUMN B
1.4.1	Causes damage to a plant ovary such that the ovule is not fertilised.	A lesser grain borer
1.4.2	Pest whose larvae grows in individual grains of a particular crop and eats it from the inside out.	B maize weevil
1.4.3	Satellite network that orbits Earth and provides precise co-ordinates of any location.	C GIS
1.4.4	A reusable medium suitable for hydroponics.	D quick-coupling straight-line system
1.4.5	The most economical and basic sprinkler irrigation system.	E coco peat
		F ablactation
		G micro irrigation system
		H GPS
		I expanded clay
		J parthenocarpy

TOTAL SECTION A: 45

SECTION B

QUESTION 2: PLANT STUDIES

2.1 The following picture illustrates the vital process of photosynthesis. Study it carefully and answer the questions that follow.



2.1.1 Provide suitable labels for (a), (b) and (c). (3)

2.1.2 Complete the following equation which represents the process of photosynthesis.
...(a)... + H_2O + sun's energy → ...(b)... + O_2 (2)

2.1.3 Where does photosynthesis take place in the leaves? (1)

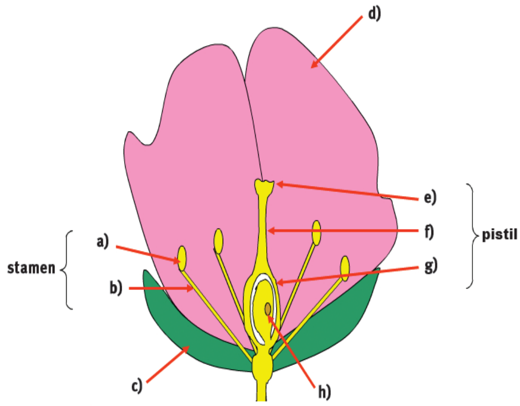
2.1.4 Name the pigment that provides plants with a yellow, orange or red colour. (2)

2.1.5 Photosynthesis takes place in 2 phases. Where does the dark phase take place? (1)

2.1.6 Where do plants store their food temporarily during the day? (1)

2.2 Briefly state 5 negative impacts of inorganic fertilisers on the environment. (5)

2.3 Refer to the figure of a flower below and answer the questions that follow.



- 2.3.1 Name the non-sexual parts of the flower and indicate the figure labels that correspond to these parts. (4)
- 2.3.2 Briefly describe the function of the parts named in (2.3.1). (2)
- 2.3.3 Define pollination. (2)
- 2.3.4 Provide a label for the parts involved in pollination. (2)

2.4 Name the 4 processes involved in seed germination. (4)

2.5 Name the method used to bring seeds out of dormancy. (1)

2.6 Asexual reproduction in plants is the reproduction from pieces of the parent plant other than the seeds.

- 2.6.1 Name 3 types of specialised stems and roots that can be used in this form of reproduction. (3)
- 2.6.2 Explain what happens to these organs at the end of the growing season. (2)

[35]

QUESTION 3: PLANT STUDIES

3.1 Agricultural biotechnology attempts to understand and manipulate the genetic makeup of organisms for use in the production and processing of agricultural products.

- 3.1.1 Give another name for genetically modified organisms. (2)
- 3.1.2 Name 5 new and desirable characteristics of genetically modified plants. (5)
- 3.1.3 Name the 2 most popular genetically modified crops in South Africa. (2)
- 3.1.4 Briefly describe 2 disadvantages of genetic modification. (2)

3.2 Biological weed control has been successfully applied to eradicate the prickly pear cactus. Discuss this statement. (5)

3.3 Integrated pest management is a system that uses good cultivation practices based on an ecological approach, combined with chemical and biochemical methods, to control pests.

- 3.3.1 One of the main principles of IPM is to establish action thresholds. Briefly explain what is meant by this statement. (4)
- 3.3.2 Outline the 6 steps to follow when implementing such a programme. (6)

OPTIMAL RESOURCE UTILISATION

3.4. Define soil erosion. (2)

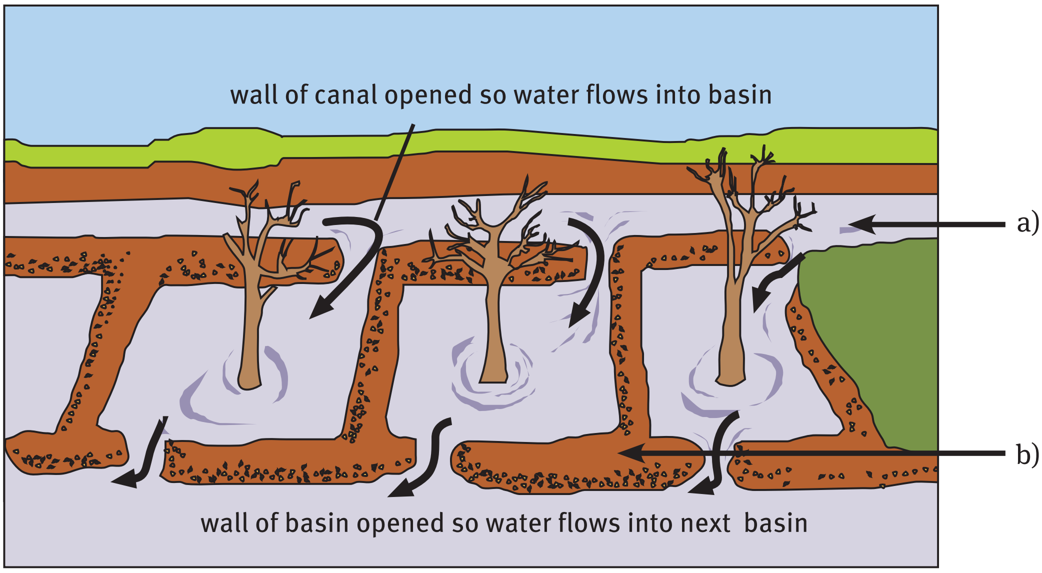
3.4.1 Name 3 types of soil erosion and briefly describe each one. (6)

3.4.2 Name one other important soil characteristic. (1)

[35]

QUESTION 4: OPTIMAL RESOURCE UTILISATION

4.1 Irrigation is the movement or supply of water from a water source to the site of growing crops to improve their production. The diagram below illustrates one form of irrigation used by farmers. Study it carefully and answer the questions that follow.



4.1.1 Name the type of irrigation illustrated in the diagram. (1)

4.1.2 Provide suitable labels for (a) and (b). (2)

4.1.3 Briefly describe the system named in (4.1.1). (4)

4.1.4 Name one advantage and one disadvantage of this system. (2)

4.2 Water quality is an important criterion to check. Name 3 measurements that can be made in a laboratory to assess water quality. (3)

4.3 Refer to the diagram below which illustrates an agricultural programme.

4.3.1 Name and describe the programme depicted by the diagram. (4)
4.3.2 Name the practice that is in direct contrast with (4.3.1). (1)
4.3.3 Name 5 factors to consider when planning such a programme. (5)
4.4 Name 3 aims of soil cultivation. (3)
4.5 A greenhouse is a building used to grow plants.
4.5.1 Explain why a greenhouse may be preferred to growing crops outside in a field. (2)
4.5.2 Discuss the materials required to construct the cover of a greenhouse. (4)
4.6 Define hydroponics. (2)
4.6.1 Name 2 types of hydroponic systems. (2)

[35]

TOTAL SECTION B: 105

Answers to Exam Practice questions

AGRICULTURAL SCIENCES Paper 1: Suggested memorandum

SECTION A

QUESTION 1

1.1.1 d	1.1.2 b	1.1.3 b	1.1.4 d	
1.1.5 a	1.1.6 b	1.1.7 c	1.1.8 d	

1.2.1 halogen
1.2.2 carbon dioxide
1.2.3 A-horizon
1.2.4 inorganic
1.2.5 brown
1.3.1 ionic bonding
1.3.2 methanogenesis
1.3.3 polyunsaturated fatty acid
1.3.4 peds
1.3.5 capillarity
1.3.6 anaerobic
1.3.7 phospholipids
1.3.8 young soil
1.3.9 soil bulk density

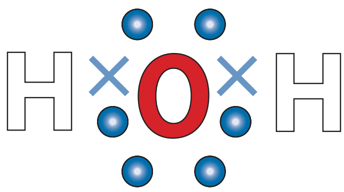
1.4.1 B	1.4.2 C	1.4.3 E	1.4.4 A	1.4.5 F

SECTION B

QUESTION 2

2.1.1 Valence electrons are the outermost electrons around an atom and the most likely to take part in chemical reactions.

2.1.2



or using straight lines for the 2 O-H bonds.

2.1.3 Hydrogen bonding: a strong, electrostatic attraction between a hydrogen atom and an electronegative atom, e.g. nitrogen, oxygen, fluorine.

2.1.4 Flexibility and flow characteristic
- Hydrogen bonds that hold water molecules together are quite strong
- But covalent bonds between atoms in a water molecule are stronger
- Thus hydrogen bonds often break and reform which provide this property

Answers to Exam Practice questions

2.1.5 Mention any 2 of:
- Capacity to absorb high levels of heat energy before its temperature is raised
- Release of high amounts of heat energy upon vaporisation of water
- High surface tension

2.1.6 polar

2.1.7 An electronegative atom is one that attracts/pulls electrons strongly towards it.

2.2.1 Essential amino acids cannot be synthesised by the organism. Non-essential amino acids are synthesised by the body from essential amino acids.

2.2.2 List any 4 of: arginine (not for adults), histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine

2.2.3 Peptide bond formation occurs between COOH of one amino acid and NH_2 of an adjacent amino acid. It occurs in a condensation reaction during which a water molecule is lost.

2.2.4 List any 2 of: allow ligand binding and protein folding, provide catalytic activity, stabilise final conformation.

2.3 Protein synthesis in plants:
- takes place mainly in the youngest plant tissues, i.e. meristematic tissues
- nitrogen is obtained from soil
- carbon is obtained from carbohydrates produced during photosynthesis
- N and C are contained in storage carbohydrates in seeds
- amino acids are formed in seeds and leaves (mainly in leaf chloroplasts)

QUESTION 3

3.1 a) proteins; b) major cell membrane constituent; c) nucleic acids; d) heritable

3.2.1 cheese / fatty meats (or any animal fat); coconut oil / chocolate (or any vegetable product)

3.2.2 Name any 2 of:
- provide the appropriate stiffness and structure to cell membranes and tissues
- strengthen the immune system
- involved in inter-cellular communication (e.g. protect against cancer)
- involved in the function of cell membrane receptors (e.g. protect against diabetes)
- lung and kidney function, hormone production
- suppress inflammation
- saturated animal fats carry fat-soluble vitamins A, D and K2 which promote good health

3.3.1 $C_x(H_2O)_x$

3.3.2 Calvin cycle / carbon reduction cycle

3.3.3 glycosidic bond

Answers to Exam Practice questions

3.3.4 $C_6H_{12}O_6$
3.3.5 maltose
3.4.1 soil textural triangle
3.4.2 How to determine textural class:
- analyse soil composition in a laboratory and use the soil textural triangle
- analyse soil in the field and estimate the soil textural class

3.4.3 Factors affected by soil textural class:
- seed germination
- water holding capacity
- drainage properties
- root development
- pesticide movement

3.4.4 clay
3.4.5 Properties of clayey soils and their implications
- low infiltration rate – when dry, hard clay soils limit seed germination
- poorly drained and aerated – become waterlogged in rainy seasons

QUESTION 4

4.1.1 a) soil colloids; b) soil aggregates; c) clods
4.1.2 type/shape, class/size, grade
4.1.3 List any 4 of:
- increase organic content
- green manuring
- reduce or eliminate tillage and cultivation
- avoiding soil disturbance:
- ensure sufficient ground cover:
- apply gypsum (calcium sulfate) to irrigated land

4.2 a) macro pores; b) micro pores; c) hygroscopic; d) adhesion forces; e) not available
4.3.1 T is transpiration, I is interception
4.3.2 R is for runoff. This occurs when precipitation rate exceeds water infiltration rate.
4.3.3 E is for evaporation. It can be limited by restricting solar energy from reaching the soil surface, not irrigating frequently, and using deeper irrigations at longer intervals. (mention any 1 of the 3 strategies)
4.4 Soil micro-organisms decompose dead plants and animals, and animal dung. Soil macro-organisms decompose dead organic matter so that micro-organisms can decompose it further.
4.4.1 Soil micro-organisms require oxygen in the air as they are mostly aerobic organisms.

4.4.2 Name any 3 of: algae, bacteria, fungi, protozoa
4.4.3 Global warming:
- decomposition by aerobic micro-organisms = release of carbon dioxide (CO_2)
- decomposition by anaerobic micro-organisms = release of methane (CH_4)
- methane contributes much more to global warming then carbon dioxide
- burying organic matter in landfills contributes to global warming

AGRICULTURAL SCIENCES Paper 2: Suggested memorandum

SECTION A

QUESTION 1

1.1.1 d 1.1.2 b 1.1.3 b 1.1.4 b
1.1.5 d 1.1.6 a 1.1.7 b 1.1.8 c
1.2.1 diffusion
1.2.2 liquid
1.2.3 abalone
1.2.4 ion
1.2.5 precision
1.3.1 chlorosis
1.3.2 harrow
1.3.3 gypsum
1.3.4 selection
1.3.5 soil survey
1.3.6 basin irrigation
1.3.7 surface water
1.3.8 vermiculite
1.3.9 integrated agriculture-aquaculture / IAA
1.4.1 F 1.4.2 B 1.4.3 H 1.4.4 I 1.4.5 D

SECTION B

QUESTION 2

2.1.1 a) carbon dioxide or CO_2; b) oxygen or O_2; c) chlorophyll
2.1.2 a) CO_2; b) carbohydrates
2.1.3 chloroplasts
2.1.4 carotenoid
2.1.5 stroma of chloroplasts
2.1.6 leaf cells

2.2

- environment negatively affected when fossil fuels are burned during their production
- release substances that contribute to acid rain and greenhouse effect
- cause water contamination
- do not add any organic material into the soil, thus organic material is depleted by soil micro-organisms
- contain sulphuric acid and hydrochloric acid which increase soil acidity, thus decreasing nutrient availability and killing *Rhizobium*, a nitrogen-fixing bacteria

2.3.1 sepal (c); petal (d)

2.3.2 The petals (collectively referred to as the corolla) and sepals (collectively referred to as the calyx) support the sexual parts of the flower. The calyx protects the ovary and the corolla attracts insects to the flower.

2.3.3 Pollination is the process by which pollen is transferred from the anther to the stigma in plants, enabling fertilisation and sexual reproduction.

2.3.4 anther (a); stigma (e)

2.4 Process 1: imbibition, process 2: respiration, process 3: activation of enzyme systems, process 4: radicle emergence and seedling growth

2.5 scarification

2.6.1 Name any 3 of: bulbs, tubers, rhizomes, stolons/runners

2.6.2 The shoots die down and remain dormant in the soil until the next growing season.

QUESTION 3

3.1.1 transgenic organisms

3.1.2 Name any 5 of:

- plants that are resistant to diseases, pests and stress
- fruits and vegetables that stay fresh for longer
- plants that possess healthy fats and oils and increased nutritive value
- soybeans with a higher expression of naturally occurring anti-cancer proteins
- higher value-added feed for livestock
- higher fibre extraction rates in paper and pulp industry (lignin modification in trees)

3.1.3 Bt insect resistant maize and Roundup Ready (RR) herbicide-tolerant maize

3.1.4 Name any 2 of:

- Environmental: indiscriminate use of weed killers on herbicide resistant crops
- Health: long-term effects have not been established
- Economic: too costly for small-scale farmers

3.2 The cochineal bug has been used successfully to eradicate the prickly pear cacti. The cactus was imported from Central America and covered almost a million hectares of farmland in the Eastern Cape. The bug was bred in laboratories and used to suck sap from leaves which was spread by birds that visited prickly pears for fruit.

3.3.1 IPM programmes first work to establish acceptable pest levels, called action thresholds, and apply controls if these thresholds are crossed. By allowing a pest population to survive at a reasonable threshold, selection pressure is reduced. This stops the pest gaining resistance to chemicals produced by the plant or applied to the crops.

3.3.2

1) Proper identification of pests
2) Learn pest and host lifecycle and biology
3) Monitor the environment for pest population
4) Establish action threshold
5) Choose an appropriate combination of management tactics
6) Evaluate results

3.4 Soil erosion is the transport of soil by natural forces (mainly water and wind).

3.4.1

- Rill erosion: rills are small furrows caused by surface runoff on bare soil, often begins
- on paths used by people;
- Donga erosion: dongas or gullies form when smaller rills become deeper and wider;
- Sheet erosion: removal of thin top layer evenly over a large area, caused by strong winds or heavy rain in an area with little or no vegetation

3.4.2 Name any 1 of: soil texture, soil depth, rockiness of soil, slope

QUESTION 4

4.1.1 basin irrigation

4.1.2 a) main canal; b) soil wall

4.1.3 Basin irrigation:

- requires flat or gently sloping land (< 5% gradient)
- soil walls divide field into a number of basins
- starting from a main canal, water is led from basin to basin
- each basin must be flat

Answers to Exam Practice questions

4.1.4
- Name any 1 advantage: no power needed, no expensive equipment needed, even spread of water
- Name any 1 disadvantage: requires a lot of water, difficult to control delivery of water, difficult to set up and manage

4.2 Name any 3 of: salinity, sodicity, toxic chemicals, turbidity, biological/chemical pollutants

4.3.1 Crop rotation
- growing different crops in sequence in the same field over a number of years
- sub-divides field (into 4) and plant different family of crops on each piece of land
- swap crop families and land sections every year
- after four years, same crop is grown on original patch

4.3.2 monoculture

4.3.3 profitability, pest management, soil moisture and fertility, residue management, crop choice

4.4 Aims of soil cultivation
- killing and removal of weeds
- mixing in of organic matter and fertiliser
- burying or mixing crop residue

4.5.1 Reasons why a greenhouse is preferred:
- crops protected from natural elements and large pests
- crops can be cultivated out of season due to temperature control

4.5.2 Covers of a greenhouse:
- made of cheap polyethylene (PE) or polyvinyl chloride (PVC) materials
- materials have light transmission properties comparable to glass
- PE is UV protected, PVC will last up to five years
- can be used with light and cheap frames

4.6 Hydroponics is a method of growing plants in tightly controlled greenhouses in a medium without soil.

4.6.1 open / run-to-waste hydroponics, closed / continuous flow hydroponics