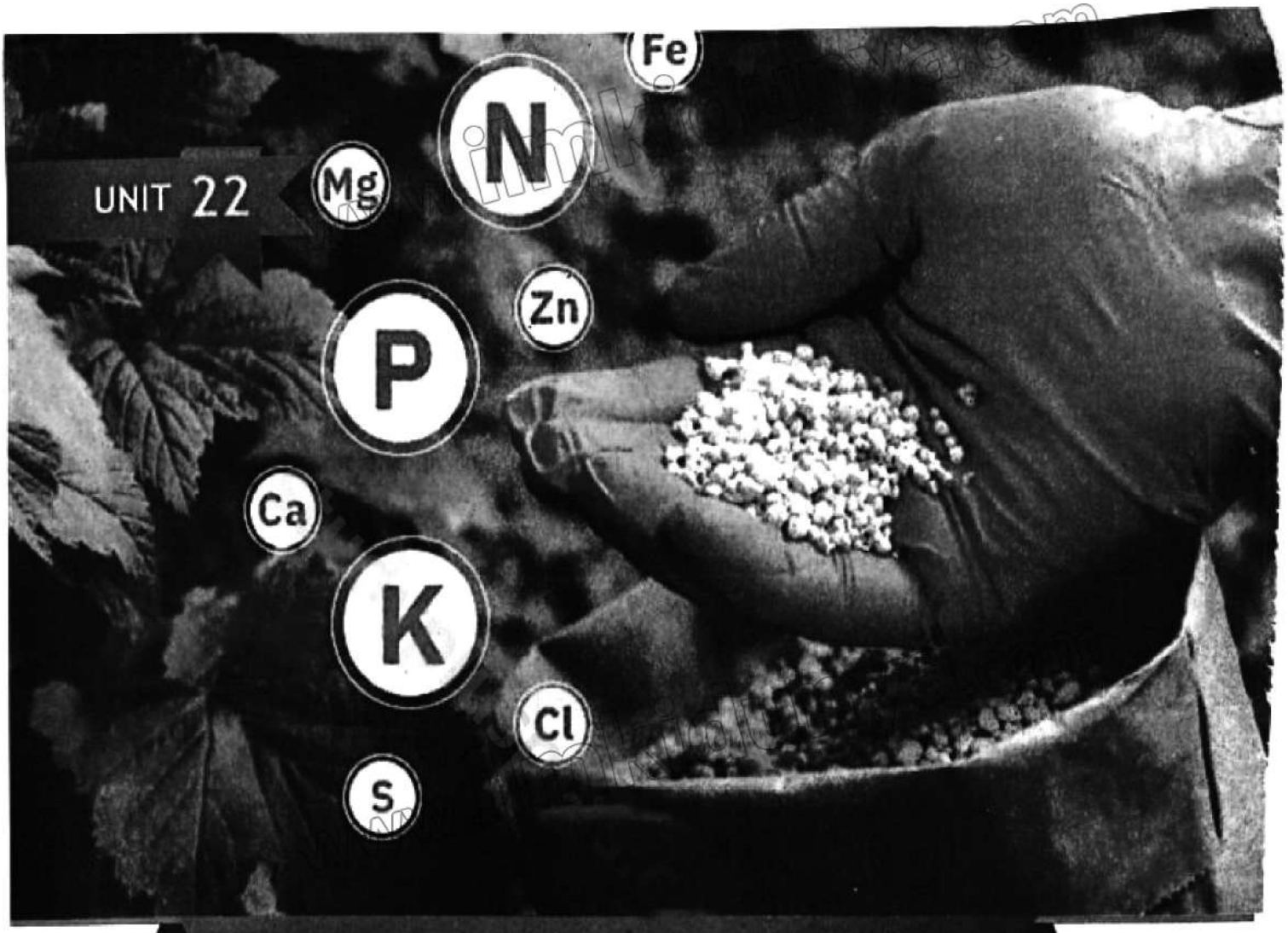


UNIT 22

AGRICULTURE

Student Learning Outcomes (SLOs)

- Explain the chemical composition and function of different types of fertilizers, including their role in providing essentials nutrients to crops and the impact of their applications on the soil health
- Identify the different types of pesticides used in agriculture and describe their mode of action, including the potential benefits and risks associated with their use.
- Identify the chemical reactions that occur when acid rain falls on crops and soil and explain the effects it has on crop growth, including nutrient uptake and crop yield.
- Explain the basics of genetic engineering and how it is used in agriculture, including the development of genetically modified crops and the potential benefits and risks associated with their use.
- Explain how changes in temperature, precipitation, and extreme weather events can affect crop growth and yield, including the potential for crop failure food storages, as well as the potential to develop new crop varieties that are more resilient to changing climate conditions.

This chapter covers basic aspects of agriculture such as fertilizers and plant protection products (pesticides), advantages and disadvantages of pesticides. Learn about the effects of acid rain on plants and soil. You will also learn the basics of genetic engineering and modified crops and the pros and cons of their use. Finally, you will learn how extreme weather events, such as climate change, temperature fluctuations, etc. affect plants.

22.1 Fertilizer

Fertilizers are natural or artificial substances containing elements that improve plant growth and productivity. Fertilizers increase the natural fertility of the soil or replace the elements taken from the soil by previous crops.

The fertility of the soil is the quality of the soil that allows the production of compounds in sufficient quantity that plants need for their growth. Other factors such as light, humidity, temperature and soil structure are also important for plant growth. If the soil fertility is not good, natural or artificial materials can be added to provide the plant with the necessary nutrients.

Historically, fertilizers are obtained from either natural or man-made sources: compost; animal manure, manure, harvested minerals, crop rotation, and human (and natural industrial) byproducts (e.g., fish processing waste, blood meal, animal by-products from animal slaughter, etc.). However, from the late 19th century onwards, after advances in plant nutrition were made, a synthetic-based agricultural industry began to develop. This shift transformed the world's food system, enabling large-scale, industrialized agriculture and large-scale harvests.

Nutrients in organic products are gradually released while the substance decomposes over time, while artificially synthesized inorganic products allow for the rapid uptake of nutrients by plants. However, the organic type of fertilizer is better for the soil and the ecosystem in the long run.

22.2 Composition of Fertilizers

Chemical fertilizers contain all nutrients. They contain nitrogen, phosphorus, and potassium as macronutrients and zinc, manganese, copper, iron, calcium, boron, magnesium, and molybdenum as trace elements.

22.1.1 Function of different types of Fertilizers

- **Nitrogen fertilizers**

N-fertilizers are especially useful in the middle phases of a plant's life cycle when the plant needs the most support to keep growing and leafing out. The two most popular types of chemical nitrogen-based fertilizers are ammonium nitrate, calcium ammonium nitrate, and urea. Nitrogen fertilizer must be applied at the start of the season.

- **Phosphorus fertilizers**

Phosphorus fertilizers serve to reinforce roots and stems, and are crucial at all stages of the plant's growth cycle. They also boost flowering, seed production, and fruit. Important P-

fertilizers are superphosphate, triple superphosphate, diammonium phosphate, ammonium dihydrogen phosphate, and ammonium polyphosphate.

- **Potassium fertilizers**

Potassium fertilizers promote root development in plants. Potassium helps plants maintain healthy photosynthesis and limits the spread of diseases. Leaves may become yellow or brown around the edges if your plants are lacking in potassium. If you don't add potassium fertilizer on time, the leaves will wither and fall off. Some examples of potash-type fertilizers are potassium chloride (KCl), potassium sulphate (K_2SO_4), and potassium nitrate (KNO_3).

22.1.2 Impact of fertilizers on soil health

Whether in synthetic or organic fertilizer types, the right nutrients applied at the right stage of plant growth are essential for a healthy crop, which in turn leads to improved crop yields. Imbalanced application of fertilizers can change soil pH and increase pest attack, acidification and soil erosion, resulting in reduced soil organic carbon and beneficial organisms, reduced plant growth and yield, and even greenhouse gas emissions.

22.3 Pesticides

The chemical substances used in agriculture to control or kill pests including insects, fungi, rodents, and weeds are called pesticides. Pests can damage crops and reduce yields. There are numerous types of pesticides. Each pesticide has its mechanism of action. Common types of pesticides are as follows:

Insecticides:

Insecticides are chemicals used to control insects. For example;

- **Organophosphates and Carbamates:** These chemicals inhibit enzyme the acetylcholinesterase, which is involved in transforming nerve signals to insects. This causes an increase in acetylcholine, which in turn causes overstimulation of the nervous system and paralysis of insects.
- **Pyrethroids:** The chemicals disrupt sodium channels in insect neurons, producing repetitive nerve impulses and paralysis.
- **Neonicotinoids:** These chemicals affect the nicotinic acetylcholine receptors in the insect nervous system, disrupting the transmission of nerve signals and causing paralysis.

1. **Herbicides:** Herbicides are chemicals used to control unwanted plants also called weeds. For example;

- **Glyphosate:** Glyphosate is a widely used herbicide that controls broadleaf weeds and grasses It inhibits protein production and ultimately kills the plant.
- **2,4-D and Dicamba:** These herbicides stimulate the effects of the plant hormone auxin, leading to uncontrolled growth and eventual death.
- **Paraquat:** Paraquat acts by inhibiting photosynthesis and causes the death of a plant.

2. **Fungicides:** Fungicides are pesticides that kill or prevent the growth of fungi and their spores. They are used to control fungi that damage plants. For example;
- **Triazoles:** Triazoles control the biosynthesis of ergosterol, which is an important component of fungal cell membranes. They break membrane integrity and cause cell death.
- **Strobilurins:** They interrupt the electron transport chain in fungal mitochondria, hence interrupting energy production and causing cell death.
- Copper-based fungicides: They cause cell death by interrupting various cellular processes in fungi.
- **Rodent poisons:** These chemicals disrupt blood clotting by inhibiting vitamin K, causing internal bleeding in rodents.
- **Zinc phosphide:** They react with stomach acid to form phosphine gas, toxic to rodents.

3. **Nematicides:** A nematicide is a type of pesticide used to kill plant-parasitic nematodes. For example;
- **Organophosphates:** They disrupt the nervous system of nematodes.
- **Biopesticides:** Biopesticides are a type of pesticide derived from natural materials such as animals, plants, bacteria, and certain minerals. For example, canola oil and baking soda are considered biopesticides. They can control nematode populations through various mechanisms.

22.4 Benefits and Risks of Pesticides

The use of pesticides in agriculture and other industries can have benefits and risks. It is important to find a balance between effective pest control and minimizing harm to human health and the environment.

22.4.1 Benefits of Pesticides

Pesticides are beneficial in many ways.

1. Pesticides help protect plants from pests and diseases. Hence contribute to increasing yield and food production.
2. Pesticides can control the spread of disease between plants, animals and humans. Therefore, they contribute to reducing the risk of epidemics and improving human health.
3. The use of pesticides can be more cost-effective than alternative pest control methods.
4. Pesticides can promote the production of higher-quality fruits and vegetables by preventing damage caused by pests. Hence contributing to food security and stability worldwide.

22.4.2 Negative aspects of Pesticides

Pesticides also pose many risks.

1. Pesticides can be carcinogenic, and neurotoxic. So, they can cause adverse health effects to farmers, co-workers, and consumers.
2. Pesticides can have negative effects on non-target organisms. Beneficial insects, birds, and aquatic organisms can also be affected by pesticides. Runoff water from fields can contaminate water sources and harm aquatic organisms.

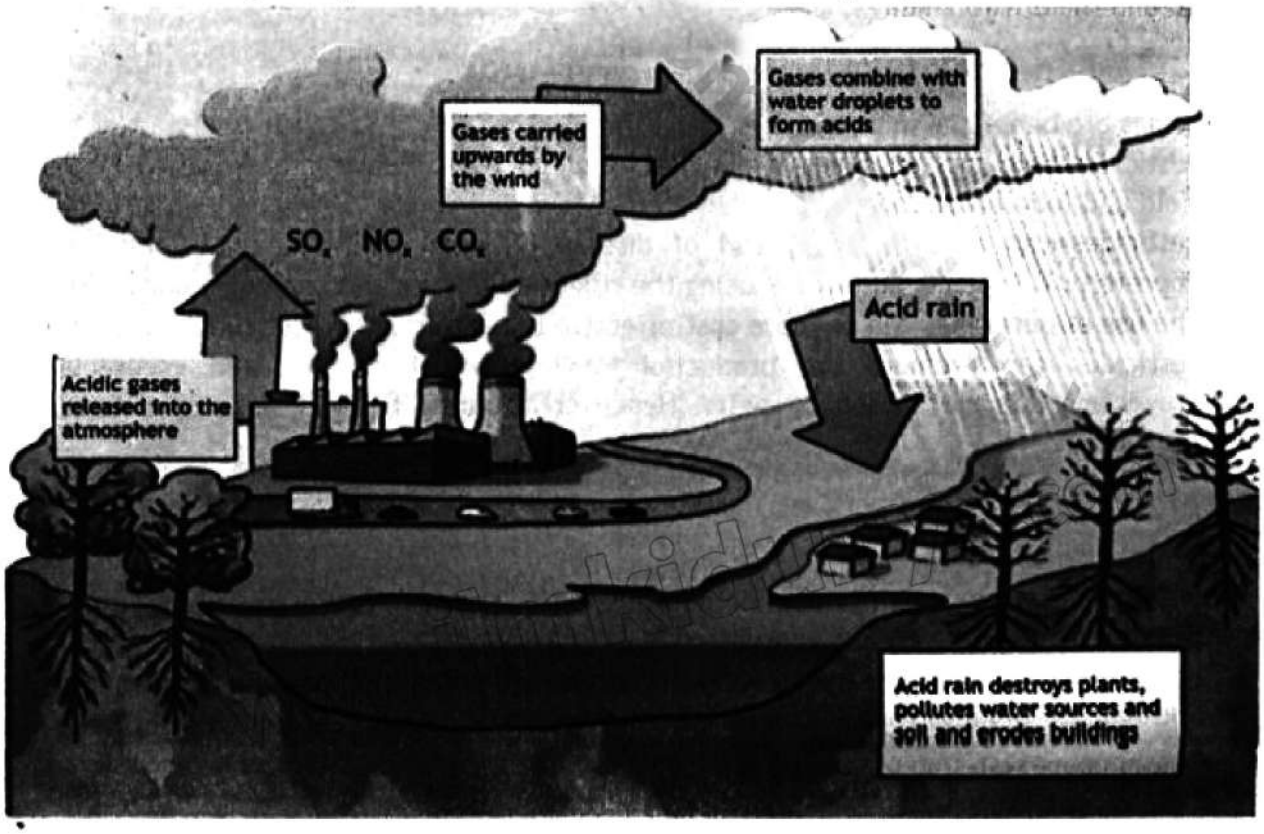
3. Leftover residues of pesticides on fruits, vegetables, and other crops, can cause health effects on consumers.
4. Over time, pests can develop resistance against certain pesticides, making them less effective. This can lead to the use of stronger or more toxic pesticides, which can further aggravate environmental and health issues.
5. Pesticides can reduce the number of beneficial insects, causing imbalances in the ecosystem and loss of biodiversity.
6. Pesticides can also be harmful to pollinators such as bees, which play a key role in pollinating many crops. Pollinator population declines can cause far-reaching agricultural consequences.
7. The inappropriate use or disposal of pesticides can lead to soil and water contamination, causing environmental pollution.

22.5 Acid Rain

Normal rainwater is saturated with carbon dioxide. It has pH of 5.6. Rain with a pH lower than 5.6 is called acid rain. Acid rain is caused by air pollution from sulphur oxides (SO_x) and nitrogen oxides (NO_x), dissolved in rainwater producing sulfuric acid (H_2SO_4) and nitric acid (HNO_3), respectively. As a result, rainwater has a pH as low as 2.1. This value is lower than that of lemon juice or vinegar. When acid rain falls on plants and soil, it can cause a number of chemical reactions. These reactions affect soil chemistry, nutrient availability, and ultimately crop growth and yield.

22.5.1 Impact of acid rain on soil:

Effects of acid rain on crops and soil can be devastating in many ways.



- Acid rain lowers the pH of the soil and makes it more acidic. Increased acidity can cause important nutrients such as calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), and sodium (Na^{+}) to leach from the soil and be replaced by hydrogen ions (H^{+}) of acid rain. This reaction reduces the availability of these essential nutrients to plants. So, the required nutrients are leached away from the soil.

Example:

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + H_2O + CO_2$$

- Increased acidity of soil causes the leaching of aluminium from the soil.

$$Al_2O_3 + 3H_2SO_4 + 6H_2O \rightarrow 2Al(OH)_3 + 3SO_4^{2-} + 6H^{+}$$

Aluminium ions are poisonous to plants and can kill them. It also makes it difficult for plants to absorb water.

- Direct acid rain can damage the waxy surface of leaves, increasing water loss and making plants more susceptible to disease and the environment.
- Studies have shown that acid rain can significantly affect the performance of sensitive plants such as soybeans, wheat, and peanuts by changing their physiological and biochemical processes. Soy and wheat crops are sensitive to changes in soil pH. Acid rain can reduce soybean and wheat yields by reducing nitrogen fixation in soybeans and affecting the nutrition of both crops.
- Acid rain can negatively affect soil microbial communities, which play an important role in nutrient cycling and decomposition of organic matter. This can further affect nutrient availability and soil structure, affecting crop yields.

All of the factors mentioned above reduce crop yield.

22.6 Genetic Engineering

Genetic engineering also called genetic modification is a technique used to change an organism's gene to enhance the capabilities of the organism. This means genetic engineering is the process of altering an organism's genome. This can range from changing one single DNA base to deleting or inserting a whole region of DNA.

Table 22.1: GM crops

Alfalfa	Melon	Rose	Flax, Linseed
Argentine Canola	Papaya	Soybean	Potato
Carnation	Petunia	Squash	Tomato
Chicory	Plum	Sugar Beet	Maize
Cotton	Polish canola	Sweet pepper	Rice
Creeping Bentgrass	Poplar	Tobacco	Wheat

For example, genetic engineering can produce more efficient or nutritious crop plants. In agriculture, genetic engineering is applied to develop genetically modified (GM) crops with desired traits such as increased yield, resistance to pests and diseases, and tolerance to stresses like drought, salinity, and extreme temperature changes.

Basics of Genetic Engineering:

Genetic engineering is practised in four basic steps.

1. Scientists first identify a desired trait, such as drought tolerance or pest resistance.
2. The gene responsible for this trait is identified and isolated from the organism.
3. Using various techniques, the isolated gene is inserted into the target plant's genome.
4. The genetically modified plant is grown and tested to ensure it has acquired the desired traits and is safe for consumption and the environment.

22.6.1 Use of Genetics in Agriculture:

Genetic engineering has led to the development of many genetically modified crops, including

- Crops like soybeans, corn, and cotton have been engineered to tolerate specific herbicides (e.g., glyphosate). This has enabled farmers to control weeds without harming the crops.
- Bt crops (e.g., Bt corn, Bt cotton) contain a gene from the bacterium Bacillus thuringiensis, which produces a protein which is toxic to specific insects. This has reduced the need to use chemical pesticides.
- Some crops have been engineered for resistance against viruses, fungi, and bacteria. For instance, rainbow papaya which is resistant to the papaya ringspot virus.
- Some crops have been developed to deal with vitamin A deficiency. For example, Golden *rice is* genetically modified to produce beta-carotene, a precursor of vitamin A.

22.6.2 Potential Benefits of Genetically Modified Crops

Some of the benefits of genetic engineering in agriculture are as follows.

- It has increased crop yields.
- It has reduced production costs for food or medicine.
- It has reduced the need for pesticides.
- It has improved food composition and food quality.
- It has produced crops resistant to pests and diseases.
- It has improved food safety, and medical benefits for the growing population.

22.6.3 Potential Risks of Genetically Modified Crops

Little information is available about the long-term impact of GM crops on humans. Genetically modified foods may cause antibiotic-resistant diseases. GM crop cultivation may reduce agricultural biodiversity. Genetically modified crops may result in the development of disease-resistant pests. Cross-pollination of genetically modified genes with wild relatives may lead to unforeseen consequences.

Changes in temperature, precipitation patterns, and extreme weather events can significantly impact crop growth and yield in various ways.

22.7 Impacts of Climate Change on Agriculture

Changes in temperature, precipitation, and extreme weather events can affect crop growth and yield.

Effects of temperature Changes

How does temperature stress affect plants?

Heat stress causes dehydration and affects plant growth and development. High temperatures affect their photosynthesis, respiration, and water absorption. In extreme cases, this can cause slow growth, reduced yield, and even crop failure.

Similarly, cold temperatures can damage crops. Cold can kill young plants or damage their structures, resulting in reduced or complete yield loss.

Effects of Precipitation Changes

Precipitation is essential for crop health. It provides the water and nutrients needed for plant growth and development. When it rains sufficient, the crop can absorb the water and nutrients it needs, and the soil around it stays moist and fertile. This allows the plants to grow and produce large and healthy crops. Heavy rainfall can leach essential nutrients from the soil, reducing crop availability. Therefore, an optimal amount of rainfall is necessary for optimal crop growth and yields. Drought conditions can lead to moisture stress, causing plants to wilt, and reducing crop yields.

Effects of Extreme Weather Events

Storms can cause physical damage to crops, such as uprooting, branch damage, or lodging (crops that have been flattened). Strong winds can also speed up the loss of moisture from leaves, making drought stress severe. Hail punctures leave, stems and fruits, causing tissue damage, and photosynthetic failure. Severe Hail can cause significant yield loss or complete crop destruction. Sudden and extended heat waves can put crops under extreme heat stress, speeding up the loss of water through transpiration, resulting in leaf burning, reduced flowering, and reduced yields.

Impacts on Food Security and Storage

Crop failures due to adverse weather conditions can disrupt food supply chains. It can lead to food shortages and price increases, especially in areas that rely heavily on local agricultural production. Crop reductions can also affect food supplies such as smaller quantities being available for processing and distribution. This can lead to increased food waste, and threaten food security.

Development of sustainable crop varieties

Climate change requires the development of crop varieties that are more resilient to changing environmental conditions. This means the breeding or genetic modification of crops with traits such as heat tolerance, drought tolerance, disease resistance and water and nutrient use efficiency.

Crop failures due to adverse climate conditions can disrupt food supply chains, leading to food shortages and price spikes, particularly in regions heavily reliant on local agricultural production.

Reduced crop yields may also impact food storage facilities, as lower quantities of produce are available for processing and distribution, potentially leading to increased food wastage and compromised food security.

Development of Resilient Crop Varieties

Climate change necessitates the development of crop varieties that are more resilient to changing environmental conditions. This involves breeding or genetically engineering crops with traits such as drought tolerance, heat tolerance, disease resistance, and improved water and nutrient use efficiency.

KEY POINTS

- Fertilizer, are natural or artificial substances containing elements that improve plant growth and productivity.
- N-fertilizers are especially useful in the middle phases of a plant's life cycle.
- Phosphorus fertilizers serve to reinforce roots and stems, is crucial at all stages of the plant's growth cycle.
- Potassium fertilizers promote root development in plants.
- The chemical substances used in agriculture to control or kill pests including insects, fungi, rodents and weeds are called pesticides.
- Normal rainwater is saturated with carbon dioxide. It has a pH of 5.6
- Acid rain lowers the pH of the soil and makes it more acidic.
- Aluminium ions are poisonous to plants and can kill them. It also makes it difficult for plants to absorb water.
- Genetic engineering also called genetic modification is a technique used to change an organism's gene using technology.
- Genetically modified crops may result in the development of disease-resistant pests.
- High temperatures affect their photosynthesis, respiration, and water absorption.
- Heavy rainfall can leach essential nutrients from the soil.
- Climate change requires the development of crop varieties that are more resilient to changing environmental conditions.

EXERCISE

1. Multiple Choice Questions (MCQs)

i. What is the primary cause of acid rain?

a) Carbon dioxide emissions b) Sulphur dioxide and nitrogen oxides emissions

c) Methane emissions d) Chlorofluorocarbons emissions

ii. How does acid rain affect soil pH?

a) Increases soil pH b) Decreases soil pH

c) Does not affect soil pH d) Depends on the type of soil

iii. Which nutrient leaches away from the soil due to acid rain?

a) Nitrogen b) Phosphorus c) Calcium d) Oxygen

iv. What role do soil microbes play in the context of acid rain?

a) They thrive in acidic soil conditions

b) They help neutralize acid rain

c) They are unaffected by acid rain

d) They play a vital role in nutrient cycling and decomposition

v. Which of the following is NOT a potential benefit of genetic engineering in agriculture?

a) Increased crop yields b) Reduced biodiversity

c) Pest resistance d) Enhanced nutritional content

vi. What is the primary purpose of inserting genes into target plants in genetic engineering?

a) To increase crop diversity b) To improve crop yield

c) To express desired traits d) To reduce genetic variation

vii. Which technique is commonly used to transfer genes into target plant cells?

a) CRISPR-Cas9 b) Gene guns (biolistics)

c) Polymerase chain reaction (PCR) d) Microinjection

viii. Golden rice is genetically modified to address deficiencies in which vitamin?

a) Vitamin C b) Vitamin D c) Vitamin A d) Vitamin E

ix. Which genetically modified crop produces a protein toxic to specific insects, reducing the need for chemical pesticides?

a) Herbicide-tolerant soybeans b) Bt cotton

c) Disease-resistant tomatoes d) Golden rice

x. What is one of the primary benefits of using pesticides in agriculture?

a) Decreased crop yields b) Increased biodiversity

c) Enhanced food quality d) Reduced global food security

xi. Which of the following is NOT a risk associated with pesticide use?

a) Development of pesticide resistance b) Loss of biodiversity

c) Enhanced soil fertility d) Human health concerns

xii. What environmental impact is associated with pesticide runoff from fields?

a) Soil erosion prevention b) Water contamination

c) Enhanced aquatic ecosystems d) Increased biodiversity

xiii. What potential risk arises from the development of pesticide resistance in pests?

a) Decreased use of pesticides

b) Increased effectiveness of pesticides

c) Need for stronger or more toxic pesticides

d) Improved pest control methods

xiv. Which change in weather pattern is likely to impact water availability for crops?

a) Increased temperature b) Altered rainfall patterns

c) Heat stress d) Enhanced nutrient uptake

xv. How does breeding resilient crop varieties help in adapting to climate change?

a) Reduces pesticide use b) Enhances nutritional content

c) Improves resistance to stress d) Increases soil acidification

2. Short Answer Questions

i. Describe the chemical reactions involved in soil acidification due to acid rain.

ii. Explain the role of phosphorus in plant growth and development.

iii. Discuss the potential environmental impacts of excessive nitrogen fertilizer use.

iv. Describe the chemical composition of superphosphate fertilizer and its function in soil fertility

v. How does acid rain affect nutrient uptake by plants?

vi. Explain the impact of acid rain on soil microbial activity.

vii. Discuss the effects of acid rain on crop yield.

viii. Explain the process of genetic engineering in agriculture.

ix. Explain how pesticides contribute to increased crop yields.

x. Discuss one human health concern associated with pesticide exposure.

xi. What is meant by the term "pesticide resistance," and why is it a concern?

xii. How would you determine the appropriate fertilizer to use for a crop with phosphorus deficiency?

xiii. How does the mode of action of insecticides differ from that of herbicides?

xiv. What are the potential environmental risks of excessive pesticide use?

xv. Design a plan to minimize the negative impacts of fertilizer runoff into nearby water bodies.

xvi. How does acid rain affect nutrient availability in the soil?

xvii. What are the potential consequences of long-term soil acidification on crop yield?
xviii. How can genetic engineering be used to reduce pesticide use in agriculture?
xix. How would you modify irrigation practices to cope with altered rainfall patterns?
xx. What is the impact of extreme weather events on food storage and supply chains?
xxi. How do different types of pesticides (insecticides, herbicides, fungicides) target pests differently?
xxii. What are the long-term impacts of pesticide use on soil health?

3. Long Answer Questions

i. How do pesticides contribute to the decline of biodiversity?
ii. Name three traits that genetically modified crops may possess and provide an example of each trait.
iii. Critically analyse the role of genetic engineering in addressing global food security challenges.
iv. Compare and contrast the benefits and risks of using genetically modified crops versus traditional breeding methods in agriculture.
v. Evaluate the role of micronutrient fertilizers in crop production. Discuss the symptoms of micronutrient deficiencies in plants and the strategies to address these deficiencies, considering the environmental and economic impacts.
vi. Describe the different types of pesticides used in agriculture, including insecticides, herbicides, fungicides, and rodenticides.
vii. Critically evaluate integrated pest management (IPM) strategies. How do these strategies aim to reduce the negative impacts of pesticide use? Provide examples of successful IPM practices and discuss their long-term sustainability.
viii. Identify and explain the chemical reactions that occur when acid rain falls on crops and soil. Discuss the effects of acid rain on crop growth, nutrient uptake, and crop yield. Propose mitigation strategies to counteract the negative effects of acid rain on agriculture.
ix. Analyse the impact of acid rain on soil chemistry and plant physiology. How does acid rain affect soil pH and nutrient availability? Discuss the long-term implications for crop production and soil health if acid rain continues to be a persistent problem.
x. Critically analyse the role of genetic engineering in developing crops that can withstand biotic and abiotic stresses. Provide examples of genetically modified crops designed for drought tolerance, pest resistance, or enhanced nutritional content. Discuss the challenges and future prospects of genetic engineering in sustainable agriculture.
xi. Analyse the impact of climate change on global agriculture. Discuss how different regions are affected differently by climate change and the adaptive measures being taken. Evaluate the effectiveness of these measures and propose additional strategies to enhance the resilience of agriculture to climate change.

PROJECT

Create a report or multimedia presentation summarising the research, experiments, findings, and practical solutions for sustainable agriculture.