Study Guide
BS Rural Development

INTRODUCTORY HORTICULTURE

COURSE CODE: 7905



Department of Agricultural Sciences
ALLAMA IQBAL OPEN UNIVERSITY

INTRODUCTORY HORTICULTURE

Code-7905



DEPATMENT OF AGRICULTURAL SCIENCES
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COURSE TEAM

Chairman of Course Team: Prof. Dr. Sher Muhammad

Written by: Dr. Zaid Mustafa
Department of Agricultural Sciences, AIOU, Islamabad

Dr. Wajid Khan Bloch
Manager Landscape and Horticulture, Defense Housing Authority, Islamabad-Rawalpindi

Dr. Sakeena Tul Ain Haider
Department of Horticulture
Bahaudin Zakariya University Multan

Reviewed By: Dr. Ayesha Maryam
Department of Agricultural Sciences AIOU, Islamabad

Dr. Qasim Ali
Department of Soil Science
The Islamia University of Bahawalpur

Dr. Hafiz Amjad Ali Rana
Department of Outreach and Continuing Education
MNS-University of Agriculture, Multan

Dr. Muhammad Shahzad
Department of Agriculture Extension Education
The Islamia University of Bahawalpur

Course Coordinator: Dr Zaid Mustafa

Editor: Mr. Fazal Karim

PREFACE

The study of horticulture holds great importance in the agricultural and economic development of any nation. This book, *Introductory Horticulture*, has been compiled with the primary objective of providing students and beginners with a clear, concise, and practical foundation in the subject. It is designed to introduce the fundamentals of horticulture, including its branches, scope, basic cultural practices, and the role it plays in ensuring food security, environmental sustainability, and human well-being.

Special attention has been given to the needs of learners and growers of Pakistan. The book highlights importance, scope, local crops, their morphology, climatic conditions, propagation and challenges relevant to our agricultural systems. By associating theory with practical examples, this book aims to prepare students not only for academic learning but also for field application, entrepreneurship, and research.

This book is intended for undergraduate students of horticulture and agriculture, as well as teachers, extension workers, and enthusiasts who wish to acquire a basic yet comprehensive understanding of the subject. It has been structured in a simple and organized way so that readers can progress step by step, from introductory concepts to applied knowledge.

I gratefully acknowledge the efforts of my colleagues, students, and all those who provided guidance, encouragement, and constructive feedback during the preparation of this work. It is my hope that this book will serve as a useful reference and a steppingstone for further exploration of horticultural sciences in Pakistan and beyond.

Prof. Dr. Nasir Mahmood
Vice Chancellor
Allama Iqbal Open University,
Islamabad

FOREWORD

In a world of increasing urbanization and digital saturation, the ability to cultivate and understand plants is not just a pleasure, it is a critical skill. Horticulture feeds our communities, beautifies our environments, and sustains our ecosystems. The horticulture sector holds immense potential for Pakistan's national development. Our diverse climatic conditions allow the cultivation of a wide range of fruits, vegetables, and ornamental plants. Horticultural crops such as mangoes, citrus, dates, and cut flowers not only contribute significantly to agricultural GDP but also serve as vital export commodities, earning valuable foreign exchange for the country. Moreover, the sector provides employment opportunities to millions of people, supports rural livelihoods, and contributes to poverty alleviation. With the rising demand for quality food, urban landscaping, and sustainable farming practices, horticulture offers promising avenues for innovation, entrepreneurship, and research in Pakistan.

This book, “Introductory Horticulture” has been carefully prepared to provide a foundational understanding of the subject. The chapters ahead are structured to take you from theory to practice. You will move from the basics to the applied techniques of propagation, pest management, and landscape design. Each concept is presented with the beginner in mind, with clear illustrations and straightforward language. It introduces students and beginners to the essential principles, practices, and applications of horticulture in a clear and structured manner. Special emphasis is placed on both theoretical concepts and practical skills, so the learners can connect classroom knowledge with real-world applications.

The authors are confident that this book will serve as a valuable resource for learners at various levels, guiding them toward further exploration of horticulture as a profession, a research field, and a way of life. We hope that this book will inspire readers to not only acquire technical knowledge but also to appreciate the beauty, creativity, and responsibility linked with plant cultivation.

Prof. Dr. Sher Muhammad
Dean faculty of Sciences
Allama Iqbal Open University,
Islamabad

COURSE INTRODUCTION

Horticulture is an integral branch of agricultural sciences that deals with the cultivation of fruits, vegetables, flowers, ornamental plants, and plantation crops. It is a field that combines scientific knowledge with practical skills to ensure efficient production, quality enhancement, and sustainable utilization of plant resources. As a dynamic discipline, horticulture plays a vital role in ensuring food and nutritional security, promoting environmental sustainability, and improving livelihoods through entrepreneurship and agribusiness opportunities.

In Pakistan, horticulture has immense importance due to the country's diverse agro-climatic zones, which allow the cultivation of a wide variety of crops such as mango, citrus, guava, dates, potato, onion, tomato, cut flowers, and ornamental plants. The sector contributes significantly to agricultural GDP, foreign exchange earnings, rural employment, and poverty alleviation. With increasing consumer demand for high-value crops, organic products, and improved landscaping, horticulture offers great potential for innovation, research, and commercialization.

This course, Introductory Horticulture, is offered as part of the BS Agricultural Extension program. It is designed to provide students with a foundational understanding of horticultural science and practices, covering both theoretical concepts and hands-on applications. The course introduces the scope, importance, and branches of horticulture, along with basic crop production techniques, postharvest management, and the role of modern technologies in sustainable horticultural development.

Through this book, students will be equipped with essential knowledge and skills to pursue advanced studies, research, and professional careers in horticulture and agricultural extension. The emphasis is placed not only on academic learning but also on practical problem-solving, critical thinking, and application of horticultural practices to address national agricultural challenges.

SPECIFIC OBJECTIVES:

This book has been developed with the following objectives:

1. To highlight the importance of horticulture in Pakistan's context, with emphasis on major crops, climatic adaptability, and economic contribution.
2. To provide students and beginners with a clear and systematic introduction to the principles and practices of horticulture.
3. To serve as a ready reference guide for teachers, extension workers, and learners involved in horticultural education and training.
4. To bridge theoretical knowledge with practical applications, enabling students to connect classroom learning with field practices.
5. To encourage skill development in nursery management, crop production techniques, postharvest handling, and value addition.
6. To act as a foundation for advanced studies and research in horticulture and related agricultural sciences.

Dr. Zaid Mustafa
Lecturer/Course Coordinator
Department of Agricultural Sciences
Allama Iqbal Open University Islamabad

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Unit:1

BASICS OF HORTICULTURE

Written By: Dr. Wajid Khan Bloch
Reviewed By: Dr. Ayesha Maryam

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INTRODUCTION

Horticulture is a specialized branch of agriculture concerned with the intensive cultivation of fruits, vegetables, flowers, medicinal plants, and ornamentals for food, health, and aesthetic purposes. Horticulture is quietly different from agronomy and forestry as they focus on field crops and forest trees, while horticulture emphasizes high-value crops that are often perishable, nutritionally rich, and aesthetically pleasing. It holds immense importance by contributing to economic growth, food and nutritional security, cultural practices, environmental sustainability, and job creation. The scope of horticulture is vast, encompassing pomology, olericulture, floriculture, landscape horticulture, plant breeding, post-harvest technology, medicinal and aromatic plants, agroforestry, and urban horticulture. As both an art and a science, horticulture integrates biological knowledge with practical cultivation techniques, playing a crucial role in human well-being, sustainable development, and the enhancement of natural and urban environments.

OBJECTIVES:

- To familiarize students with the concept, importance, and scope of horticulture
- To highlight the differences between horticulture, agronomy, and forestry
- To explain the economic, nutritional, environmental, aesthetic, and cultural roles of horticulture
- To introduce students to the branches and applications of horticulture in modern agriculture and urban development

LEARNING OUTCOMES:

By the end of this unit, students will be able to:

- Define horticulture and explain its distinctive features compared to agronomy and forestry
- Identify and describe the branches of horticulture (pomology, olericulture, floriculture, etc.)
- Recognize the economic, nutritional, and environmental importance of horticultural crops
- Understand how horticulture contributes to aesthetic values, cultural practices, and sustainability
- Apply knowledge of horticultural practices to food production, landscape development, and conservation

1.1 Difference between Horticulture, Agronomy, and Forestry

The term *horticulture* is derived from two Latin words *hortus,* 'garden' and *colere,* 'to cultivate'. Halfacre and Barden (1979) state that the first known use of the term horticulture was in 1631. Bailey (1939) "Observed that horticulture is concerned with production within an enclosure. Gardens are distinguished from fields by the concept of enclosure. Jamck defines horticulture as "that branch of agriculture concerned with intensively cultured plants used for food, for medicinal purposes, or for esthetic gratification."

Therefore, if agriculture is defined as the technology of raising plants and animals, then horticulture would be that part of plant agriculture which deals with garden crops (Richard, 2014).

Agronomy and forestry are the branches of agriculture covering field crops and forest trees, respectively. Horticulture may be considered as a parallel discipline to agriculture, since the Latin word *ager* means 'field', and agriculture is defined as the cultivation of field crops, whereas horticulture is the cultivation of garden crops. However, the concept of a garden has evolved from that of an enclosed place to that of intensively cultivated land. The differences among horticulture, agronomy, and forestry are mainly defined by custom. Horticultural produce usually has a high-water content, is highly perishable, and is usually utilized fresh; whereas agronomic and forestry products are often utilized in the non-living state and usually contain high percentages of dry matter (Richard, 2014). Crops like potatoes and sweet potatoes may be considered agronomic crops when they are used as staple foods. For us in Pakistan, potatoes and sweet potatoes are vegetable crops. Trees like walnut, mango, and pine are forest crops when planted for wood, and horticultural crops when used as fruit and ornamental trees. Horticultural crops often have high value and are intensively cultivated on relatively small areas. Thus, melons can be either an agronomic or a horticultural crop, depending on whether they are grown extensively or intensively. The high cash value of horticultural crops justifies a large input of capital, labour, and technology per unit area of land. Sweet corn is different from maize only by a single gene, but this one gene increases its value enough to warrant the use of hybrid seed and intensive cultural methods. This, plus its use by humans, changes its category from an agronomic crop to a horticultural crop. The input per unit area for agronomic crops like cotton and sugarcane is also very high and may be more than for some horticultural crops. One such characteristic is that horticultural products are sources of aesthetic pleasure, i.e. beauty and pleasant flavor. Some fruits and vegetables, like cashews and garlic, are highly nutritious but they are eaten primarily as a source of flavor and pleasure. Thus, horticultural foods may be distinguished from agronomic food products by their aesthetic as well as their food value. Horticulture deals with a large number of plant species. Traditionally, it includes fruits, vegetables, and ornamental plants. Even

medicinal plants, beverage plants (tea, coffee), and spices are considered horticultural crops. Horticulture is an art as well as a science. It deals with a combination of the botanical and agricultural aspects of plants. Thus, one may define horticulture as the culture and biology of garden crops, including both the aesthetic and the scientific dimensions (John and Paul, 2005).

1.2 Importance of Horticulture

Horticulture is the science and art of growing fruits, vegetables, flowers, and ornamental plants. It plays a significant role in several aspects of human life, society, and the environment. Here are some key points highlighting its importance:

1.2.1 Economic Importance:

Horticulture is a major contributor to global agriculture and the economy. The production of fruits, vegetables, herbs, and flowers supports millions of jobs and is vital for food security. The horticultural industry provides income through the sale of crops, plants, and related products, benefiting farmers, laborers, and local economies.

1.2.2 Nutritional Value:

Fruits and vegetables grown in horticulture are essential components of a healthy diet. They provide vital nutrients, vitamins, and minerals, contributing to overall public health. A varied diet of fresh produce helps prevent chronic diseases and supports growth and development (Richard, 2014).

1.2.3 Environmental Benefits:

Horticulture plays a key role in enhancing biodiversity, improving soil fertility, and reducing environmental pollution. Planting trees and landscaping can also help mitigate the effects of climate change by absorbing carbon dioxide and releasing oxygen (Cardoso and Vendrame, 2022).

1.2.4 Aesthetic Value:

Horticultural practices improve the aesthetic appeal of urban and rural landscapes. Gardens, parks, and other green spaces contribute to mental well-being and the overall quality of life by providing places for relaxation, recreation, and environmental enrichment.

1.2.5 Cultural Significance:

Many cultures have a deep connection to horticultural practices. Plants, flowers, and fruits are often central to religious ceremonies, traditional celebrations, and

rituals. Gardening and the cultivation of plants are part of cultural heritage and identity (Richard, 2014).

1.2.6 Job Creation:
The horticultural industry creates jobs in various fields, such as farming, landscape design, floriculture, plant breeding, nursery management, and horticultural research. It also supports sectors such as retail, food processing, and tourism.

1.2.7 Sustainability:
With the increasing global population and environmental challenges, horticulture plays a role in promoting sustainable agriculture. By focusing on efficient use of water, soil conservation, and organic farming techniques, horticulture helps maintain ecological balance (Cardoso and Vendrame, 2022).

1.3 Scope of Horticulture

The scope of horticulture is vast, and it covers multiple branches of plant science and production. It includes the cultivation, breeding, and management of plants for various purposes, including food, medicine, and ornamental uses (Monisha *et al*., 2025). The breakdown of the scope of horticulture is as follows:

1.3.1 Fruit Production (Pomology):
This branch focuses on the study and cultivation of fruit crops such as apples, bananas, berries, citrus fruits, and tropical fruits. It involves the propagation, care, and harvesting of these crops for both fresh consumption and processing.

1.3.2 Vegetable Production (Olericulture):
Olericulture deals with the cultivation of vegetables like tomatoes, potatoes, carrots, cucumbers, and leafy greens. It also involves the production of root, stem, and leaf vegetables, which are essential for human diets worldwide.

1.3.3 Floriculture:
This branch focuses on the cultivation and commercialization of flowers and ornamental plants. It includes growing flowers for decorative purposes, landscaping, and the cut flower industry. Floriculture also involves breeding new flower varieties (Rabiya 2024).

1.3.4 Landscape Horticulture:
Landscape horticulture concerns the design, installation, and maintenance of gardens, parks, and green spaces. This is essential for urban planning, public

spaces, and private landscapes, contributing to environmental and aesthetic well-being (John and Paul, 2005).

1.3.5 Breeding of Horticultural Crops:
Horticulturists involved in plant breeding focus on developing improved plant varieties with desirable traits such as disease resistance, higher yields, and better quality. This is vital for the future of food security and sustainability (Monisha *et al*., 2025).

1.3.6 Post-Harvest Technology:
This field involves the handling, storage, and processing of horticultural products after they are harvested. Proper post-harvest techniques help extend the shelf life of fruits, vegetables, and flowers, reducing food waste and enhancing market value.

1.3.7 Medicinal and Aromatic Plants:
Horticulture also covers the cultivation of plants for medicinal and aromatic purposes. Plants such as herbs, spices, and medicinal plants are valuable in traditional and modern medicine and the perfume industry (Cardoso and Vendrame, 2022).

1.3.8 Agroforestry and Environmental Horticulture:
Agroforestry integrates trees and shrubs into agricultural systems, improving land use and environmental sustainability. Environmental horticulture focuses on the role of plants in environmental conservation, such as erosion control, habitat restoration, and carbon sequestration (Rabiya 2024).

1.3.9 Urban Horticulture:
This area focuses on cultivating plants in urban settings, including rooftop gardens, vertical farming, and community gardens. Urban horticulture is gaining importance due to its contribution to local food production, improving urban green spaces, and promoting sustainability in cities (John and Paul, 2005).
Overall, it can be concluded that horticulture is not only vital for the global economy and food security but also enhances environmental sustainability, aesthetic values, and public health. Its scope covers diverse areas, ranging from fruit and vegetable production to ornamental gardening and landscape design, making it a key sector for both agricultural and urban development.

1.4 Self Assessment Questions

Fill in the blanks with appropriate text

i. Agronomy and forestry are the branches of agriculture covering …… and forest trees, respectively.

ii. ……. is the science and art of growing fruits, vegetables, flowers, and ornamental plants.

iii. ……. involves the handling, storage, and processing of horticultural products after they are harvested.

iv. ……. horticulture concerns the design, installation, and maintenance of gardens, parks, and green spaces.

v. ……. focuses on the cultivation and commercialization of flowers and ornamental plants.

vi. ……... deals with the cultivation of vegetables like tomatoes, potatoes, carrots, cucumbers, and leafy greens.

vii. …… focuses on the study and cultivation of fruit crops such as apples, bananas, berries, citrus fruits, and tropical fruits.

Answers

i. field crops

ii. Horticulture

iii. Post-harvest technology

iv. Landscape

v. Floriculture

vi. Olericulture

vii. Pomology

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Unit:2

DIVISIONS OF HORTICULTURE

Written By: Dr. Wajid Khan Bloch
Reviewed By: Dr. Muhammad Shahzad

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INTRODUCTION

Horticulture is a specialized branch of agriculture with three primary divisions: pomology (fruit production), olericulture (vegetable production), and floriculture/landscape horticulture (ornamental plants and environmental beautification). Additional branches include nursery culture, seed production, greenhouse crops, pharmaceutical crops, and post-harvest industries.

Pomology focuses on fruit production, orcharding, viticulture, and citriculture. It requires high investment and specialized operations like pruning, training, and post-harvest handling due to the perishable nature of fruits. In Pakistan, citrus and mango dominate fruit production, followed by banana, guava, date palm, apple, and stone fruits.

Olericulture deals with vegetables, grown in flexible systems such as home gardening, market gardening, truck farming, vegetable forcing, processing, seed production, and mushroom culture. It ensures household food security, supports commercial production, and can adapt quickly to consumer demand.

Floriculture and Landscape Horticulture focus on beautification, urban greening, pollution control, and economic opportunities through nurseries, cut flowers, essential oils, and exports. Pakistan's nursery hub is Pattoki, while globally, floriculture is a major foreign exchange earner (e.g., Holland).

OBJECTIVES

- To introduce the main branches of horticulture
- To explain the scope, methods, and importance of fruit, vegetable, and ornamental plant production.
- To highlight the role, strengths and diversity of Pakistan in fruit, vegetable, and ornamental crop cultivation.
- To discuss propagation, cultural practices, and post-harvest handling in fruit and vegetable production.
- To explore economic opportunities in nursery, floriculture, cut flower exports, and landscape design.

LEARNING OUTCOMES

By the end of this topic, students will be able to:

i. Define and understand pomology, olericulture, and floriculture/landscape horticulture
ii. Differentiate between fruit, vegetable, and ornamental crop production systems
iii. Identify major fruit and vegetable crops of Pakistan
iv. Explain propagation techniques, cultural operations, and post-harvest handling methods in pomology.
v. Understand different types of vegetable production systems (home, market, truck, forcing, processing).
vi. Distinguish the role of floriculture and landscape horticulture in environmental beautification and economic development.
vii. Evaluate the opportunities for commercialization, exports, and modern production methods in horticulture.

2.1 Pomology

The study of fruits is called pomology. Botanically, a fruit is a ripened ovary. The horticultural definition of fruit also includes other floral parts as well and fruit can be the edible, fleshy or dry portion of a plant whose development is closely associated with the flower.

The commercial production of fruits is known as **orcharding**. It is typically based on long-lived perennials, many of which do not bear fruit until several years after they are planted. Grape plantations are called **vineyards**, and the cultivation of grapes is called **viticulture (Fig. 1)**. Similarly, citrus orchards are typically called **citrus groves (Fig. 2)** and the cultivation of citrus is known as **citriculture**. Orcharding and other types of fruit growing require high capital investment for years on a fixed site, without immediate return. In Pakistan, most of these operations are carried out year-round manually with both skilled and unskilled labour. Since it is costly to get into or out of the fruit-growing business, selection of sites, species, and cultivars should be made very carefully (Richard, 2014).



Fig 1: Viticulture



Fig 2: Citrus Grove

All major fruits are clonally propagated. In most cases, the commercial varieties are used as scion (bud/piece of twig budded/grafted onto a rootstock), and the rootstock (part on which the scion is budded/grafted) is of a different species or variety. Commercial cultivars are used as scion, while the rootstock belongs to a different species.

Farm operations like pruning and training of trees and thinning of fruits are unique to pomology. With the exception of a few nuts, fruits are highly perishable. Post-harvest handling of fruits is itself a specialized discipline, dealing with grading, packing, storing, processing, and shipping operations. Similarly, marketing of fruits requires special attention to take advantage of seasonal markets and to avoid losses due to perishability.

World production (by weight) of fruits is close to that of staple food crops. The greatest production is of grapes, followed by citrus, bananas, and apples. In Pakistan, thanks to: four seasons and soil diversity, about 30 different fruits are grown. Among the fruits grown in Pakistan, citrus ranks first, with 95 percent of its area and production concentrated in the plains of the Punjab. Mango is next to citrus, and is mostly grown in the southern districts of Punjab and Sindh. Banana, guava, date palm, and apple are next in rank. Significant quantities of stone fruits (drupes-peaches, plums, apricots, and almonds) are also produced. There are several other important fruits grown in different parts of this country.

2.2 Olericulture

The study of vegetable production is called olericulture, derived from oleris, an herb. A vegetable may be defined as the edible portion of an herbaceous plant used fresh or processed. The edible portion may be the fruit, foliage, tuber, root, or any other plant part. The edible portion of the tomato is a fruit; the potato is a tuber (stem); the sweet potato is a root; peas are seeds and lettuce is the leaf. Potatoes and other vegetables together produce more food (by weight) than any other food crop in the world. In Pakistan, about 50 different vegetables are grown in two growing seasons. As compared to orcharding, the vegetable industry is characterized by its flexibility. Because most vegetables are grown as annuals, shifts in cultivars and crops can be readily made. There are three main categories of vegetable production: home gardening, market gardening, and truck gardening. In addition, there are several small, specialized production types, including vegetable forcing, production for processing, seed production, and mushroom culture (Nirmal et al., 210).



Fig 3: Olericulture

2.2.1 Home gardening:

Home gardening is the growing of vegetables for home use. It is the oldest form of vegetable production, and is still the most important source of vegetables in our rural households. Besides being very economical, this is the only method of assuring fresh produce, and the choice of crops can be made according to the

liking of the family members. If intensive methods are followed, from an area of 10-20 marlas, sufficient vegetables and some fruits can be grown for an average family, and at times, additional income can be earned by selling the excess. In the western world, organic farming, farming without the use of chemical fertilizers or pesticides, has emerged as an important form of home gardening. People have realized that the produce sold in the market carries a heavy load of chemicals, which may be injurious to their health. The only way to get fresh and uncontaminated vegetables is through organic home gardening.



Fig 4: Home Gardening

2.2.2 Market gardening:

Near large centers of population, many kinds of perishable vegetables are grown for sale. The produce from this kind of vegetable culture is sold in local markets, which are usually within a few miles of cities. This type of market gardening has been developed to meet the requirements of people with no land, time, or interest in growing their own vegetables. Improved roads and transport facilities have made it possible for market gardeners to serve distant areas. Because of the high value of land in the immediate vicinity of cities, and the availability of road transport, market gardening is now also practiced at places far away from the centers of consumption. Because of intense competition among producers, specialized production of particular crops has begun to be practiced, with

emphasis on grading and preservation of freshness and appearance of produce. Market gardens in the immediate vicinity of big cities utilize city sewer water as a source of fertilizer and irrigation. Often, heavy use of chemicals is made to control the spread of insects and diseases carried in city refuse. Vegetables produced on land fertilized with sewage may have a heavy load of chemicals and amoebic organisms, which are a health hazard to humans. Market gardeners typically face glut periods when there is surplus produce in the market with very little return to the growers. By choosing the time of sowing carefully and selecting of the right kind of varieties, progressive growers can avoid glut seasons, and the wastage of produce and loss of income they entail.



Fig 5: Market Gardening

2.2.3 Truck gardening:

Truck gardening or farming is the production of vegetables in relatively large quantities for distant markets (Fig. 6). Special crops are selected and grown in different agro-ecological regions. The usual choices are the less perishable or non-perishable crops. Production of potatoes in Okara District, melons and peas in Gujranwala District, winter muskmelons in lower Sindh, and a late summer crop of onions in Balochistan and Swat are a few examples of truck farming. Truck farming is less intensive than market gardening. Also, the grower can usually wait from a few days to weeks between harvesting and marketing. The marketing is

done in wholesale markets. With improvements in means of communication and transport roads, trucks, and refrigerated transportation, and information on distant markets, the outlook of truck farming has changed. Now, most of those perishable vegetables that were formerly grown in market gardens can be grown on the truck farming pattern. Tomatoes, even though highly perishable, are being cultivated in frost-free areas during winter and shipped to distant markets.



Fig 6: Truck Gardening

2.2.4 Vegetable forcing:

Production of vegetables out of their normal season of outdoor production is known as vegetable forcing. There is demand for out-of-season produce and the consumer is willing to pay extra. The most common form is the early or late production of summer vegetables (Fig. 7). A usual limitation on the production of summer vegetables like tomatoes, cucumbers, eggplants, bell peppers, melons, and gourds is frost. In developed countries, such crops are grown in greenhouses, making it the most intensive type of cultivation. Commercial production of greenhouse crops in our country is not feasible (FAO, 2018). Nature has blessed Pakistan with a wide range of agro-ecological climates. There are several frost-free pockets in Punjab and NWFP, and summer vegetables can be grown out-of-season in the entire lower Sindh. Parts of Malakand and the *katcha* area of Khushab District are big producers of tomatoes. Most summer vegetables are

shipped from lower Sindh to other parts of the country. Traditionally, market gardeners produce early vegetables on a small scale, providing protection from frost by covering the germinated seedlings, using *sarkanda* or branches of trees. The use of plastics has gained importance in recent years. Low plastic tunnels are erected on field beds for crops like vegetable marrow. High plastic tunnels are used for crops like cucumbers, tomatoes, bottle gourds, peppers, and eggplant. In the West, plastic tunnels are used as a low-cost alternative to the greenhouse vegetable production for processing. Processing refers to the ways and means by which vegetables or their products are preserved for future use instead of fresh consumption. This sector of the vegetable industry has not developed properly in this country. In many parts of the world, this is an important area and vegetables are grown specifically for processing. Vegetable processing can utilize the excess produce during the glut season, stabilize prices and availability of vegetables over prolonged periods, and fulfill emergency needs. Important types of vegetable processing include canning, freezing, dehydration, and making industrial products like tomato ketchup, potato chips, and juices. Peas, beans, and mushrooms can be canned. Vegetables like spinach, okra, peas, and sweet corn can be frozen. Onions, garlic and many root vegetables can be dehydrated and stored for future use. Vegetable seed production is a small component of the vegetable growing industry, but is considered an important and highly specialized area. Similarly, mushroom culture (cultivation of mushrooms) is a branch of olericulture that has the potential for expansion in some areas.



Fig 7: Tunnel farming is a typical example of vegetable forcing

2.3 Floriculture and Landscape horticulture

This branch of horticulture deals with plants and their layout for beautification of the environment (Fig. 8). A tremendous number of plants are classed as ornamentals based on their decorative value and personal choices. There are seasonal flowering plants, foliage plants, lawn grasses, evergreens, and deciduous shrubs and trees. Fruit trees grown in home gardens can also be selected for landscape and ornamental purposes. Selection of plants according to the physical situation of a house, public or private building, road, public facility like an airport, or recreational place like a park is known as landscape design. Landscape and ornamental horticulture can play an important role in the modification of domestic and urban environments and pollution control. Growing awareness of the importance of plants in the environment has increased the appreciation of the public and policymakers for landscape and ornamental horticulture (Rabiya, 2024). The nursery business has expanded in recent years to meet increasing demands for landscape and ornamental plants. Producers and wholesalers are located both in the vicinity of large cities and in more remote areas, which supply plant materials to retailers in the cities. Pattoki in District Kasur is a major center of the nursery business. A variety of plant materials are imported for landscape and ornamental purposes. Also, significant quantities of seeds of flowering plants are imported every year. Landscape and ornamental plants are also grown for the extraction of byproducts like essential oils and aromatic compounds (jasmine and rose), for sale as cut flowers (rose, tube rose and gladiolus), and for medicinal purposes (menthol, amaltas). There is considerable scope for the export of cut flowers. To enhance the scope of landscape and ornamental horticulture, annual flower shows and design competitions are held in all the big cities. In Holland, more than 95% of foreign exchange is from floriculture (Antonio and Ferrini, 2023).



Fig 8: Landscape Horticulture

2.4 Self Assessment

Fill in the blanks with appropriate words.

i. The study of fruits is called……

ii. ……. is the branch of horticulture that deals with plants and their layout for the beautification of the environment

iii. Production of vegetables out of their normal season of outdoor production is known as ……...

iv. …… is the production of vegetables in relatively large quantities for distant markets.

v. Vegetables produced on land fertilized with …… may have a heavy load of chemicals and amoebic organisms, which are a health hazard to humans.

vi. In the western world, ……; farming without the use of chemical fertilizers or pesticides has emerged as an important form of home gardening.

vii. There are three main categories of vegetable production……., market gardening, and truck gardening.

viii. Botanically, a fruit is a ripened……...

ix. Cultivation of citrus is known as……...

x. Orcharding and other types of fruit growing require ……. for years on a fixed site, without immediate return.

Answers

i. pomology

ii. Floriculture and Landscape horticulture

iii. vegetable forcing
iv. Truck gardening
v. sewage
vi. organic farming
vii. home gardening
viii. ovary
ix. citriculture
x. high capital investment

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Unit:3

CLASSIFICATION OF HORTICULTURAL CROPS

Written By: Dr. Wajid Khan Bloch
Reviewed By: Dr. Ayesha Maryam
Dr. Hafiz Amjad Ali Rana

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INTRODUCTION

Horticultural classification groups plants based on their morphology, growth habit, lifespan, and seasonal adaptation. Categories include herbs, shrubs, trees, vines, annuals, biennials, and perennials, as well as distinctions between deciduous and evergreen, hardy and tender plants. Fruits and vegetables are further classified by their edible parts (roots, tubers, leaves, fruits, or flowers), while ornamentals are grouped as flowering, landscape, or indoor plants. This classification helps growers and researchers understand plant behavior, adaptability, and practical uses.

Botanical classification, or taxonomy, organizes plants scientifically using evolutionary and morphological characteristics, with the binomial system of naming (genus and species) introduced by Linnaeus. Horticulturally important groups include gymnosperms and angiosperms, the latter divided into monocots and dicots. Industrial classification, on the other hand, focuses on economic and practical uses of crops, dividing them into categories such as fruits, vegetables, ornamentals, spices, medicinal and aromatic plants, timber and agroforestry species, seed and nursery crops, and post-harvest or processed products. These three systems of classification provide a foundation for both scientific study and commercial horticulture.

OBJECTIVES

- To describe horticultural classification based on morphology, lifespan, and environmental adaptations
- To explain botanical classification, taxonomy, and plant naming systems
- To outline industrial classification and its role in agriculture and related industries
- To emphasize the practical applications of classification in horticultural science and commerce

LEARNING OUTCOMES

By the end of this unit, students will be able to:

i. Differentiate between plant types such as herbs, shrubs, trees, vines, annuals, biennials, and perennials
ii. Explain botanical taxonomy, including the use of genus, species, varieties, and cultivars
iii. Identify the key features of monocots, dicots, gymnosperms, and angiosperms
iv. Categorize horticultural crops according to industrial importance (fruits, vegetables, ornamentals, spices, medicinal plants, forestry, etc.).
v. Apply plant classification knowledge to crop production, marketing, and industrial applications.

3.1 Horticultural Classification:

Horticultural classification is a logically conceived system of description, nomenclature, and identification of plants. There can be several ways to classify plants, like growth habits, life span, temperature relations, uses, morphology, and cultural requirements. However, the botanical classification system remains the basis of plant nomenclature and identification. On the basis of growth habits and physiological characteristics, horticultural plants can be classed as succulent, herbaceous, or woody.

In floriculture, the term **succulent** is usually used for foliage plants with extremely tender and watery stems and leaves. **Herb** is a term used for self-supporting succulents. Herbaceous plants usually have tender stems, either drooping or self-supporting. Most vegetables and many floral and ornamental plants are herbaceous in their growth habit. Self-supporting woody plants are known as **shrubs or trees (**Singh et al. 2024).

The difference between shrubs and trees is made arbitrarily on the basis of the number of stems and plant height. Trees are characterized by a single central stem, and shrubs have more than one stems. Trees are usually taller than shrubs, but the distinction between trees and shrubs may be obscured by growth environments and training practices. Plants with climbing or trailing stems can be woody or non-woody. A climbing plant with a non-woody stem is known as a **vine**, whereas a woody plant with a climbing growth habit is called a l**iana**.

Some plants shed their leaves during winter; these are referred to as **deciduous**. Plants with persistent leaves are called **evergreen**. Most deciduous plants are native to temperate climates, and, with the -exception of pines, evergreens are considered tropical in origin. Plants are annuals, biennials, and perennials, according to their lifespan. An **annual plant** completes its entire life cycle in a single growing season. Many vegetables and seasonal flowering herbs are annuals. The **biennial plant** completes its life cycle in two growing seasons. The first season's growth is entirely vegetative and is typically characterized by short, low internodes called **rosettes.** In the second season, it bolts, i.e. sends up a flowering stalk with extended internodes bearing flowers and fruits. **Root vegetables** like carrots and beets; **leafy vegetables** like lettuce and cabbage, and others like onions are biennial in nature. Climate is the critical factor in determining the life span of plants. Annuals and biennials can vary in their life spans in different climates. Most of the above-named biennial vegetables are harvested for consumption after the first season of growth and are thus treated as annuals for cultivation purposes. Perennial plants grow for years: and most of them are woody. Their growth can be divided into juvenile and mature phases. During the first phase, the plants grow vegetatively for several years. In the second phase, reproduction starts, and vegetative and reproductive growth are

concurrent. All of our fruit trees and ornamental shrubs and trees are perennial, and some herbaceous plants are also perennial. For example, asparagus, potatoes and many bulbs are perennial. The above ground parts of such plants are killed in winter while the underground storage structures, like the tubers of potatoes, survive. Some plants, like tomato and eggplant, are perennial in tropical climates and annual in temperate zones because of winter kill. The flowering habits of plants are very important in horticulture. Flowers can be described according to their functional parts as hermaphrodite, perfect, complete, or incomplete. Plants with flowers having both male and female sex organs in the same flower, like peas, are hermaphroditic. Plants with flowers of only one sex are **dioecious** (date palm, papaya, spinach, asparagus). Another category of plants bears two or three kinds of flowers, male, female, and sometimes **hermaphroditic** flowers as well. Plants with separate flowers of a single sex are called **monoecious** (e.g. cucurbits). Plants can also be classified according to their temperature relations, i.e, temperature requirements for growth and tolerance to low temperature. Vegetables are grouped as **summer** (warm season) and **winter** (cool season) vegetables on the basis of their growing season temperatures. A winter vegetable in the plains of Punjab can be successfully grown during the summer at higher altitudes. Most summer vegetables are grown all year round in the frost-free areas of lower Sindh. Cool-season crops require that the maximum temperature not exceed 80-85°F and the minimum temperature should not fall below 35-40°F. The optimum for most such crops is 65°F. For warm-season crops, the optimum is above 80°F. They are usually frost-sensitive and cannot grow if the minimum temperature falls below 50°F. Fruits are categorized as temperate, subtropical, and tropical. **Temperate** fruits are mostly deciduous and require a certain amount of chilling to flower. Apples, pears, Peaches, plums, almonds, and apricots are important temperate fruits. **Subtropical and tropical** fruits are native to warm climates; they are frost sensitive and unless hardened properly in the late summer, the foliage can be destroyed by frost. **Subtropical** plants like citrus, guava, and grapes can tolerate frost. Tropical plants like banana, papaya, and mango are much more sensitive to low temperature exposures. Horticulturists speak of tender and hardy plants according to their ability to withstand low winter temperatures. **Hardy plants** are resistant to frost and **tender** ones are not (Cardoso and Vendrame, 2022).

Fruits borne on low-growing plants like shrubs and vines, e.g. grapes, falsa and strawberry, are known as small or **soft fruits**. **Nuts** are edible seeds like almonds, walnuts, pecans, etc. **Fleshy fruits** are those whose edible part is the soft flesh as opposed to the seed. **Systematic Pomology** is a branch of pomology that describes fruits according to their structural development. **Pomes** (apple, pear, quince) are false fruits in which the edible part is the thalamus. **Berries** (grape, banana, citrus) are true fruits developed from the ovary walls. **Stone fruits**, also

known as drupes, are also true fruits (peach, apricot, plum, cherry). An **aggregate fruit** is derived from a flower having many pistils on a common receptacle. The individual fruits of the aggregate may be drupes, as in blackberries, or achenes, as in straw berries. **Multiple fruit** is a name for fruits derived from many separate but closely clustered flowers. Common examples are pineapple, fig, and mulberry.

Vegetables may be grouped according to their edible portions and cultural requirements. **Root crops** are vegetables with underground edible parts like carrots, radishes, turnips, potatoes, and sweet potatoes. In a strict botanical sense, the potato is not a root, but all the above require similar methods of sowing and other cultural practices. **Leafy vegetables** like lettuce, cabbage and spinach have edible leaves. **Vine** crops include most of the cucurbits. Other important groups are **solanaceous fruits** (tomatoes, peppers, eggplant) and **flower crops** like cauliflower and broccoli.

Plants used as ornamentals are commonly separated into flowering or landscape plants. Flowering plants include seasonal annuals, perennials, and bulbs with underground storage organs. Landscape plants are usually foliage plants varying from ground covers or lawn grasses to hedges, trees and shrubs. Indoor plants are ornamental plants with persistent evergreen foliage. Other horticultural plant categories which do not fit into the popular horticultural classification of fruits, vegetables, and ornamentals are beverage plants, which are used for their flavours and plants which produce aromatic or fragrant products. There are industrial crops like jojoba (an oilseed), rubber, resin crops, and many drug and medicinal plants (Tamayo and Augustin, 2017).

3.2. Botanical Classification

Scientific plant classification is based on the phylogenetic relationships of organisms. The science of classification is known as taxonomy, derived from the Greek word *taxon,* meaning group or category. All forms of life are related, with lower organisms the progenitors of higher organisms. The similarities and differences among the organisms form the basis for classification. In the mid-18th century, Linnaeus recognized the value of using the morphology of the sexual or reproductive parts as a basis for taxonomy. These plant organs are less influenced by environmental conditions, and similarities and differences in floral organs have become basic to the classification of higher plants. The plant kingdom consists of about a dozen major phyla or divisions. The most highly evolved or advanced division is known as Tracheophyta. A vascular or tracheary system is the common feature of all higher plants, hence the name Tracheophyta. Almost all horticultural plants except mushrooms, belong to this division; the division Tracheophyta is divided into several classes. Horticulturally important ones are Filicinae (ferns), Gymnospermae (cycads, conifers), and Angiospermae (flowering plants). Each

class is subdivided into orders, and the orders are further divided into families. Each family comprises a number of genera. Within each genus, there are various species. An identical group of individuals within a species is called a variety/strain. All categories need not be used, but the sequence is important. Sometimes intermediate subdivisions are named with the prefix *sub-*. The categories from kingdom to family are called the major taxa, and those below the level of family are called the minor taxa. The magnitude of genetic diversity decreases in order from genus to variety and to individual (Monisha et al., 2025). The gymnosperms are a small group of about 700 living species. Most of them are evergreen trees with needle-shaped leaves, belonging to the temperate zones. The name is derived from the characteristic of their seeds, which are borne 'naked', as opposed to angiosperms which bear enclosed seeds. Gymnosperms are sources of timber, wood pulp, turpentine, resin, edible seeds, and many highly valued ornamental plants. The angiosperms are the largest group of higher plants, with more than 2,50,000 species. Characteristically, their seeds are enclosed in the fruit, and the leaves are broad (not needles). They are the primary sources of food, fiber, and shelter. The class Angiospermae is divided into two subclasses, the Dicotyledonae (dicots) and the Monocotyledonae (monocots). The dicots have two cotyledons (seed leaves), flower parts in fours or fives or multiples of these numbers, reticulate leaf venation, and the presence of vascular cambium. The monocots have a single cotyledon, flower parts in threes or multiples, parallel leaf venation, and a lack of vascular cambium. There are about 200,000 dicotyledonous plant species, and approximately 50,000 monocots. Within each class, there are several orders and families.

The identification and description of plant materials is based on two part Latin names, which refer to the genus and the species. The genus is named first, followed by the species. The genus begins with a capital letter and the species name with a small letter. When printed, both names are italicized. The name of the person who first named and described the species (or abbreviation of the name) follows the binomial designation. The genus is a group of species that have many common morphological, genetic, and cytological features. The members of a genus can sometimes cross among themselves, but can never cross with the plants of any other genus. Thus, a species is made up of plants having morphological similarities and producing like progeny. A **species** can be considered as a normally exclusive interbreeding population. A sub-classification of the traditional species is the variety. When a population of plants within a species differs in appearance from the original members of the species, it may be called a variety. A variety is named by adding a third name after the species name. It should not be confused with the cultivated variety, or cultivar. The term ***cultivar*** refers to a named group of plants within a cultivated species that maintain their identity when propagated either sexually or asexually. In horticulture, clonal

cultivars, which are propagated vegetatively (asexually) are very important. Variants among clones are called strains or sports. Sexually propagated cultivars fall into three groups: (1) pure-line or self-pollinated cultivars, (2) open-pollinated or cross-pollinated cultivars, and (3) hybrid cultivars. Hybrids are developed by crossing divergent parents, and do not breed true by sexual propagation (Tamayo and Augustin, 2017).

3.3. Industrial Classification

Horticultural crops can be classified into different categories based on their industrial use, characteristics, and the purpose they serve. The classification of horticultural crops can be broadly divided into the following industrial categories:

3.3.1 Fruits and Nut Crops (Pomology)

These are crops grown primarily for their edible fruits or nuts. They have a high economic value, and production often supports processing industries for juices, jams, jellies, dried fruits, and more.

- **Citrus Fruits**: Oranges, lemons, limes, and grapefruits.
- **Pome Fruits**: Apples, pears, quinces.
- **Stone Fruits**: Cherries, peaches, plums, apricots, nectarines.
- **Berries**: Strawberries, blueberries, raspberries, blackberries.
- **Tropical Fruits**: Mangoes, bananas, pineapples, papayas, guavas.
- **Nuts**: Almonds, walnuts, pistachios, cashews, hazelnuts.

3.3.2 Vegetable Crops (Olericulture)

Vegetables are grown primarily for human consumption, either fresh or processed (canned, frozen, dried, etc.). Vegetables are classified into the following types:

- **Leafy Vegetables**: Lettuce, spinach, cabbage, kale, mustard.
- **Root and Tuber Vegetables**: Potatoes, carrots, beets, radishes, sweet potatoes, onions.
- **Fruit Vegetables**: Tomatoes, cucumbers, peppers, eggplants, zucchini.
- **Leguminous Vegetables**: Beans, peas, lentils, chickpeas.
- **Flower and Stem Vegetables**: Cauliflower, broccoli, artichokes, celery, asparagus.

3.3.3 Flower and Ornamental Plants (Floriculture)

These crops are cultivated for their aesthetic value, and the products derived are used in landscaping, decoration, and floral arrangements. This category includes:

- **Cut Flowers**: Roses, lilies, tulips, carnations, chrysanthemums.
- **Flowering Plants**: Geraniums, petunias, marigolds, impatiens.
- **Ornamental Shrubs and Trees**: Azaleas, lilacs, holly, boxwood, hydrangeas.

- **Potted Plants**: Orchids, ferns, begonias, African violets.
- **Foliage Plants**: Ivy, ferns, palms, hostas.

3.3.4 Spices and Condiments

Spices are plants grown for their aromatic, flavorful, or pungent properties. Many are used in food processing, cosmetics, and medicines.

- **Spices**: Pepper, cardamom, ginger, cloves, cinnamon, turmeric.
- **Herbs**: Basil, thyme, rosemary, mint, parsley, oregano.
- **Essential Oil Crops**: Lavender, lemongrass, eucalyptus, peppermint.

3.3.5 Medicinal and Aromatic Plants

These plants are grown for their medicinal properties and are used in traditional medicine, pharmaceuticals, and for the production of essential oils.

- **Medicinal Plants**: Aloe vera, ginseng, echinacea, chamomile, turmeric, mint.
- **Aromatic Plants**: Lemon balm, lavender, rosemary, sage, thyme.
- **Plants for Essential Oils**: Peppermint, rosemary, citronella, lavender, eucalyptus.

3.3.6 Tree and Shrub Crops (Agroforestry and Timber)

These crops are cultivated for timber, fruits, nuts, or other non-timber products. They include:

- **Timber Trees**: Pine, oak, teak, mahogany, eucalyptus.
- **Non-Timber Forest Products**: Rubber, resin, bamboo, cork.
- **Tree Crops for Fruits**: Mango, avocado, papaya, cashew.

3.3.7 Seed and Plant Propagation Crops

These crops are primarily cultivated to produce seeds for the next generation of crops. They are vital in supporting the agricultural industry.

- **Seed Production**: For vegetables, fruits, flowers, and grasses.
- **Nursery Crops**: Trees, shrubs, flowers, and other plants that are raised for transplanting to gardens or landscapes.

3.3.8 Post-Harvest Products and Processed Crops

This category focuses on crops that are harvested and then processed or packaged for commercial use. Processing can increase the shelf-life and marketability of products.

- **Processed Fruits and Vegetables**: Canned fruits, dried fruits, fruit juices, pickles, jams, and sauces.
- **Preserved Flowers**: Dried flowers, pressed flowers, and ornamental floral products.

- **Herb and Spice Products**: Dried herbs, ground spices, essential oils.

3.3.9 Cover Crops and Forage Crops

These are crops grown to protect the soil, enrich it, or serve as fodder for livestock. They also have industrial relevance in the livestock feed industry.

- **Forage Crops**: Alfalfa, clover, ryegrass, Bermuda grass.
- **Cover Crops**: Legumes (peas, beans) and grasses (rye, oats) grown to improve soil health by adding organic matter and preventing erosion.

3.3.10 Other Specialized Crops

There are other niche horticultural crops with specific industrial uses:

- **Mushrooms (Mycology)**: Edible fungi such as oyster mushrooms, button mushrooms, and shiitake.
- **Algae and Aquatic Plants**: Used in the production of biofuels, supplements, and food products (e.g., seaweed).
- **Fodder and Silage Crops**: Crops grown for use as feed in livestock farming.

Overall, it can be concluded that the industrial classification of horticultural crops spans a wide variety of plants that contribute to food security, economic growth, and cultural practices. These crops are not only consumed directly as food but are also vital to many other industries such as pharmaceuticals, cosmetics, and environmental sustainability. The diverse applications of horticultural crops make them an essential part of modern agriculture and industry.

3.4 Self Assessment Questions

Fill in the blanks with appropriate words.

i. Lettuce, spinach, cabbage, kale and mustard are …….

ii. The term ……. refers to a named group of plants within a cultivated species that maintain their identity when propagated either sexually or asexually.

iii. Aloe vera, ginseng, echinacea, chamomile, turmeric and mint are grown for their ……. Value.

iv. ..... crops grown for use as feed in livestock farming

v. ..... are vegetables with underground edible parts like carrots, radishes, turnips, potatoes, and sweet potatoes.

vi. Rubber, resin, bamboo and cork are ……. forest products

vii. In floriculture, the term …… is usually used for foliage plants with extremely tender and watery stems and leaves.

viii. The …… plant completes its life cycle in two growing seasons.

ix. ……. is a term used for self-supporting succulents.

x. A ……. can be considered as a normally exclusive interbreeding population.

Answers

i. leafy vegetables
ii. cultivar
iii. medicinal
iv. Fodder and silage
v. Root crops
vi. non-timber
vii. succulent
viii. biennial
ix. Herb
x. species

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Unit: 4

PROPAGATION OF HORTICULTURAL CROPS THROUGH SEED

Written By: Dr. Wajid Khan Bloch
Reviewed By: Dr. Hafiz Amjad Ali Rana
Dr. Muhammad Shahzad

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INTRODUCTION

Seed propagation in horticulture, though often leading to variability in seedlings and delayed fruiting, remains important due to its role in breeding, hybridization, raising rootstocks, and producing annuals, vegetables, and certain fruit crops. While seed propagation has drawbacks such as long juvenile phases and variability in cross-pollinated plants, it also offers advantages like hardiness, longevity, and disease resistance. Proper seed collection, storage, and pre-germination treatments such as stratification or seed coat softening are essential to ensure high germination rates and uniform seedling quality.

Seedling preparation methods include flat beds, raised beds, pots, and plug culture. Each method has its own advantages and limitations, ranging from cost-effectiveness and large-scale production (flat beds) to better root development and easy transplanting (plug culture). Successful transplantation depends on key factors such as correct seedling age, acclimatization (hardening off), soil quality, root integrity, and favorable environmental conditions. Careful management of these practices ensures vigorous seedlings with high survival rates and strong establishment in the field, making seed propagation a critical step in horticultural production.

OBJECTIVES

- To explain the advantages and limitations of seed propagation in horticulture
- To describe seed handling practices, including collection, storage, and pre-germination treatments
- To introduce different methods of seedling preparation and their practical uses
- To outline the key factors influencing the success of seedling transplantation
- To highlight the role of seed propagation in breeding, crop production, and raising rootstocks

LEARNING OUTCOMES

By the end of this unit, students will be able to:

1. Differentiate between the merits and drawbacks of seed propagation compared to vegetative propagation
2. Describe proper seed collection, storage, and pre-sowing treatments such as stratification and scarification
3. Identify and compare methods of seedling preparation (flat bed, raised bed, pot method, plug culture)
4. Explain the critical factors affecting seedling transplanting success, including timing, hardening off, soil, water, and root care.
5. Apply knowledge of seed propagation to breeding programs, hybrid development, and raising rootstocks for budding and grafting.
6. Evaluate which seedling preparation method is most suitable under different crops, environments, and resource conditions.

4.1 Reproduction Through Seed

Plant propagation is the process of multiplying or perpetuating plants, creating new ones from seeds or vegetative parts of a parent plant. There are two primary methods: sexual propagation, which involves seeds formed by the union of pollen and egg, creating new plants with a mix of parental genes, and asexual propagation, which uses plant parts like stems or leaves to produce genetically identical clones of the single parent plant. Reproduction through seed is sexual, except in some apomictic species. Seeds of some species, including mango, give rise to more than one seedling per seed (Singh et al., 2024). In such cases, however, only one seedling is zygotic; the rest are produced from nucellus cells and are called nucellar seedlings. This phenomenon is called polyembryony. Nucellar seedlings can be utilized to raise uniform plants.

Raising horticultural plants from seeds has several drawbacks. Ordinarily, when cross-pollinated plants produce seeds, the seedlings do not reproduce the characters of their parents. Fruit tree seedlings take a long time to come into bearing and have a tendency to grow tall, which adds to maintenance and harvesting costs. However, propagation through seed also has some merits. Seedlings are generally hardy, bear heavy crops, and are long-lived. Most of the fruit varieties in commercial production are chance seedlings having desirable characteristics of yield, quality of fruit, or disease resistance, which have been propagated vegetatively and established as clonal varieties (Singh et al., 2024).

Reproduction through seeds is also essential in the breeding of hybrids and new varieties and in raising seedlings to be used as rootstock in vegetative propagation. In some species, seeds are the only economical means of reproduction. For the propagation of forest species, vegetables, and annual and biennial flowers, seeds are the most convenient, easiest, and cheapest method of reproduction. The method is usually employed for the following purposes.

Establishment of seed gardens: Seed gardens are established for the selection of promising chance seedlings with desirable yield and fruit characteristics to be perpetuated as clonal varieties. Evolution of promising new varieties through controlled crossbreeding.

Crop production: Most vegetable crops, annual and biennial flowers, and some fruit crops such as papaya, coconut, and *falsa* can be produced through seed conveniently and cheaply. Some citrus species and a few mango varieties are polyembryonic. The zygotic seedlings or variants are generally weak and retarded in growth and are rogued out to maintain a uniform crop of nucellar seedlings identical in all respects to the seed parent. Since most of the viruses in citrus trees are not transmitted through seed, the phenomenon of polyembryony is being used in some countries to screen out virus diseases and to establish commercial plantations using nucellar seedlings.

Raising rootstock: In vegetative propagation, particularly in budding and grafting operations, seedlings of congenial rootstock species are always needed.

4.2 Preparation for Sowing

There are several factors that must be considered before actually sowing the seed.

4.2.1 Collection of seed: Collection of seed from reliable sources minimizes the chances of seedling variation. The fruits selected for seed extraction should possess good fruit and keeping-quality characteristics. In most cases, they should be fully mature and taken from healthy, vigorous plants with a high degree of disease resistance.

4.2.2 Storage of seed: Seeds of most of the evergreen fruit species lose viability soon after extraction and should be sown without prolonged storage. In case it becomes necessary to store the seeds, they should be carefully washed, surface dried, mixed with an equal part of ground charcoal, and packed in suitably sized wooden or metallic containers, which should be stored in a dry, cool place with a temperature between 3.0°C and *13°C*.

4.2.3 Pre-germination seed treatment: In some deciduous fruit species, like apple, pear, peach, plum, and cherry, the seeds need a certain period of rest after extraction before they germinate. Such seeds must be stored with alternate layers of moist sand, at a controlled cold temperature and suitable moisture conditions before sowing. This process is called stratification; it allows the embryos in the seeds to complete their development. Seeds with hard shells, like *ber* (jujube) and guava, need to have the seed coat cracked or softened by soaking in water for several hours or days. Seeds of mango, citrus, *papaya, falsa,* jaman, and loquat do not need any treatment before sowing (Garner and Chaudhri 1976). Sowing. The seed is either sown in pots, trays, plastic bags, or in beds in nursery rows. With species that do not tolerate transplanting well, seeds are sometimes sown in specially prepared holes, at the recommended distance from plant to plant and row to row for the species and variety that is to be used as scion. The seedlings thus raised are budded or grafted *in situ.*

When a small number of seedlings is required, they are raised in earthen pots, wooden trays, plastic bags, or in advanced countries 'jiffy pots', discs of compressed peat encased in netting, which swell to several times their original size on absorption of water. The containers are filled with a potting mixture of equal parts of topsoil, sand, and well-rotted leaf mold or FYM.

In nurseries, seeds are sown in well-prepared beds, where the soil has been thoroughly worked, pulverized, and mixed with well-rotted FYM or leaf mold. The distance allowed varies with crop species. Seeds of most species of fruit can be sown in lines 10 cm apart. A sowing depth two to three times the diameter of

the seed is usually satisfactory. The seeds are covered with sand or leaf mold and watered after sowing.

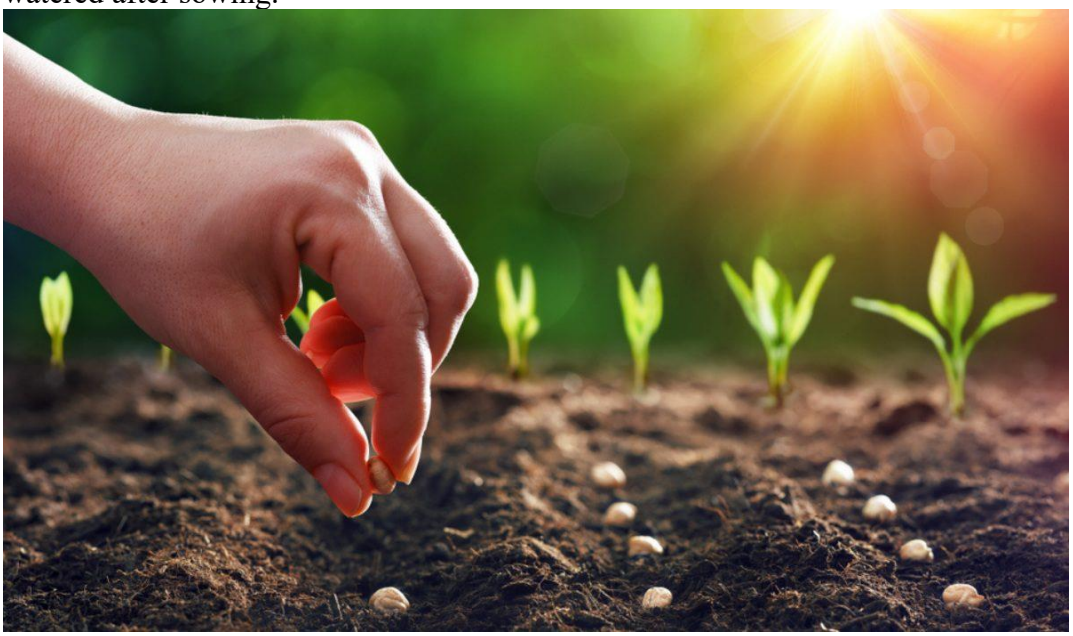


Fig 9: Sowing of seed

4.3 Methods of Seedling Preparation

Seedling preparation refers to the practices used to grow young plants or seedlings until they are ready for transplanting into the field or garden. Different methods are employed depending on the type of crops, the environment, and the available resources (Priyanka, 2025). Below are some common methods of seedling preparation:

4.3.1 Flat Bed Method:

In this method, seeds are sown directly on a flat or level surface (bed) with soil, usually in a nursery or greenhouse. The soil is kept moist, and the seedlings are nurtured until they are strong enough to be transplanted.

4.3.1.1 Steps for Flat Bed Seedling Preparation

I. **Soil Preparation:** Loosen the soil in the nursery bed and make sure it is free of weeds. Mix organic matter like compost to improve fertility.
II. **Sowing Seeds**: The seeds are sown evenly on the surface of the bed and lightly covered with a thin layer of soil or mulch.
III. **Watering:** The bed is kept moist to encourage germination.
IV. **Thinning:** Once the seedlings have sprouted, thinning is done to avoid overcrowding and to allow each plant enough space for healthy growth.

Advantages:

a) Simple and cost-effective.
b) Suitable for crops that are directly sown in the ground.
c) Large-scale seedling production.

Disadvantages:

a) Greater risk of pests and diseases.
b) Crowding can occur if proper thinning isn't done.
c) Limited control over environmental factors like temperature.



Fig 44: Flat bed method of plantation in plants

4.3.2 Raised Bed Method:

A raised bed is similar to a flat bed, but it is elevated above the ground. The soil in the raised bed is enriched with organic material, ensuring good drainage and aeration, which can promote healthier seedlings.

4.3.2.1 Steps for Raised Bed Seedling Preparation:

I. **Construction:** Raised beds are built with wooden planks, bricks, or other materials to create an elevated bed.
II. **Soil Filling:** The bed is filled with a mixture of well-draining soil, compost, and organic matter.

III. **Sowing Seeds:** Seeds are sown in rows, with spacing according to the plant's needs.
IV. **Watering and Care:** Regular watering and care are provided to ensure seedling growth.

Advantages:

a) Better drainage and aerationreduce the risk of waterlogging.
b) Easier to manage for people with limited mobility.
c) Enhanced seedling health due to reduced soil compaction.

Disadvantages:

a) Requires more materials and labor to construct.
b) May dry out faster than traditional flat beds, requiring more frequent watering.



Fig 45: Raised bed method of plantation in plants

4.3.3 Pot Method:

This method involves growing seedlings in individual pots or containers. It's ideal for plants that require more space for root development before being transplanted.

4.3.3.1 Steps for Pot Seedling Preparation

I. Selection of Pots: Use pots of a suitable size depending on the plant species. Pots can be made of plastic, clay, or biodegradable materials.
II. Soil Mixture: Use a well-draining soil mixture, typically a combination of garden soil, compost, and perlite or vermiculite.
III. Sowing Seeds: Seeds are sown individually in each pot. In the case of larger seeds, more space may be provided.
IV. Watering and Care: Regular watering is needed to maintain moisture. Care must also be taken to prevent overcrowding if the pots are too small.

Advantages:

a) Ideal for crops with deep roots or plants that need more space.
b) Easy to manage the growing conditions, including water and nutrients.
c) It can be moved easily to different environments, like greenhouses or shaded areas.

Disadvantages:

a) More expensive and labor-intensive compared to other methods.
b) Limited space for root growth in smaller pots.
c) It may require more frequent watering compared to other methods.



Fig 46: Pot method of plantation in plants

4.3.4 Plug Culture Method:

Plug culture is a method where seedlings are grown in small individual cells or plugs within a larger tray or flat. Each cell contains its own soil, allowing for easy separation of seedlings when transplanting.

4.3.4.1 Steps for Plug Culture Seedling Preparation

I. **Tray Preparation:** Special seedling trays or flats with individual cells (plugs) are used to sow the seeds.
II. **Soil:** The cells are filled with a sterile, well-draining seedling mix to prevent disease.
III. **Sowing Seeds:** Seeds are sown in each plug or cell, ensuring that they are placed at the correct depth.
IV. **Watering and Care:** The tray is watered gently, and seedlings are monitored for growth. Adequate light and temperature are provided for healthy development.

Advantages:

a) Efficient use of space with more seedlings in a small area.
b) Better root development as each seedling has its own plug.
c) Easy transplanting with minimal root disturbance.

Disadvantages:

a) Requires specialized equipment (seedling trays, plugs).
b) It can be more expensive due to the need for trays and soil.
c) It may require more attention to prevent the roots from becoming root-bound.



Fig 47: Plug culture method of plantation in plants

4.4 Factors Affecting Seedling Transplantation

Transplanting seedlings is a critical step in the growing process, and the success of transplanting depends on several factors:

4.4.1 Timing of Transplantation:

I. **Age of Seedlings:** Seedlings should be transplanted when they have developed strong roots and are large enough to withstand environmental stress. For most crops, transplanting occurs after 4-6 weeks of growth.

II. **Environmental Conditions:** Transplanting should ideally occur when the soil and air temperatures are favorable for the seedlings. Too early or late transplanting can cause shock or poor establishment.

4.4.2 Acclimatization (Hardening off):

I. Hardening off refers to the process of gradually exposing seedlings to outdoor conditions, such as direct sunlight, wind, and fluctuating temperatures. This helps the seedlings adjust and become more resilient to transplant shock.

II. Seedlings should be moved outdoors for a few hours each day, gradually increasing the duration over a week or two before transplanting into the field.

4.4.3 Soil Preparation and Quality:

I. **Soil Fertility:** The soil should be rich in nutrients and well-drained. Poor soil fertility can cause stress to the seedlings after transplantation.
II. **Soil Temperature:** Transplanting seedlings into soil that is too cold or too hot can stunt growth. Ideal soil temperatures vary by crop, but most seedlings prefer a moderate temperature (around 60-75°F or 15-24°C).
III. **Soil Structure:** Loose, well-aerated soil helps new roots establish quickly and grow freely.

4.4.4 Watering and Moisture Levels:

I. **Pre-Transplant Watering:** Ensure seedlings are well-watered before transplantation. Dry seedlings are more likely to suffer from transplant shock.
II. **Post-Transplant Watering:** After transplanting, seedlings should be watered thoroughly to help them settle in and reduce shock. Consistent moisture is critical for root establishment.

4.4.5 Root System and Root Disturbance:

I. **Root Integrity:** During transplantation, care must be taken to minimize root damage. A damaged root system can cause transplant shock and slow down the establishment of the seedling.
II. **Root Binding:** In pots or plug culture, roots can become bound (entangled or overgrown) and must be gently teased apart during transplanting.

4.4.6 Environmental Factors (Temperature, Humidity, and Light):

I. **Temperature:** Transplanting in extreme heat or cold can stress seedlings. Ideal conditions are mild temperatures with little fluctuation.
II. **Humidity:** High humidity can help reduce water loss from transplanted seedlings, reducing the risk of wilting.
III. **Light:** After transplanting, seedlings should be exposed to adequate light levels to encourage healthy growth. However, direct sunlight may cause stress initially, especially if the seedlings are not hardened off.

4.4.7 Plant Variety and Growth Habit:

Some plants are more tolerant of transplanting than others. For example, tomatoes, peppers, and many herbs transplant well, while crops like carrots, lettuce, and beans may have more difficulty adjusting after transplantation due to their sensitive root systems.

It can be concluded that the seedling preparation is essential to ensure that plants grow strong and healthy after transplantation. The method chosen for seedling preparation (flat bed, raised bed, pots, or plug culture) depends on the specific

needs of the plants, available space, and resources. Proper timing, acclimatization, soil preparation, and watering are all crucial factors that affect the success of seedling transplantation and the growth of plants in the field.

4.5. Self Assessment Questions

Fill in the blanks with appropriate words.

i. After transplanting, seedlings should be ……. thoroughly to help them settle in and reduce shock.

ii. Reproduction through seed is sexual, except in some …….. species.

iii. Seedling preparation refers to the practices used to grow young plants or seedlings until they are ready for ……. into the field

iv. In some ……. species, like apple, pear, peach, plum, and cherry seeds need a certain period of rest after extraction before they germinate

v. High humidity can help reduce ……. loss from transplanted seedlings, reducing the risk of wilting.

vi. Seeds of most of the ……. species lose viability soon after extraction and should be sown without prolonged storage.

vii. …… is a method where seedlings are grown in small individual cells or plugs within a larger tray or flat.

viii. Collection of seed from reliable sources minimizes the chances of……..

ix. Raising horticultural plants from seeds has several…….

x. A raised bed is like a flat bed, but it is elevated above the…….

Answers

i. watered
ii. apomictic
iii. transplanting
iv. deciduous fruit
v. water
vi. evergreen fruit
vii. Plug culture
viii. seedling variation
ix. drawbacks
x. ground

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Unit: 5

VEGETATIVE PROPAGATION IN HORTICULTURAL CROPS

Written By Dr. Zaid Mustafa
Dr. Wajid Khan Bloch
Reviewed By Dr. Ayesha Maryam

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INTRODUCTION

Vegetative propagation is a fundamental method in horticulture that enables the production of true-to-type plants, quicker fruiting, and exploitation of desirable scion–rootstock combinations. Techniques such as cuttings, grafting, budding, layering, division, and specialized underground structures (bulbs, corms, tubers, rhizomes, runners, etc.) are widely practiced. Each method has specific applications: cuttings are used in grapes, guava, and ornamentals; grafting and budding are critical in fruit trees like mango, citrus, and rose, while layering suits plants that are difficult to root by cuttings. These methods allow growers to regulate tree size, improve yield and quality, adapt to diverse conditions, and convert inferior orchards into superior ones. Despite their benefits, vegetative propagation has limitations, such as reduced vigor and the inability to create new varieties.

Plant tissue culture represents a modern advancement in vegetative propagation. It enables rapid, large-scale clonal multiplication of disease-free plants using shoot tips, meristems, or other tissues under sterile in vitro conditions. This technique is commercially valuable for elite genotypes but requires high capital, technical expertise, and an uninterrupted electricity supply. Problems such as phenolic exudation, vitrification, and microbial contamination need careful management. Tissue culture follows three main stages: establishment, multiplication, and pre-transplant hardening, along with strict sterilization and controlled environmental conditions. Together, conventional vegetative propagation and tissue culture form the backbone of horticultural crop multiplication, combining traditional skills with modern biotechnology to meet commercial and scientific needs.

OBJECTIVES

- To explain the principles, advantages, and limitations of vegetative propagation.
- To describe traditional vegetative methods (cuttings, grafting, budding, layering, division, bulbs, corms, tubers, rhizomes, etc.).
- To introduce tissue culture as a modern method for large-scale, disease-free clonal propagation.
- To highlight the commercial, technical, and biological considerations of tissue culture.

LEARNING OUTCOMES

By the end of this unit, students will be able to:

- **i.** Differentiate between sexual and vegetative propagation and explain their relative importance.
- **ii.** Identify and describe traditional vegetative techniques (cuttings, grafting, budding, layering, etc.) with their practical applications.
- **iii.** Explain the influence of rootstock on scion behavior, including adaptability, yield, and quality.
- **iv.** Recognize the advantages and disadvantages of vegetative propagation in fruit and ornamental crops.
- **v.** Describe the stages, techniques, and precautions involved in plant tissue culture.
- **vi.** Analyze the commercial and technical challenges of in vitro propagation, including contamination, vitrification, and cost factors.
- **vii.** Apply propagation methods in selecting suitable techniques for different horticultural crops and production systems.

5.1 Principles of Vegetative/ Asexual Propagation

Plant propagation is the process of multiplying or perpetuating plants, creating new ones from seeds or vegetative parts of a parent plant. Vegetative or asexual reproduction uses a part of the plant for multiplication. Plant parts used are stems, leaves, buds, roots, bulbs, corms, rhizomes, suckers, and tubers. Asexually propagated progenies are always identical to the parent plant in all respects. Vegetatively propagated plants remain relatively low-headed and bear earlier than sexually reproduced ones, with uniformity in fruit quality. These traits result in savings in cultural operations and make harvesting of the crop and its marketing easier.

The use of congenial rootstock allows wider adaptability of a variety of soil, climatic, and biotic conditions. The influence of rootstock on scion variety can also be utilized to regulate tree size, yield, quality of produce, and time of ripening. Sometimes newer varieties become popular, and growers want to replace their old orchards. In such situations, trees of older stands can easily be top worked using bud wood or graft wood of superior varieties or strains. This process saves time and expenditure on the establishment of plantations of new varieties to meet the requirements of changing demand trends.

There are only a few disadvantages to using vegetative propagation techniques. The budded and grafted plants are generally less vigorous and short-lived than seedlings. Also, new varieties cannot be evolved through asexual propagation (Moore and Bradley, 2022).

There are many methods of vegetative propagation. Some are quite simple, while others are complicated and laborious, requiring considerable knowledge and skill. The methods most prevalent in Pakistan are discussed under: -

5.2 Cutting

The process of propagation of plants by cuttings is known as cottage or clonal propagation. Cutting is a part of a plant that will produce roots when put in soil media and eventually produce a new plant quite true to the parent plant. A cutting may be a piece of stem, a leaf or part of a leaf, a piece of root, or rootstock, or even a scale of a bulb. Cuttings should only be taken from strong and healthy plants. Grapes, sweet limes, lemons, roses, and other perennial flowering shrubs are commonly propagated through cuttings(Cardoso and Vendrame, 2022).

5.2.1 Root Cutting

Plants that give rise to root suckers freely are propagated by root cuttings. To prepare root cuttings, the roots are cut into pieces 10-25 cm long, which are planted horizontally in well-prepared beds or in pots. Many perennial shrubs, such as guava, apple, pear, cherry, and persimmon, can be reproduced from root cuttings. However, the method is seldom used in Pakistan.

5.2.2 Stem Cuttings

Stem cuttings can be divided into 4 types based on the degree of maturity and lignification of wood used in making cuttings.

5.2.3 Softwood Cuttings

Cuttings are prepared from the soft succulent new spring growth of species that are 4 to 6 months old. Sometimes, the middle and basal portions are also used, provided they are soft and sappy. Softwood cuttings are mostly used to propagate flowering shrubs and guava. Cuttings of guava from terminal shoots can produce roots easily in misty conditions.

5.2.4 Herbaceous Stem Cuttings

This type of cutting is taken from succulent herbaceous greenhouse plants e.g**.** Chrysanthemum, Coleus, Carnations, Geraniums, and Cactus etc.

5.2.5 Leaf Cuttings

Certain plants with thick and fleshy leaves have the capacity to produce plantlets on their leaves. In leaf cuttings, the leaf blade with or without the petiole and axillary bud is used for starting new plants**.** Adventitious roots and shoots form at the base of the leaf and form into a new plant. However, the original leaf does not become a part of the new plant e.g. Sansevieria, Begonia rex.

5.2.6 Semi-hard Wood Stem Cuttings

Semi--hardwood cuttings are prepared from new shoots just after a flush of growth, which is partially matured.

5.2.7 Hard-wood cuttings

Hardwood cuttings are taken from the previous season's mature growth, when the stem has shed leaves and is hard and lignified. Hardwood cuttings are used in the propagation of sweet lime, lime, lemon, grapes, pomegranate, fig, and plum.

Cuttings of most plant species, which are prepared from mature wood, are of pencil thickness varying from 18-25 cm in length. The upper cut, about 5 cm from a node, is made at a right angle to reduce the size of the wound. A basal slanting cut close to the node increases the surface for nutrient absorption. The cuttings are planted 15 cm from each other in rows 30 cm apart. Any closer planting induces damping off.

Generally, two-thirds of hardwood cuttings and one-half of softwood cuttings should be inserted in the soil in a slanting position to prevent rainwater from entering through the cut surface. To expel air, the soil around each cutting must be pressed and firmed up. The beds or pots are kept moist by daily irrigation. Root growth is favoured by a soil temperature of 18-21°C. In evergreen species,

cuttings are prepared and planted in early spring or the rainy season. However, in deciduous species, the cuttings are made during the dormant season and are stored to be planted during early spring.

Cuttings of some plant species do not readily produce roots. Plant hormones (Plant growth regulators) such as indole acetic acid, indole butyric acid, naphthalene acetic acid, and naphthalene acetamide etc are used to stimulate rooting from cuttings. These chemicals are used as solutions, powders, or in lanolin. Aqueous solution of about 0.01% or 50-1000 parts per million (ppm) is generally used, depending upon the plant species. The basal ends of the cuttings are either dipped in the solution, or powder is applied to the rooting ends.

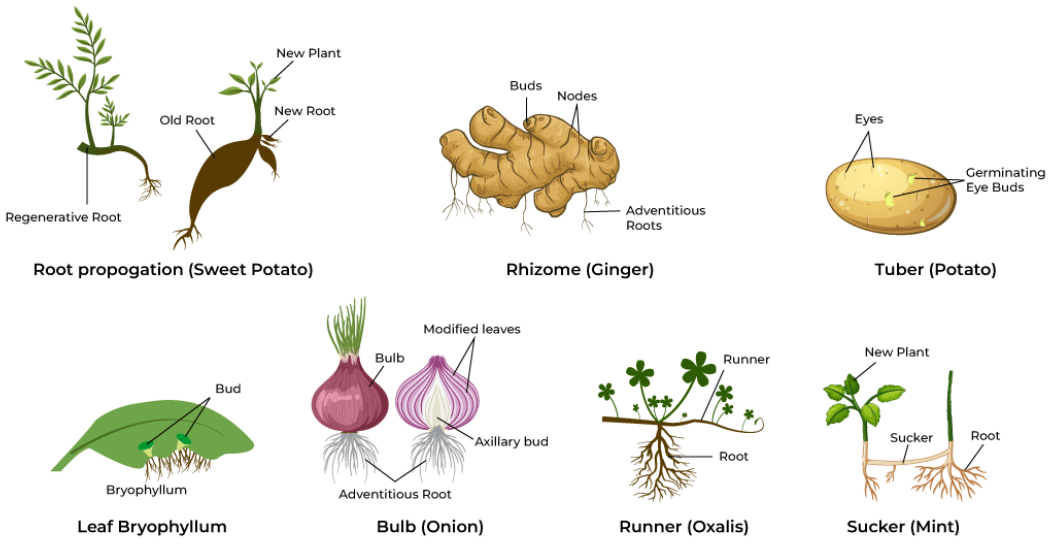


Fig 10: Different types of propagation

5.3 Grafting

Grafting is the art of joining two different plant parts together, in such a manner that they unite and continue their growth as a single plant. In grafting a bud stick (Scion), two or more buds are inserted into the rootstock (Fig 11).

Unlike with layering, division, and cuttings, a grafted plant is composed of two parts. The basal part, which provides the root system for anchorage and absorption of moisture and nutrients, is called the rootstock. The scion provides top and fruit-bearing surfaces and synthesizes food, which is transported to other parts of the plant. Scion and rootstock should be compatible and closely related, belonging to the same genus. Grafting is a process by which a piece of scion is attached to a rootstock in such a way that the cambiums of both scion and rootstock come in firm contact, so that the new secondary tissue resulting from

cambial cell division in the scion and rootstock is closely knitted. The stock usually influences the size and vigour of the tree, and the scion to yield and the quality of fruit produced. Grafting allows the utilization of varying climatic, soil, and biotic conditions with an advantage. When a single bud is used as scion and inserted into the rootstock, the method is called budding, whereas when a piece of stem or branch carrying one or more buds is used, the process is known as grafting. Several important methods of grafting used to vegetatively propagate fruit and ornamental trees are discussed below. The first step in the budding and grafting operation is to raise seedlings of compatible rootstock species, or to produce clonal rootstocks to avoid variation otherwise encountered in seedling populations. If seedlings are used, only strong, vigorous, and healthy ones should be selected to be used as rootstock (Singh et al., 2024).



Fig 11: Grafting method

5.3.1 The Selection and Care of Ccion

Scion is of the utmost importance. It must be collected from selected progeny trees that are true-to-type and have desirable fruit and yield characteristics.

Twigs that have shown growth during the previous season usually furnish the best scion wood. The buds should be well-developed, plump, mature, and in a dormant condition.

If the bud wood is not to be utilized immediately, it can be stored for a limited time. The sticks of bud wood are tied in small lots and properly labelled for identification. Both ends are sealed in melted wax to prevent excessive evaporation. The bundles are then put in sphagnum moss, wrapped in polythene bags, packed in a suitable box, and stored in a cool place. Only the most compatible scion and rootstock combinations should be used in grafting and budding. Incompatible combinations result in poor bud, weak graft or bud union, overgrowth of stock as compared to scion or vice versa, low disease resistance, excessive leaf drop, early decline, low yields of poor-quality fruit, and short life span.

5.4 Grafting Methods

5.4.1 Inarching or Approach Grafting

Unlike other grafting operations, in inarching, the scion is attached to the stock while it is still attached to the parent plant. In Pakistan, the method has been extensively used in the vegetative propagation of mango.

The method involves potting healthy one-year-old seedlings in earthen pots, which are usually 12” deep and 8” wide at the top. The earth ball, along with the root system, is kept intact and placed in the pot. The unfilled space in the pot is then filled with a mixture of well-rotted manure and canal silt. The soil is firmly pressed around the earth ball and the transplanted seedlings are then watered. Potting of seedlings is usually done one month ahead of actual inarching operations. This allows sufficient time for the seedlings to set before grafting. Inarching can either be done in the spring months or in the rainy season (July-August). July and August are preferred over the spring season because after the arching operations in the spring months, the windstorms in the early summer reduce the percentage of success. High wind velocity knocks over the pots and loosens the graft union. The potted seedlings are brought near the parent plants for inarching, hence the name grafting by approach has also been given to this method of grafting. If shoots of desirable size are available at ground level, potted seedlings are put underneath the parent scion trees and inarching operations are completed. However, if shoots are only available at a certain height, the pots are raised and provided with support. Every care must be exercised in the selection of rootstock and scion shoots. The size of the rootstock and of the scion shoot should be the same. A slanting cut about 5 cm long and 2 cm deep is made on the stock seedling at a height of 15-20 cm. A similar cut is made on the scion shoot and the corresponding cuts are then brought together and tied with plastic film. To prevent drying up, the union point is covered with moist sphagnum moss and

wrapped with polythene film. While tying, care is taken to bring the corresponding cambium surfaces into contact. The union takes place within three to four months. When the graft is still attached to the parent plant, the pot is watered twice a day during the summer months. Removal of the graft from the parent plant is a gradual process. Prior to the final cutting away of the graft from the parent plant, an incision is made on the scion 5 cm below the graft union. The period between the incision and removal of the graft should be seven to ten days. After the graft has been removed, it is placed in the shade of trees. The top of the stock is also gradually removed after they have been stored in the shade for about two weeks. They are then kept for about four to six months in the nursery before they are planted.

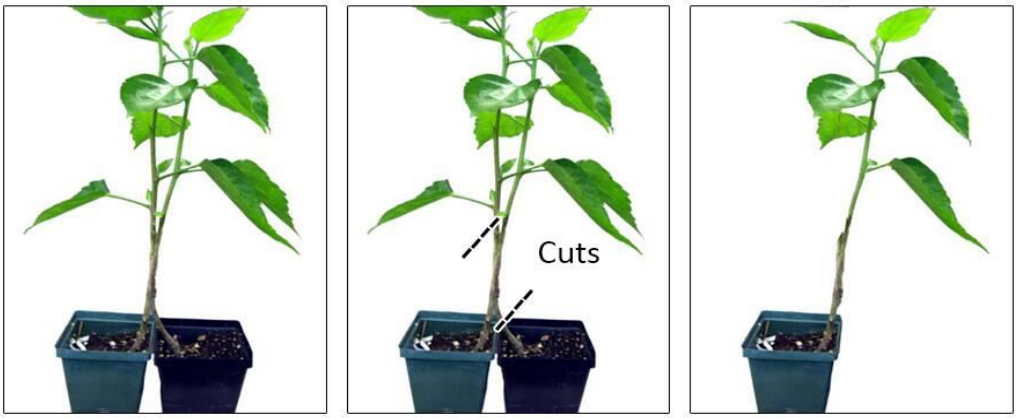


Fig 12: Approach grafting

5.4.2 Wedge or Cleft Grafting

This method is generally used in the propagation of deciduous fruits and top-working older trees of inferior varieties. Branches of the rootstock 1.25-5 cm thick or even larger are cut at the top, and a vertical split 5-8 cm deep is made in the centre of the stub with a heavy chisel or knife. The split is kept apart until scions containing at least three buds are inserted. The basal end of the scion is cut into a long, sloping wedge about 5 cm long. The side of the wedge that is to face outward is made slightly wider than the inside edge. One scion is inserted on each side of the split. After adjustment of the scions, the tool used to keep the split open is removed to allow the full pressure of the split stock to bear on the scions at the point where the cambium of stock and scion are in contact. No tying is usually needed; however, all the wounded surfaces are thoroughly waxed over. Cleft grafting is most successful when done in early spring when the buds are beginning to swell but before active growth has started.

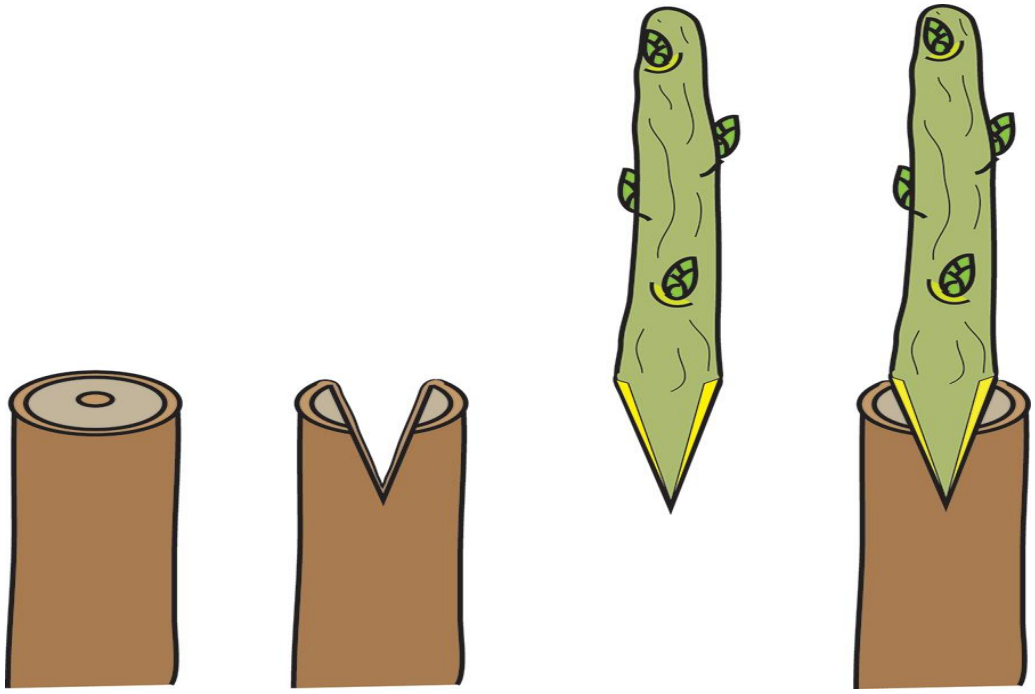


Fig 13: Wedge or cleft grafting

5.4.3 Splice Grafting

A slanting cut about 10 cm long is made at the basal end of the scion, which is placed on a corresponding cut made on the rootstock seedling at a height of 30-45 cm from ground level, and then tied together. The cambial areas of scion and stock should be in close contact to achieve it; both should be of the same thickness. The top of the plant down to the graft union is covered with a polythene bag, loosely tied at the basal end to prevent excessive transpiration. The union takes place within three weeks to three months, depending upon the plant species involved and the age and condition of the scion and rootstock. Splice grafting has been employed in grafting mango in the Philippines and Brazil, and for some varieties of apple.

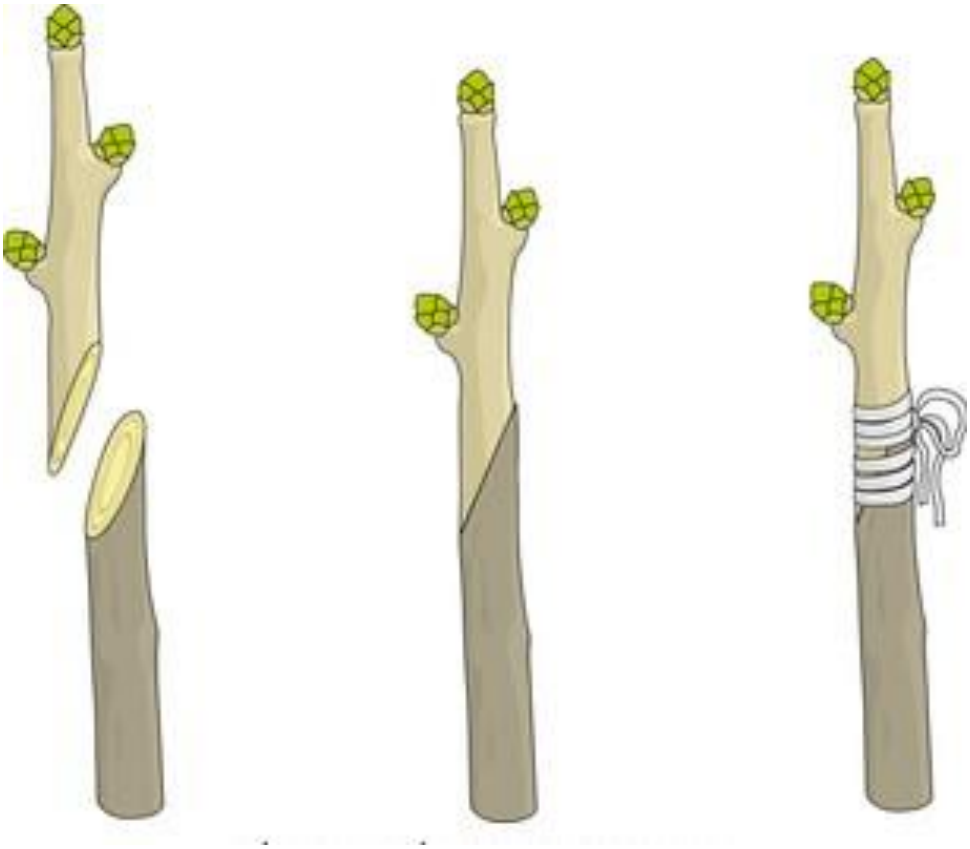


Fig 14: Splice grafting

5.4.4 Tongue Grafting

The scion and rootstock are cut exactly in the same way as in splice grafting. To provide strength and exposure of a greater cambial area for union, tongue-shaped slits are then made in both scion and stock. The secondary slits or cuts are half the length of the original slanting cuts. The scions and stocks are brought together, firmly interlocking. The graft wounds are waxed over, with or without tying.



Fig 15: Tongue grafting

5.4.5 Bark Grafting

Unlike in the cleft graft, the stub of the stock is not cut horizontally. Instead, several scions with their basal ends trimmed as wedges are inserted between the bark and the wood. The operation is done during spring when the bark can be loosened more easily.

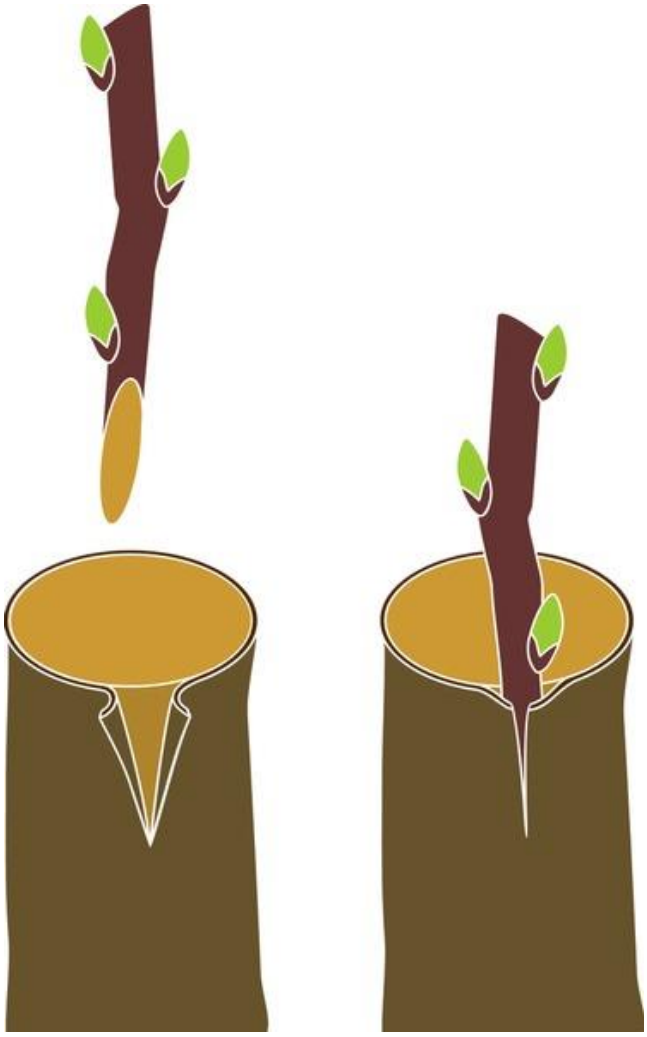


Fig 16: Bark grafting

5.4.6 Bridge Grafting

Bridge grafting is practiced to save valuable trees with diseased or damaged trunks. To prepare the tree trunk for bridge grafting, the damaged part is trimmed back to healthy tissue by removing dead or torn bark from the affected parts. Bridge grafting is best performed during early spring when the bark can be lifted easily. Scions of sufficient length to bridge over the damaged area are taken. One long slanting cut is made at each end of the scion, both cuts on the same side. A second cut is made on the back side. The bark on both upper and lower sides of the wounded area is loosened as in bark grafting, and the scions are then inserted between the bark and wood of the stock and are nailed down. All cut surfaces are

carefully coated with wax, and any sprouting on the scion surface should be removed. Complete healing takes place in a few years' time.

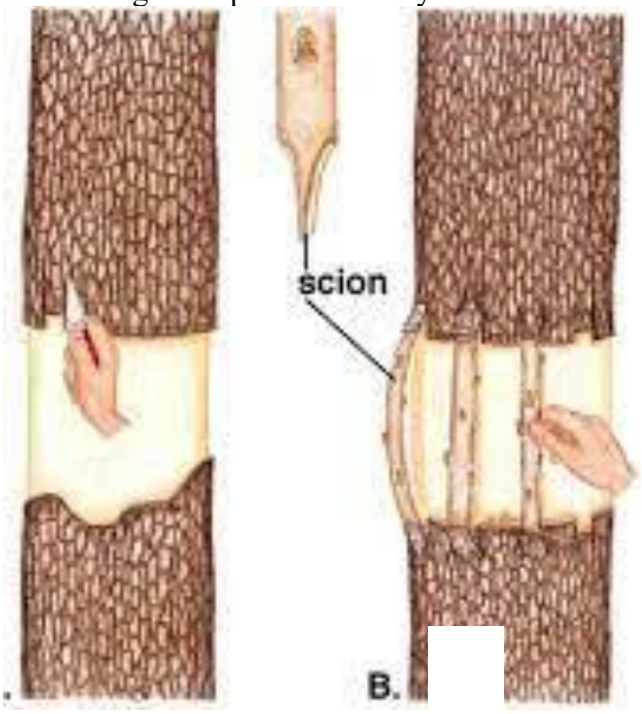


Fig 17: Bridge grafting

5.4.7 Veneer Grafting

Veneer grafting and side veneer have been successfully employed in vegetative propagation of mango and guava. The methods being followed in Pakistan are described here. Healthy, two to three-year-old vigorous stocks are selected. Scion shoots with terminal buds are used as graft wood. The scion wood is prepared by clipping off the leaves, leaving petiole stubs 0.5 cm long intact. The pre-conditioned shoots of the scion are then girdled at a place 1.5- 2.0 cm below the apex. The grafting wood is ready in about 15 days in spring and 12 days in autumn, when the wounded portion buds begin to swell. A10 cm wood graft in length is detached from the scion trees and grafted on the stock seedlings at a point having almost the same girth as that of the scion. The grafting operation is done by making a tangential cut 5 cm long through the bark of the stock, making a notch at the base. A similar cut is made on the graft wood with a wedge at the base. The cut surfaces of the stock and scion are united. The scion wood is tied with waxed cotton tape. It is then wrapped in a polythene sheet and both ends of the plastic are tied. After the union has taken place and new growth appears, the wraps are loosened. After the first flush of the scion, the cotton tape is untied. The

stock is then cut back partially. The heading-back of the stock is completed after the growth of the second flush of the grafted scion e.g. Avocado, Mango etc.

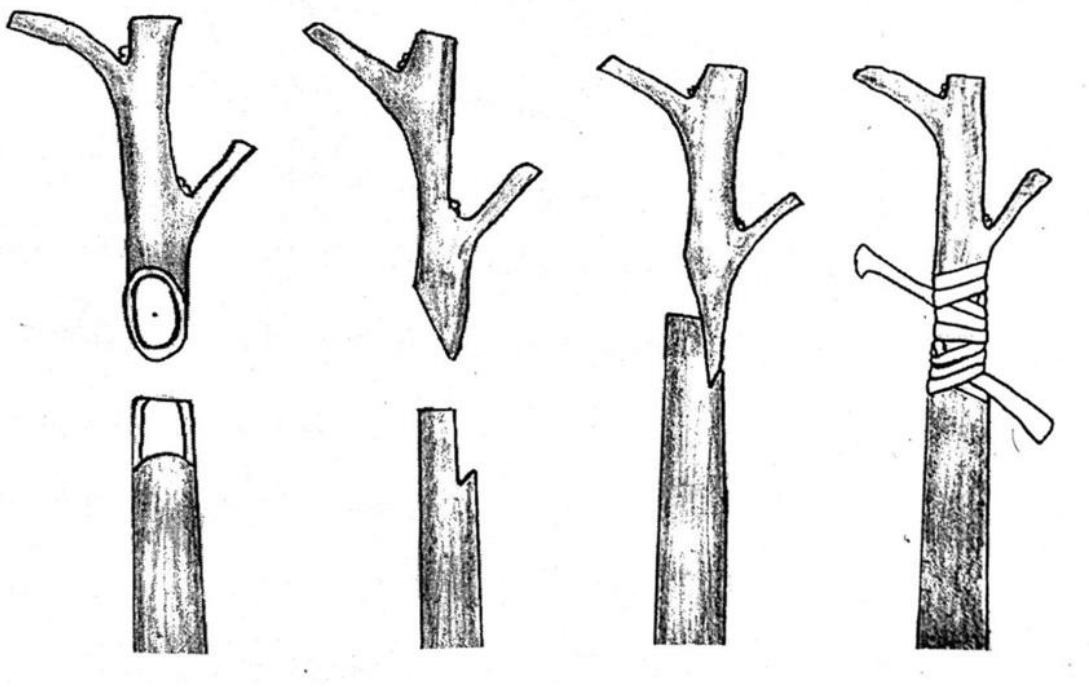


Fig 18: Veneer grafting

5.4.8 Side Grafting

Vigorous stock shoots are selected. Fresh and mature scion sticks about 12-13 cm long are collected from a desired variety and their leaves are clipped off. A two to three-year-old stock tree planted in orchard rows is selected. At the base of the scion on one side, a longitudinal cut of 5-8 cm is made, cutting away half of the girth at the base and thus making a wedge. An oblique cut is made in the stock at an angle of 20-30 degrees and about 2.5 cm deep, and the scion is inserted in the cut portion and gently pushed down until it is fixed in the bark. The union is tied with waxed cotton tape and wrapped with polythene. After the graft sprouts, the polythene is removed. The other precautions are the same as in budding. This method can be performed in both spring (March-April) and autumn (August-September), but the maximum success rate of 90 percent is achieved during spring.

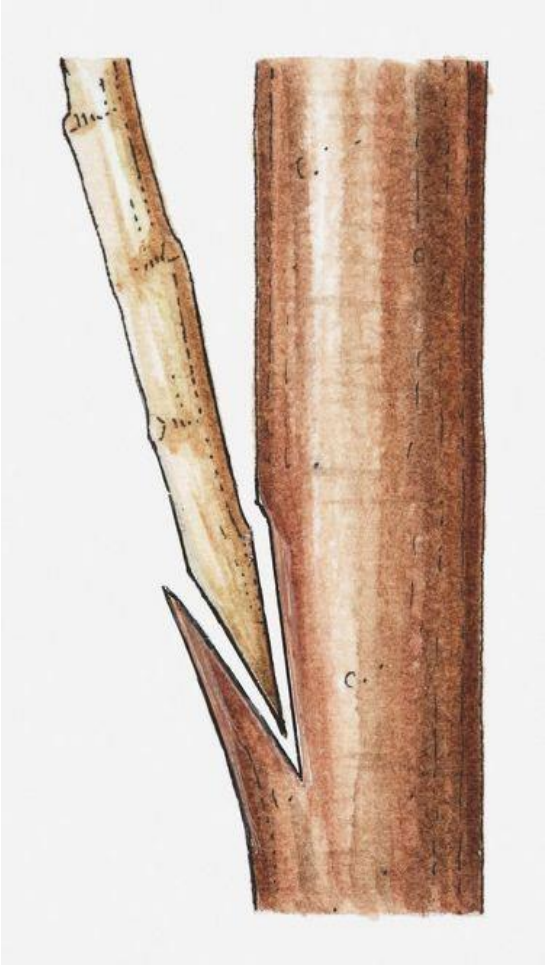


Fig 19: Side grafting

5.4.9 T-grafting

In the technique of T-grafting, the scion wood is prepared as for veneer grafting. The shape of the cut on the stock is, however, different from that made for veneer grafting. A 'T' -shaped cut is made in the stock bark, into which the scion is inserted and firmly wrapped with waxed tape. The graft is covered with polythene.

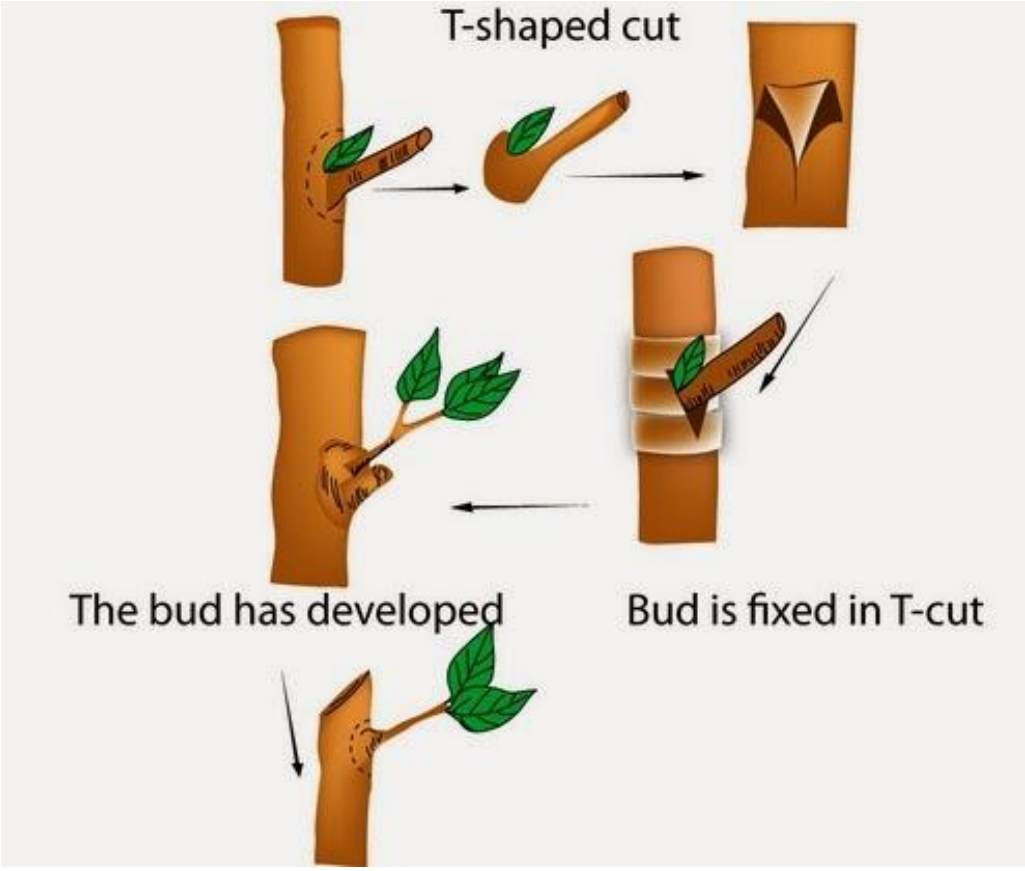


Fig 20: T-grafting

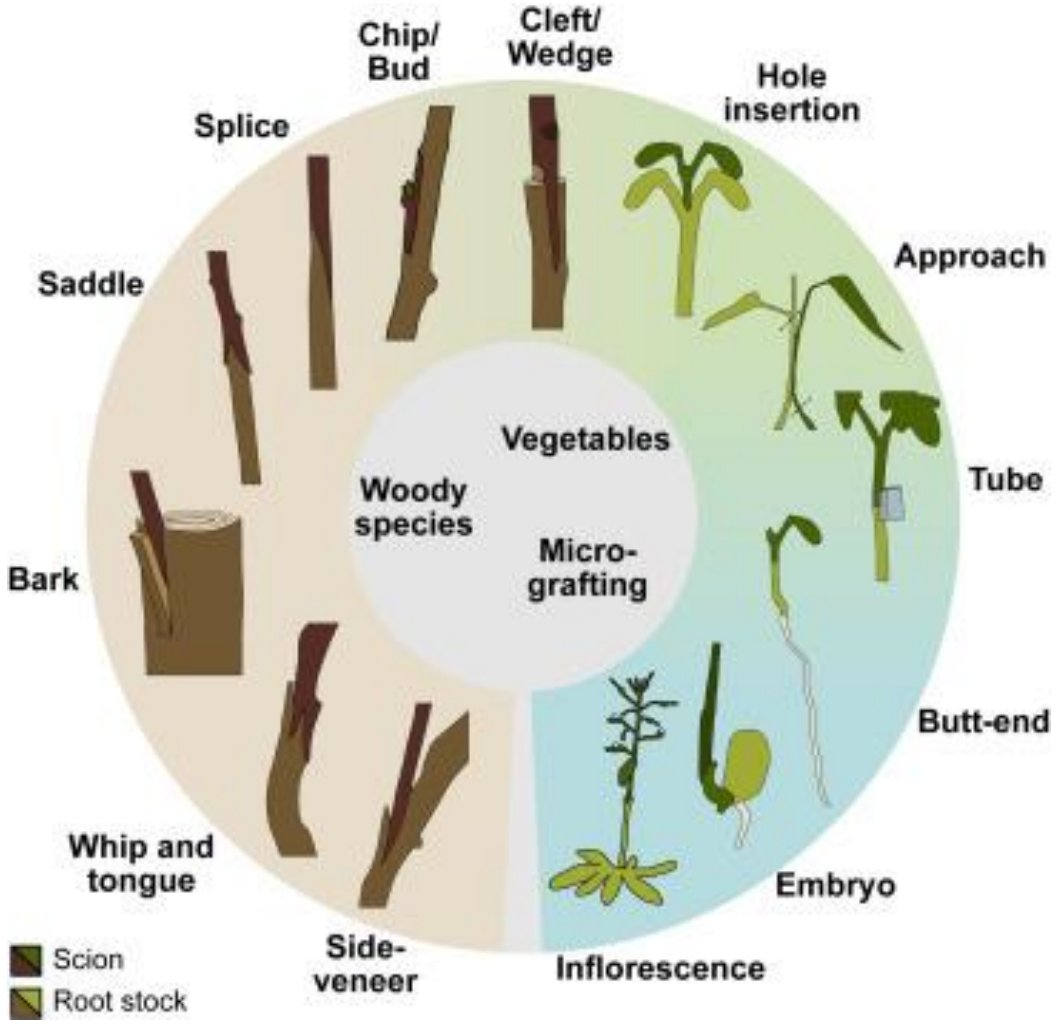


Fig 21: Different types of grafting

5.4.10 Factors Influencing Success in Vegetative Propagation

• Graft union takes place readily between varieties and species. It becomes unlikely when plants belonging to species in different genera are involved, and impossible in the case of different families.

• Only compatible stock/scion combinations should be used.

• Use seed and grafting material from well-tested, true to type parent trees with a high degree of disease resistance, and desirable yield and fruit characteristics. For better contact between cambial surfaces to assure grafting surface, rootstock and scion should be of the same vigour and thickness, and of suitable age.

• Grafted seedlings in pots or nursery rows should be carefully tended. They should also be protected from desiccating winds, direct sunlight, rain, and frost injury.

• The material used as bandages and for wrapping graft union should be removed once the bud sprouts have made some growth.

5.5 Budding

Budding is the art of joining two different plant parts together, in such a manner that they unite and continue their growth as a simple plant. In the case of building, a single bud is inserted into the rootstock, whereas in grafting, a bud stick consisting of two or more buds is inserted into the rootstock (Moore and Bradley, 2022; Singh et al., 2024).

Budding is relatively easy to do and is extensively used in the vegetative propagation of vast numbers of species of fruit and flowering trees, particularly evergreens.

Four different methods of budding are generally identified.

5.5.1 Shield Budding or 'T-budding'

This is by far the most common method of vegetative propagation of citrus, jujube, apple, loquat,' roses, ,and many other ornamental trees and shrubs. The rootstock seedling and bud wood are pre-conditioned and prepared when the sap is moving freely. For convenience in handling, before the buds are actually removed, the leaf blades are cut off, leaving the petioles intact. A narrow shield of bark 3-4 cm in length, bearing a single bud, is removed with a budding knife. The shield will have a thin layer of wood, which is removed from thorn less buds but is kept intact with thorny buds, as with some of the citrus species. A vertical cut 3-4 cm in length is made just through the bark on the rootstock. At the top end of this cut a horizontal cut about 1.25-1.5 cm long is made, so that the cut resembles the letter 'T'. In areas with heavy rainfall, sometimes an inverted 'T' cut is used to avoid the entrance of excessive moisture. Care should be taken not to injure the wood underneath. The height of budding on stock varies with stock and scion being used, climatic conditions, and the prevalence of viruses and diseases. Using the plastic or bone spur of the knife, the bud is inserted under the bark, which has been loosened from the wood. To hold the bud firmly in position and to exclude air and moisture, the bud union is carefully wrapped using suitable plastic strips, keeping the bud exposed. In most cases, the bud union is complete in about four weeks. When the buds begin to swell and sprout, the top of the budded stock is cut close to the bud union to encourage the rapid growth of budlings. After the sprouts have grown about 10 cm, the tying material is removed and the budded plants are trained to their proper size and shape. They are carefully tended in the nursery until they are disposed of for transplanting.

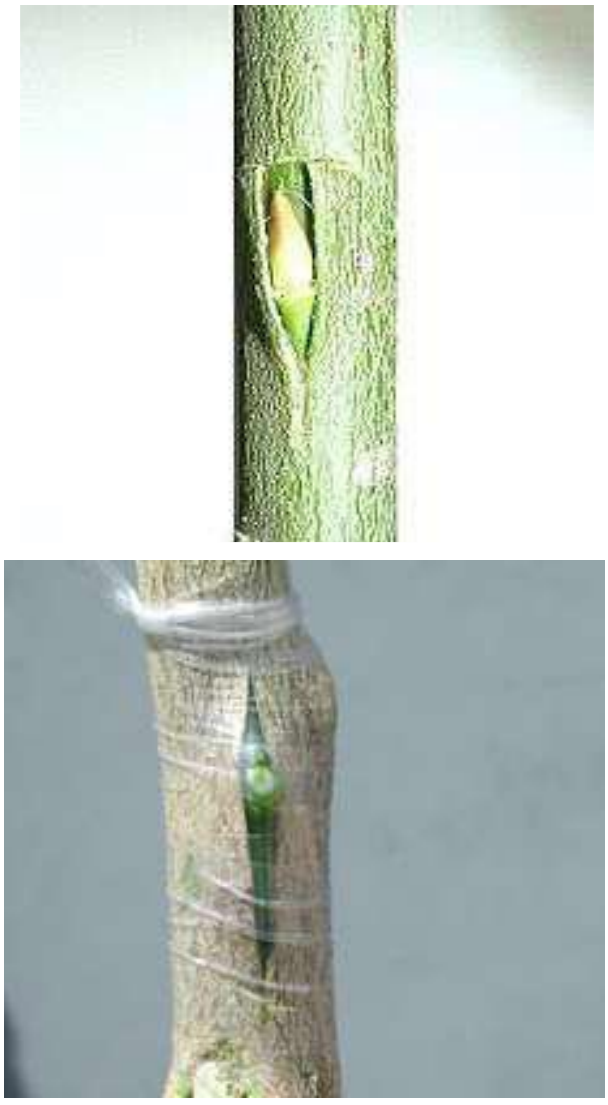


Fig 22: T Budding

5.5.2 Ring Budding

In this method, a ring of bark 1.5-2 cm in length, containing a well-developed bud, is loosened on the scion shoot and is gently pulled out from the thinner end of the shoot. In pulling off the ring, a handkerchief is used to avoid possible injury to the bud. The top of the stock seedling is removed and the bark is peeled off downward to a point where the ring of the bark bearing the bud fits tightly. No tying is necessary in ring budding. Uniformity in the thickness of the rootstock and scion shoots is desirable for a higher percentage of success. This method can be employed in the propagation of bair (Sidr), mulberry, peach, and plum.

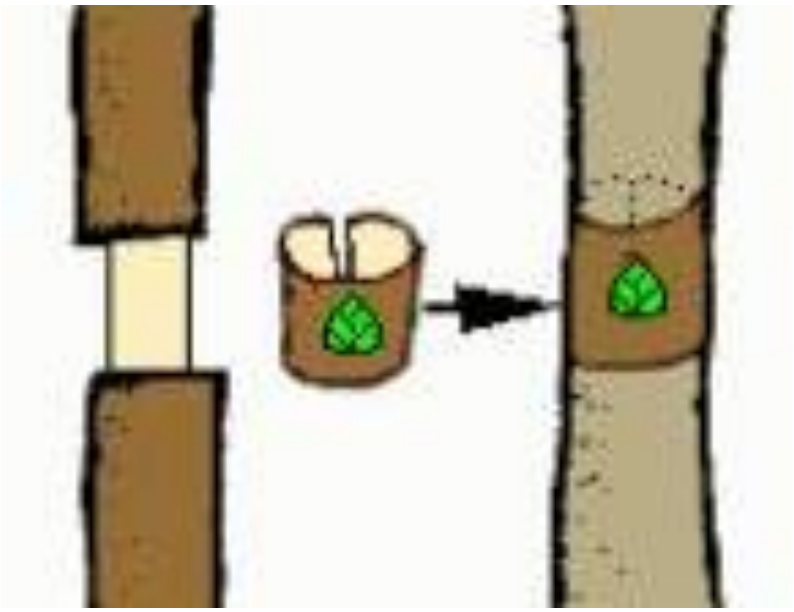


Fig 23: Ring budding

5.5.3 Chip Budding

A single bud with a large piece of wood is placed on a corresponding cut made on the stock and tied firmly. This method is rarely used.

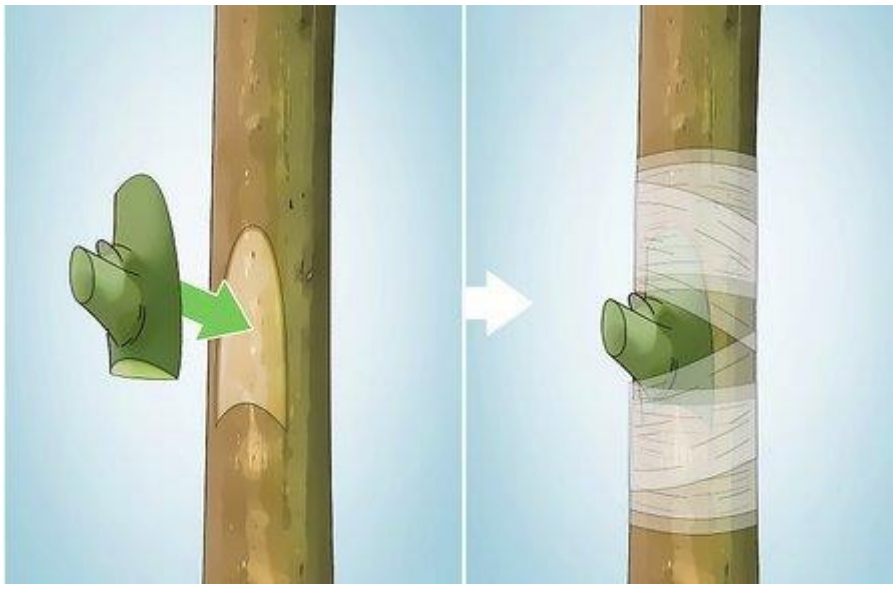


Fig 24: Chip budding

5.5.4 Flapped-patch Budding

A rectangular or square flap of bark on the stock is loosened on three sides. The corresponding bud shield is inserted underneath the loosened flap of bark. The flap is then placed over the bud shield and wrapped. It takes about two months for the buds to sprout, after which the wrapping material is removed.

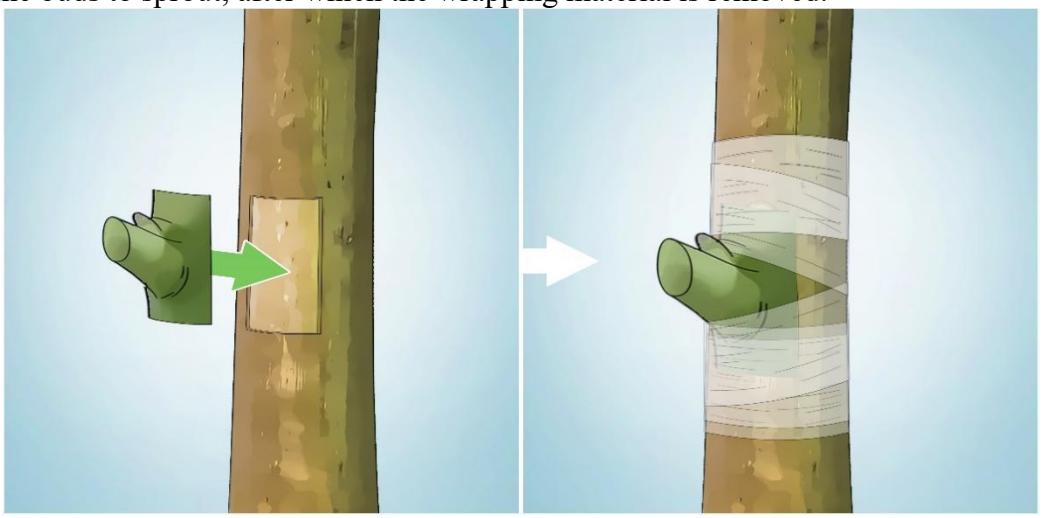


Fig 24: Patch budding

5.6 Why Grafting and Budding

Plant propagation with cuttings and leverage is very easy, cheap and economical; however, grafting and budding are necessary because.

1. When other methods are not successful.
2. Adoptability for pests, diseases, and tolerance to cold, unsuitable climate by using suitable rootstock.
3. Converting inferior plants into superior ones, e.g. side grafting in mango.
4. To modify the growth of fruit plants e.g., by using dwarfing rootstocks

5.7 Layering

Layering means rooting of shoots, stems, or branches while they are still attached to the parent plant. Some trees and bushes, like blackberry, layer themselves naturally. Strawberry produces runners, another form of natural layering.

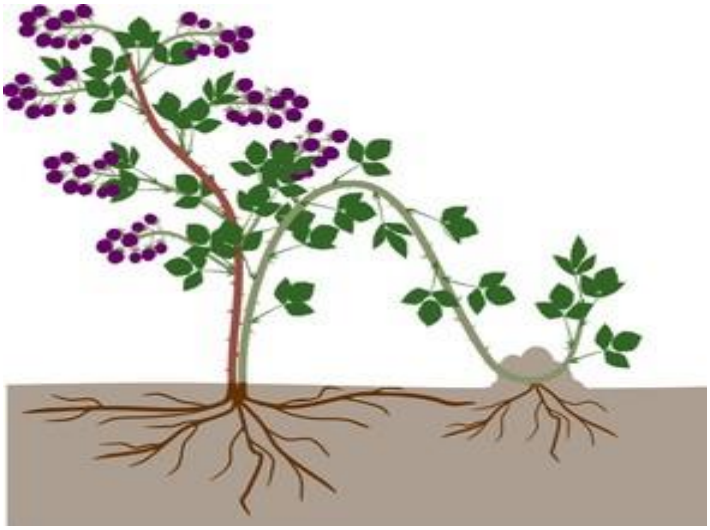


Fig 24: Layering

Advantages

Young plant continues receiving nourishment from the parent plant.
Layering can be carried out in the spring or late summer months.
Types of layering are as follows

5.7.1 Air Layering or Marcottage

When rooting is encouraged on the aerial part of a plant after wounding it, it is known as air layering or gooty or marcottage. Air layering is used for vegetative propagation of blackberry, guava and litchi etc.



Fig 24: Air layering

5.7.2 Ground Layering

In ground layering, instead of wrapping, the rigged or notched portion is buried in the ground or in soil prepared in pots. The shoot is kept in position by tying it with a peg or by putting a weight on the surface of the soil. After two months, a half cut is made in the parent branch just below the layering. If no wilting is noticed, it indicates that the new layer has developed roots. The layering is separated and set out as an independent plant.



Fig 24: Ground layering

5.7.3 Serpentine Layering

With some species that give out long and flexible branches, the shoot to be layered is covered with soil at several places to encourage rooting at more than one point. The method is thus known as serpentine layering e.g. Jasmin.

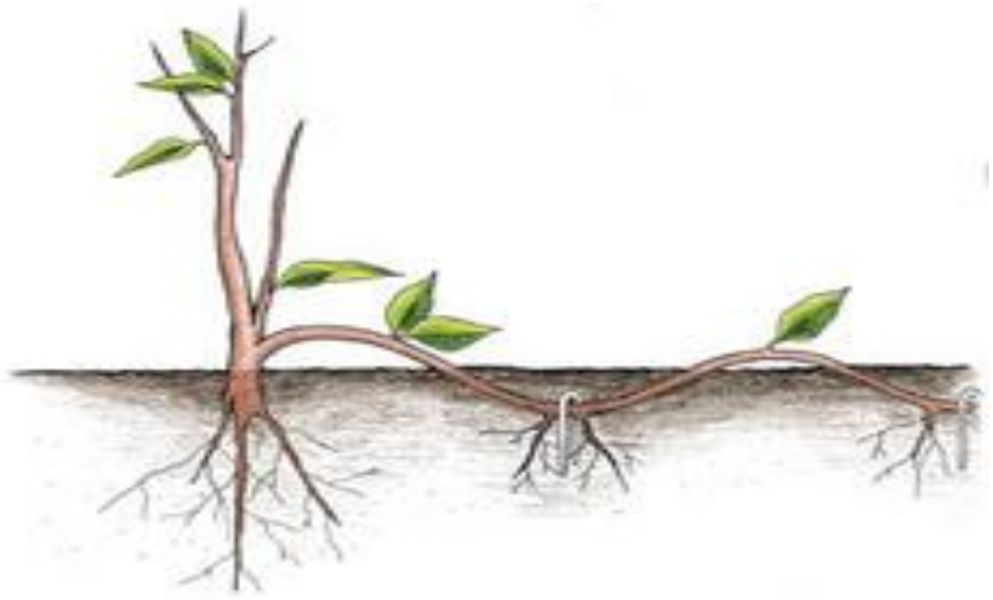


Fig. 25 Serpentine layering

5.7.4 Mound or Stool Layering

In this method, a plant is cut back at the ground during the dormant season, and soil is covered at the base of the newly developing shoots. After allowing sufficient time for root initiation, the rooted shoots are separated and taken as individual layers.

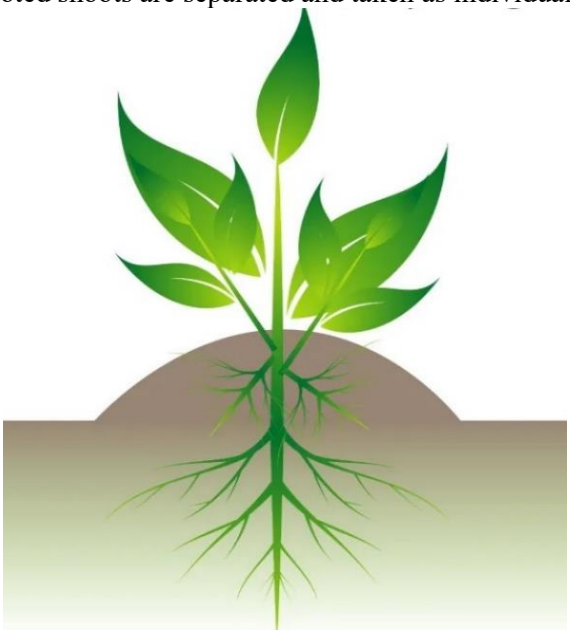


Fig 26: Mound or Stool Layering

5.7.5 Difference between Layering and Cutting

Sr. No	Layering	Cutting
1	Layering is performed only on branches of the plant	Cutting can be accomplished by using branches, leaves, and roots.
2	Plant parts are kept attached to the mother plant till the root formation takes place.	Plant parts are first detached from the mother plant and are then induced to produce roots.
3	Layers are produced on the spot only and very few layers can be produced from the plant.	Cutting can be taken easily from the plant and can be carried over long distances. More cuttings can be prepared from a plant.
4	It is a cumbersome and difficult technique	It is a very easy and simple method.
5	Those plants that are difficult to root can be propagated by layering.	Those plants are easier to root and are propagated by cuttings.

5.8 Propagation of Horticultural Crops

Horticultural crops are propagated both sexually and asexually. The asexual methods of propagation other than layering are as follows

5.8.1 Division

Separation is a method of propagation in which underground structures of plants are divided not by cutting but by breaking along natural lines between segments. Separation is breaking away of daughter structures from the parent structure to be used to establish new plants. Two specialized
underground structures, bulbs and corms-produce such materials. Among fruit crops, strawberries are propagated by runners, date palms by suckers, pineapple by offsets and crown, and bananas by suckers or rhizomes.

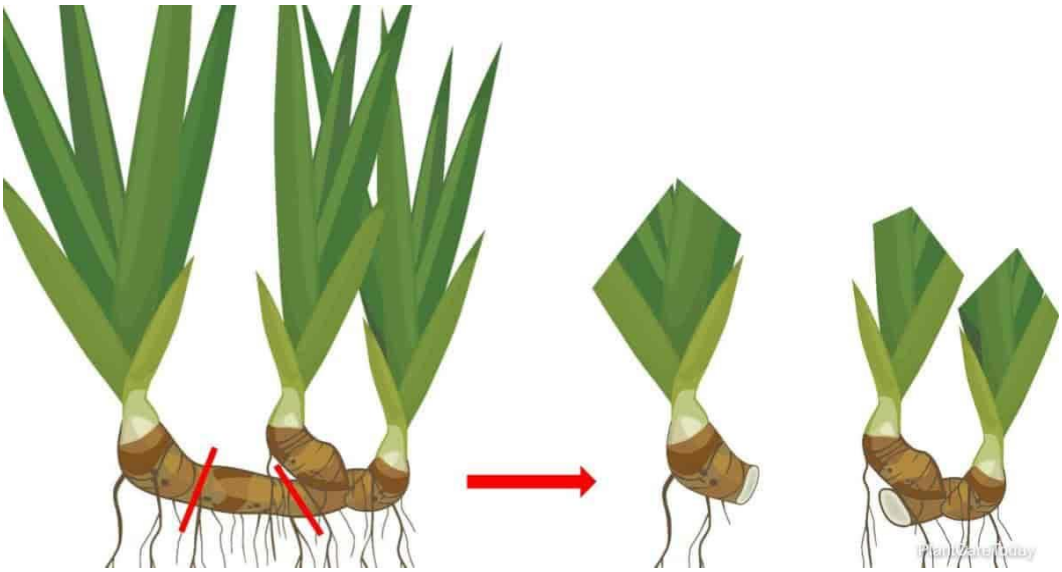


Fig 27: Division

5.8.2 Suckers

A sucker is a shoot that arises on a plant from below the ground. The most precise use of this term is to designate a shoot that arises from an adventitious bud on a root. However, in practice, shoots, which arise from the vicinity of the crown, are also referred to as suckers even though they originate from the stem tissues. The tendency to suckers is a characteristic possessed by some plants and not others e.g., Banana, red raspberry, blackberry and chrysanthemum.

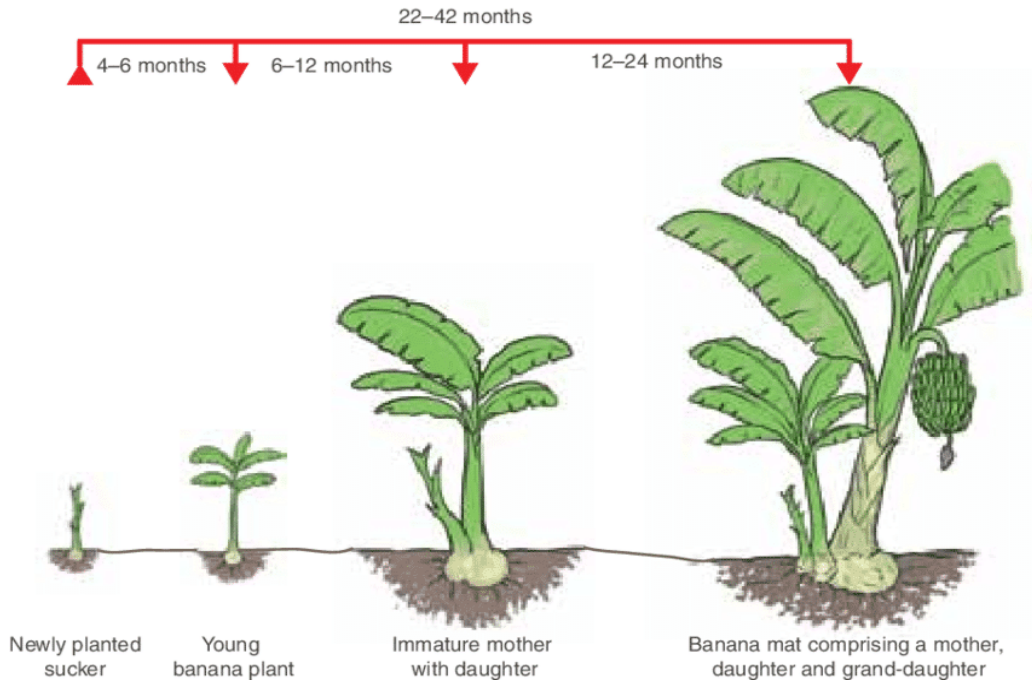


Fig 28: Propagation in a banana through suckers

5.8.3 Crown

The term crown is used to designate the part of a plant stem at and below the surface of the ground from which new shoots are produced. Division of the crown is an important method of propagation and this division will propagate plants e.g., African violet, strawberry.

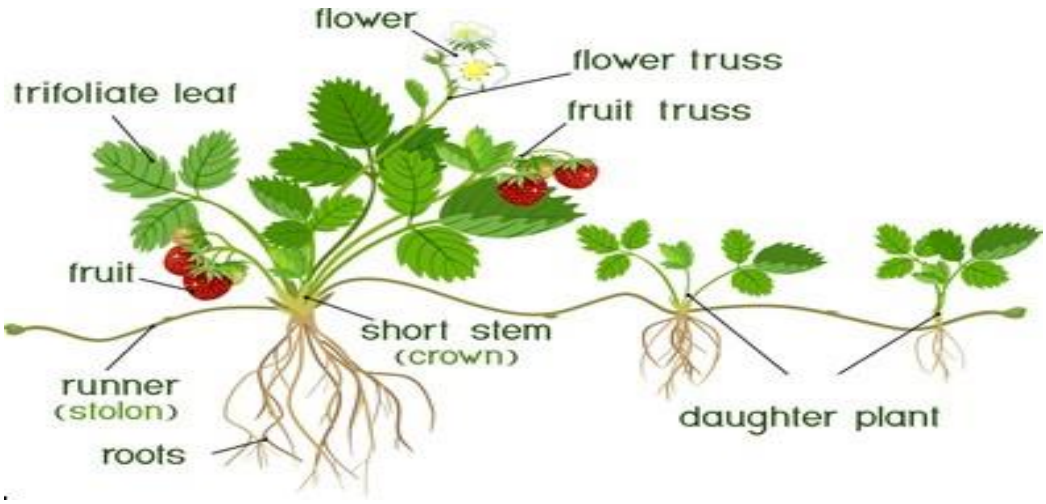


Fig. 29: Propagation in the strawberry through the crown

5.8.4 Bulb

A bulb is a specialized underground organ that consists predominantly of fleshy leaf scales growing on a stem tissue (basal plate). The scales wrap around a growing point or primordium to form a tight ball. Lateral bulblets or miniature bulbs originate in the axils of some of these scales and when developed (offsets) may be separated from the mother bulb to be planted independently as new plants. There are two types of bulbs-***Tunicate*** and ***non-tunicate bulbs***. ***Tunicate***- These bulbs have outer bulb scales that are dry and membranous. This covering, called a tunic, provides protection from drying and mechanical injury to the bulb. The fleshy scales are in continuous, concentric layers, called lamina, so that the structure is more or less solid e.g., Onion, daffodil, tulip etc. ***Non-tunicate (scaly) bulbs:*** These bulbs don't possess the enveloping dry covering. The scales are separate and attached to the basal plate. The scales are not tight but loose and can be removed individually from the bulb. In general, the non-tunicate bulbs are easily damaged and must be handled more carefully than tunicate bulbs. The daughter bulbs or bulbs let develop at the base of the scales of the mother bulb e.g. lilies, tulips, daffodils and onions (Megersa, 2017; Moore and Bradley, 2022).

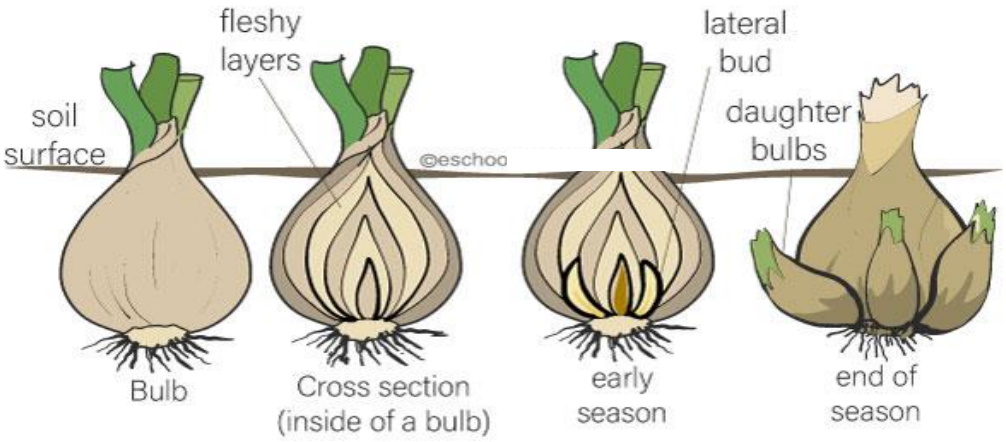


Fig 30: Propagation through bulbs

5.8.5 Corms

The bulb consists predominantly of modified leaves; the corm is a modified stem. Food is stored in this compact stem, which has nodes and very short internodes and is wrapped up in dry, scaly leaves. When a corm sprouts into a new shoot, the old corm becomes exhausted of its stored food and is destroyed as a new corm forms above it. Several small corms, or cormels, arise at the base of the new

corm. The cormels may be separated from the mother corm at maturity (die back) and used to propagate new plants e.g. Amorphophallus, Colocasia, Gladiolus etc (Singh et al., 2024).

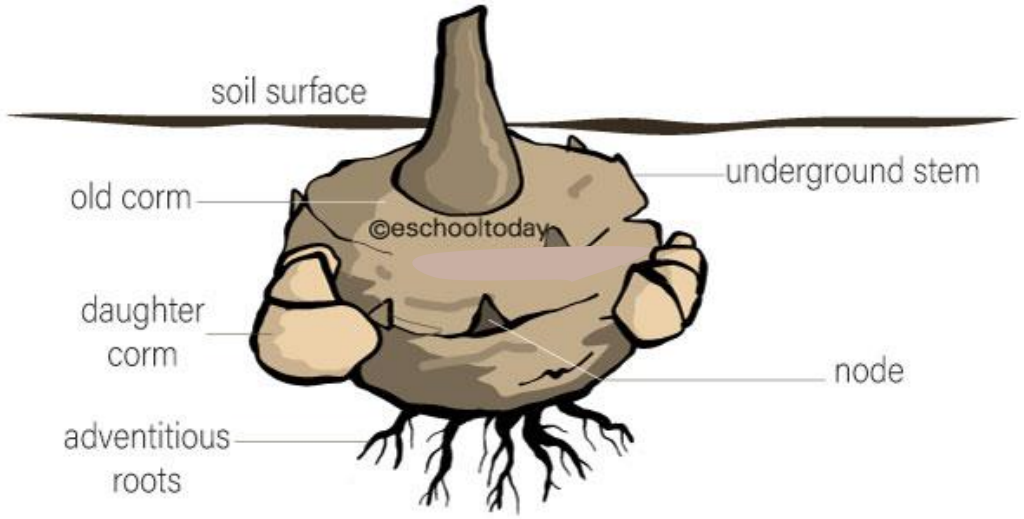


Fig 31: Corm

5.8.6 Tubers (Stem Tubers)

A stem tuber is the short terminal portion of an underground stem which has become thickened because of the accumulation of reserve food materials e.g. potato. Propagation by tuber can be carried out either by planting the whole tubers or by cutting them into sections, each containing a bud or eye.

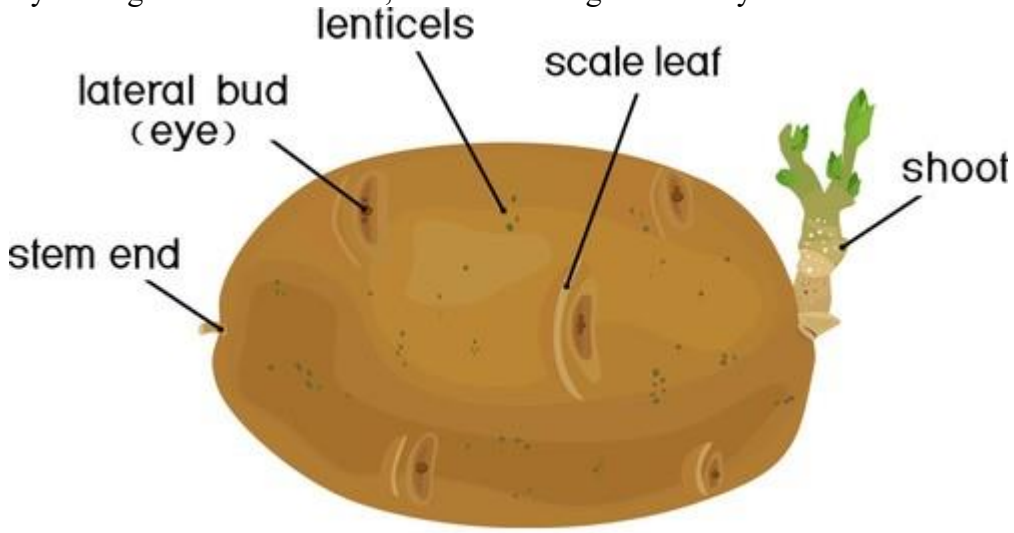


Fig 32: Tuber

5.8.7 Tuberous Roots (Root tubers)

A certain herbaceous perennial produces thickened roots that contain a large amount of stored food. The tuberous roots differ from the tubers in that they lack nodes and internodes. Adventitious buds are present only at the stem and these fleshy roots are separated and used for propagation e.g. sweet potato, dahlia.

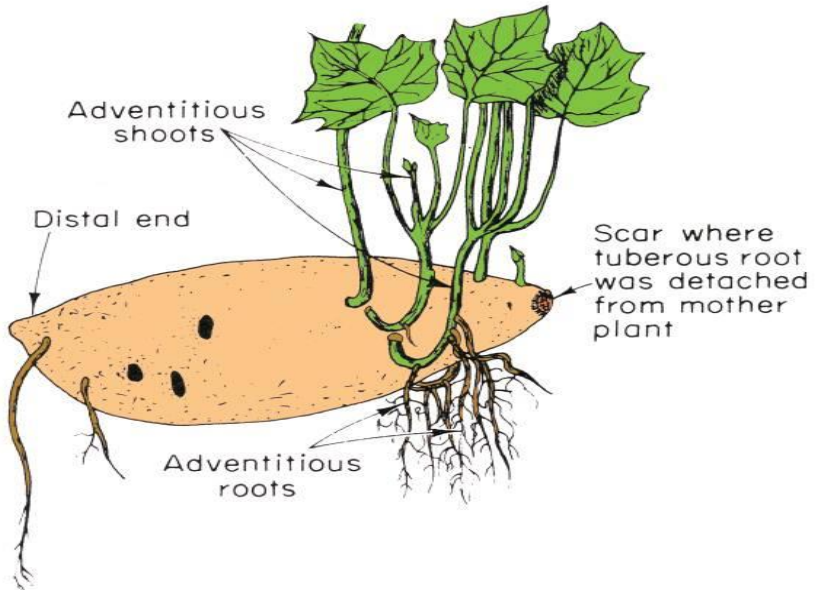


Fig 33: Tuberous roots (root tubers) in sweet potato

5.8.8 Rhizomes

A rhizome is a horizontal stem growing either underground or along the surface of the ground. Typically, it is the main axis of the plant, producing roots on its lower surface and extending leaves and flowering shoots above the ground. It may be thick and fleshy or slender and elongated, but it is always made up of nodes and internodes e.g. Canna, Ginger. Propagation by Rhizomes consist of cutting or dividing the rhizome into selection each of which is capable of producing new shoot (it should have nodes) from nodes and foods from adventitious buds of lower surface (Megersa, 2017).

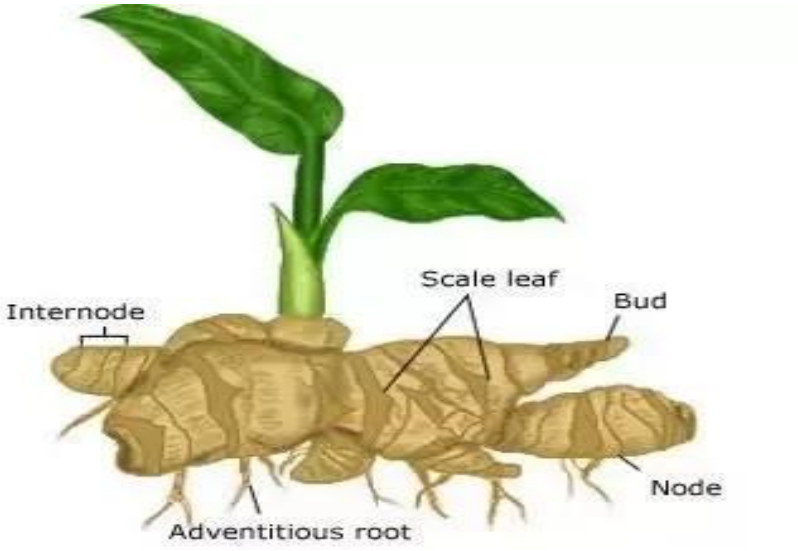


Fig 34: Ginger rhizome

5.8.9 Runners

A runner is a specialized stem that develops from the axil of a leaf at the crown of a plant. Grows horizontally along the ground and forms a new plant at one of the nodes. In propagating plants by runners, the rooted daughter plants are dug when they have become well rooted and transplanted to the desired locations e.g. strawberry, berry, oxalis, blueberry etc.

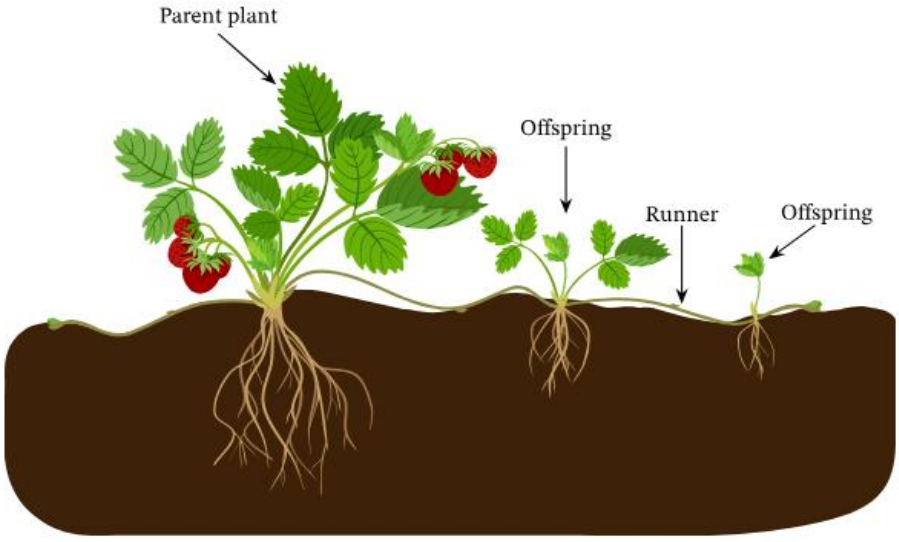


Fig 35: Strawberry propagation through runners

5.8.10 Stolen

Stolen is a term used to describe various types of horizontally growing stems that produce adventitious roots when they comes in contact with the soil. Specifically, these are prostrate stems as found in Bermuda grass (Cynoceneactyon), Mint and the underground stem of the potato that terminates as aa tuber.

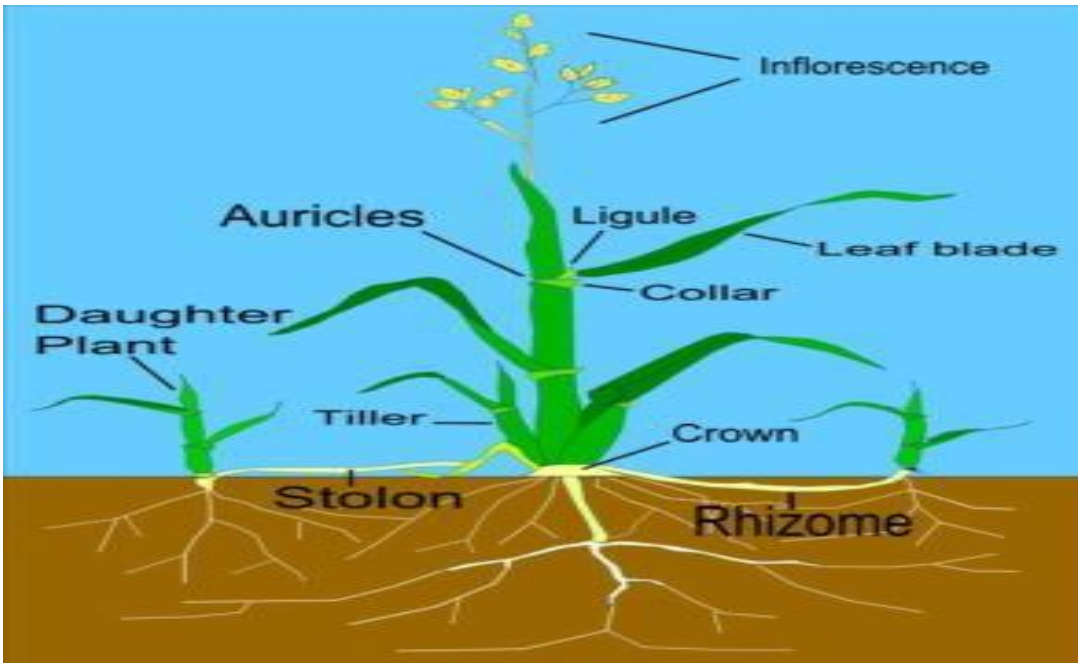


Fig 36: Grass propagation through stolen

5.9 Plant Tissue Culture

Plant tissue culture commonly refers to the *in vitro* and aseptic cultivation of any plant part (cells or tissues) on a nutrient medium in an artificial environment. Research efforts in plant cell and tissue culture have increased dramatically worldwide in recent years, including efforts in the developing nations. Plant propagation using shoot-tip culture is the most widely used area in plant cell and tissue culture and is currently being used to propagate elite genotypes of several plant species in a number of countries. **Clonal propagation,** True-to-type plants can be raised by shoot-tip/meristem culture. The terminal 2-3 mm portion of plants (meristem) is almost free from viruses, for the reason that cell divisions in such parts are very active. Virus-infected cells, on the other hand, divide comparatively slowly and lag behind. On nutritive media under controlled environmental conditions, such meristems can be made to grow into complete healthy shoots (George et al., 2008).



Fig 37: Plant tissue culture

5.9.1 Commercial Considerations in Plant Tissue Culture

Some important commercial considerations in tissue culture are, briefly:

a. Capital investment: The initial cost of a tissue culture laboratory is higher than the cost of using conventional methods.

b. Expertise: Well-trained personnel are required for this technique. They should be conversant with standard microbiological techniques and have sufficient botanical knowledge of the material and of its *in vitro* behaviour.

c. Range of applicability. Although in theory it would seem that any plant can be cultured by supp~ the appropriate metabolites in suitable *in vitro* conditions, so far only a small proportion of plants can be cultured well enough to be effectively propagated. The time and expense involved would probably be worthwhile for the major crop plants, but not necessarily for the minor crops.

d. Technical problems in Plant Tissue Culture

Phenolics and other inhibiting factors. A number of plants produce excessive amounts of phenolic substances whose oxidation products not only darken both the tissues and the medium but often inhibit growth. Where the problem is

confined to the reaction of the initial explant it may be prevented by treatment with ascorbic or citric acid.

e. Vitrification: An occasional problem with cultured plants is the development of swollen, distorted leaves which become irreversibly translucent and eventually necrotic, a condition that may lead to the death of the shoot cluster. This has been referred to as water soaking (Khan et al. 1987; Murashige 1977) and is more recently described as vitrification (Ioc. cit.). The phenomenon occurs in shoots cultured on media containing cytokinin and can generally be prevented by making sure that the concentrations are not higher than necessary.

f. Bacterial contamination: A persistent difficulty in tissue culture laboratories is the occurrence of contamination by slowly-growing and often macroscopically invisible microorganisms, particularly bacteria.

g. Quality of plants propagated by *in vitro* techniques. It has been observed that when proper culture media and conditions are not provided to the explants certain changes may occur in plants raised through tissue culture. These changes are due to epigenetic effects and genetic differences.

h. Supply of electricity: A continuous supply of electricity is essential for tissue culture techniques. Since there is frequent load-shedding in this country, an alternate power supply through generators is required for tissue culture laboratories.

5.9.2 Tissue Culture Techniques

There are three main steps or stages in the tissue culture multiplication technique.

i. **Establishment stage**: The explant or tissue fragment is sterilized in a disinfectant and placed in a carefully selected and formulated nutrient medium for a period ranging from four to eight weeks. The purpose is to confirm sterility and to establish the growth of the explant.

ii. Multiplication stage: Plant material resulting from the establishment stage is divided and each part is replanted in separate culture tubes. As multiplication occurs, the fragments are again divided and replanted in separate fresh containers. This procedure may be repeated several times to rapidly propagate shoots. Since each transplanted shoot has the ability to produce a complete new plant, it will produce new shoots of its own, each of which also has the potential to produce shoots and roots.

iii. Pre-transplant stage: Before transplantation, the prepared plants are generally hardened by deleting the hormones from the medium and by increasing the light intensity. They are then transferred to soil in the greenhouse. About two to four weeks are usually required to condition or harden a plant before potting it.

Special greenhouse procedures are required for about four to eight weeks until a complete transition from laboratory to greenhouse is completed.

5.9.3 Preparation for Tissue Culture

In preparation for the above stages, the following procedures and precautions are followed.

i. Selection of tissue: For maximum success in using the tissue culture method, the explant must be chosen systematically. The success of this method is directly related to the organ source, its age, the season in which the explant is taken, the size of the explant, and the overall quality of the plant from which the explants are obtained. Shoot tips have been satisfactory for many plants, whereas selections of root, leaf, inflorescence and other organs may be better for other plants. Tissue obtained from young plants tends to reproduce better than that from older source plants. Tissue taken from the growing point has the power of rapid cell division and is generally free from viruses and virus-like disorders. The explants should be free from visible attack of pests and diseases.

ii. Sterilization: The primary objectives of this step of *in vitro* propagation are the establishment of a microbe-free explant culture and the initiation of new growth. The outer surfaces of plants growing under natural conditions are normally infested with spores and other microbial cells.

Mature inner tissue may harbour fungi and bacteria without showing visible symptoms. Plants grown in the greenhouse or growth room are somewhat free of these maladies. Before culturing the explants, it is essential to disinfect the material and then wash it four to five times with autoclaved water to remove the residual toxic effect of the chemical. Some disinfectants commonly used for this purpose, and their concentrations, are listed below.

Disinfectant	Concentration	Dipping time
Sodium hypochlorite	0.5-5%	5-20 min
Ethyl alcohol	75-80%	Several sec
Benzalkonium chloride	0.01-0.1%	Several min
Hydrogen peroxide	3%	15-30 min
Mercuric chloride	0.01-0.1%	10-20 min

Each plant behaves differently with these disinfectants.

Since all plants have a waxy outer surface, it is usually necessary to add a small amount of detergent to the disinfectant to allow better penetration. Tween is a detergent being widely used for this purpose (Khan et a!. 1987; Murashige 1977; Qureshi et a1. 1991; Street 1977).

iii. Inoculation area: For this purpose, a special room is prepared which should be free from dust and microorganisms; it should have ultraviolet lights and be· air-conditioned to maintain the desired room temperature. It should be equipped

with a ventilation unit with laminar flow and positive pressure. A laminar flow cabinet is a special piece of equipment with a 0.3 UM HEPA filter of 99.97-99.99 percent efficiency. It should be fitted in such a way that the air is forced into the cabinet through a dust filter and is then directed over the working area at a uniform rate. Before the cabinet is used, it should be thoroughly cleaned and sterilized with 70-80% ethyl
alcohol.

iv. Culture facility: Plant tissue to be cultured on any nutritive medium should be incubated under proper conditions of well-controlled temperature and light for photoperiod and humidity control and air circulation. All these factors are directly related to the success of this technique.

v. Media for plant tissue culture: It is very important that tap water never be used for dissolving the chemicals because it contains many impurities, such as cations, anions, mineral salts, microorganisms, and gases. Double-distilled water should always be used for this purpose.
Four different media-MS, B5, White, and HelIer-are used in the propagation of horticultural plants by this technique. Of these, the medium named after Murashige and Skoog (ms) is more common.

vi. Culturing of tissues: After samples of explants are collected from healthy young plants at the juvenile stage, and before proceeding further, the worker should disinfect his hands and tools with 70-80% ethyl alcohol to avoid any contamination. The samples are disinfected with a proper disinfectant along with a few drops of detergent under a laminar flow cabinet, and
then rinsed thoroughly with autoclaved water to remove the residual toxic effect of the disinfectant. The terminal and lateral buds are removed from the sample with a scalpel and are placed in autoclaved test tubes or jars containing solidified or liquid nutritive medium. Then these test tubes/jars are covered with autoclaved polythene sheeting and closed with rubber bands. The tubes/jars are labelled with a marker, indicating the treatment, variety, date, and any other essential information. The trays of culture tubes/jars should be placed in the culture room for growth.

vii. Progress of tissue culture In Pakistan
From 1980 onwards there was a quantum leap in the number of tissue culture laboratories in various parts of Pakistan, and now a stage has been reached where the private sector is willing to invest in this new technology. Plant tissue culture has emerged as a rapidly developing science because of its proven success in agricultural improvements: elimination of diseases, evaluation of new varieties in a reduced span of time, and a shortened breeding cycle. At present at least 18 tissue culture or genetic engineering biotechnology laboratories have been established. The tissue culture laboratories at the AARI at Faisalabad and NARC,

Islamabad, have reported substantial success in *in vitro* propagation of important fruit trees and ornamental plants, including guava, apple, grape, Kinnow mandarin, date palm, chrysanthemum, and bougainvillea. The Potato Research Station at Abbottabad utilizes *in vitro* propagation to increase new potato cultivars.

5.10 Self Assessment Questions

Fill in the blanks with appropriate words

i. ……is a term used to describe various types of horizontally growing stems that produce adventitious roots when they comes in contact with the soil.

ii. Only ……. stock/scion combinations should be used.

iii. For maximum success in using the tissue culture method, the ……must be chosen systematically.

iv. A …… is a specialized stem which develops from the axis of a leaf at the crown of a plant.

v. Plant tissue culture commonly refers to *in vitro* and aseptic cultivation of any plant part (cells or tissues) on a nutrient medium in an ……. environment.

vi. A ……. is a horizontal stem growing either underground or along the surface of the ground.

vii. A stem tuber is the short terminal portion of an ……. stem which has become thickened because of the accumulation of reserve food materials

viii. A ……. is a shoot which arises on a plant from below the ground.

ix. …… means rooting of shoots, stem, or branches while they are still attached to the parent plant.

x. ……..is an art of joining two different plant parts together, in such a manner that they unite and continue their growth as a single plant.

xi. Cutting is a part of a plant that will produce roots when put in the soil media and eventually produce a new ……..quite true to the parent plant.

xii. The budded and grafted plants are generally less vigorous and short-lived than ……...

Answers

i. Stolen
ii. compatible
iii. explant
iv. runner
v. artificial
vi. rhizome
vii. underground
viii. sucker
ix. Layering
x. Grafting

xi. plant
xii. seedlings

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Unit: 6

PHASES OF PLANT GROWTH AND DEVELOPMENT

Written By Dr. Zaid Mustafa
Reviewed By Dr. Qasim Ali
Dr. Muhammad Shahzad

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INTRODUCTION

Growth and development in plants are vital processes driven by metabolic activity, where anabolic processes promote permanent increases in size and weight, while catabolic dominance leads to decline. Growth is influenced by water, oxygen, nutrients, light, and soil quality, while development encompasses the full sequence of changes in the plant life cycle, including differentiation and reproduction. Seeds play a central role in species continuity, acting as containers and protectors of embryos while storing food for germination. Depending on environmental conditions, seeds undergo epigeal or hypogeal germination, establishing young seedlings with the aid of stored reserves. Plant growth patterns vary across annuals, biennials, and perennials, each with distinct survival strategies.

Reproduction begins with floral development, where apical meristems transition from vegetative to reproductive phases. Flowers produce gametes through microsporogenesis and megasporogenesis, leading to pollination and fertilization. Cross-pollination encourages variability and hybrid vigor, while self-pollination ensures reproductive success in bisexual flowers. Double fertilization in angiosperms produces both embryo and endosperm, vital for seed development. Fruits develop under the influence of pollination, hormones, seed presence, and nutrient supply. Processes of maturity, ripening, and senescence follow, with biochemical changes such as ethylene production and climacteric respiration shaping flavor, texture, and market readiness. These interconnected stages—from vegetative growth to fruit ripening form the foundation of plant productivity and horticultural practices.

OBJECTIVES

- To explain the concepts of vegetative growth, development, and factors influencing plant growth
- To describe the structure, functions, and germination types of seeds
- To classify vegetative growth patterns into annuals, biennials, and perennials
- To discuss reproductive structures, floral development, gametogenesis, and pollination mechanisms
- To explain fertilization, embryo development, and fruit formation processes
- To distinguish between maturity, ripening, and senescence in fruits and their commercial importance

LEARNING OUTCOMES

By the end of this unit, students will be able to:

- **i.** Differentiate between plant growth and development, identifying key factors that influence them
- **ii.** Explain the role of water, oxygen, light, soil, and nutrients in sustaining healthy plant growth
- **iii.** Describe seed structure, its functions, and compare epigeal vs. hypogeal germination
- **iv.** Classify plants into annuals, biennials, and perennials, with examples
- **v.** Identify reproductive floral organs and explain processes of gametogenesis in angiosperms
- **vi.** Compare self-pollination and cross-pollination, noting their advantages and disadvantages
- **vii.** Describe fertilization, double fertilization, and subsequent embryo development
- **viii.** Explain patterns of fruit growth and the role of hormones, pollination, and seeds in fruit set
- **ix.** Distinguish between fruit maturity, ripening, and senescence, and relate these to post-harvest practices

6.1. Vegetative Growth and Development

Growth is the product of metabolic processes that take place in the plant. When conditions are favorable, anabolic (constructive) processes are dominant over catabolic (destructive) ones, with the result that there is an overall increase in size. The growth of living plants is actually the permanent deposition of material, which is utilized by the plant to construct new tissues. When conditions are unfavorable, and the rate of catabolic processes is greater than that of anabolic ones, then growth will cease, and the plant will ultimately die. In short, growth is a vital process that brings about a permanent and irreversible increase in size and weight. Some plants exhibit growth that is rapid but restricted to certain parts of the plant only, e.g. the tendrils and some fruits of some members of the Cucurbitaceae family and certain fruits such as okra or lady's finger *(Abelmoschus esculentus),* a member of the Malvaceae family.

Development is the sum of all the changes that an organism goes through in its life cycle, including growth and differentiation. It is an expression of the genetic program that directs the activities and interactions of individual cells.

6.2. Factors Affecting Growth

Adequate water is essential to maintain the turgidity of growing cells, which is basic to growth. Protoplasm is able to work properly only when it is saturated with water. Water is absorbed by the plant roots from the soil and supplied to the leaves through the xylem for the process of photosynthesis. A small amount is utilized by the plants for different processes, including growth, and the rest is lost during transpiration. Oxygen is indispensable for the process of respiration of all living plant tissues, particularly the growing parts. Respiration is a process of oxidation that releases energy, which is utilized for the many activities carried out by living tissues. Growth takes place only when the tissues of growing parts are supplied with nutrients such as carbohydrates, proteins, vitamins, hormones, mineral salts, and micronutrients.

During the initial stages of growth, light is not very essential. Actually, the process of growth takes place more rapidly at night or during darkness than in light. In fact, in some cases, light has an inhibiting effect on growth, for example, the germination of seeds. Plants require a certain rate of light intensity and wavelength to remain healthy and develop normal, sturdy stems and green leaves. The process of photosynthesis takes place during the light and the continuous absence of light is harmful to plants. Plants grown in darkness or in dim light become weak, with yellow or pale green leaves, tall, lanky stems, and a sickly appearance; they rarely produce flowers and fruits. Plants showing the above symptoms are said to be **etiolated.**



Fig 37: Etiolated and non-etiolated plant

For optimum growth, plants require soil suited to their individual characteristics. The texture of the soil is one of its most essential properties. Loam consists of about 40% silt, 40% sand, and 20% clay. The capacity of soil to retain and distribute water depends upon the arrangement of various soil particles. Well-aerated soil is suitable for plant growth because the roots of the plant get sufficient oxygen for respiration. Soils having a low rate of gaseous diffusion hamper the respiration of roots, which has an adverse effect on plant growth. Loam is considered to be ideal for the growth of beneficial microbes and plants. It has the capacity to retain enough water and permits free movement of water without preventing aeration.

6.3. Seed

The seed is one of the most important products of the plant; it maintains the continuity of the species. The seed performs the essential functions as follows:

a. Reproduction. Normally, most flowering plants reproduce through seeds, except those that are vegetatively propagated.

b. Container of Embryo. The seed is a container in which the tree embryo develops and reaches maturity.

c. Protection of Embryo. The embryo remains within the seed and is protected from excess cold, rain, heat, and other natural calamities.

d. Storage of Food. The food material for the growing embryo is stored in the cotyledons or in the endosperm, especially in monocotyledonous plants. Seeds are the most essential source of food for human beings, animals and birds. The members of the family Gramineae (Poaceae) provide cereals such as wheat, rice, maize or corn, sorghum, oats, and barley. The second most important family in this regard is the Leguminosae (Fabaceae). Its members provide protein-containing pulse seeds such as gram, beans, lentils, peas, pigeon peas, mung, and mash. Industrial oil is obtained mostly from castor and linseed. Cottonseed provides oil as well as livestock feed. The seed of the almond *(Prunus dulcis)* is ovate-shaped and is enveloped by a brown-colored seed coat and hard endocarp.

The seed coat consists of two layers fused together. The brown, comparatively thick, outer layer is called the **Testa**, and the thin, whitish, inner one the **tegmen**. On removing the seed coat from the soaked seed, the white fleshy embryo is exposed. It is made up of two fleshy cotyledons and the shoot-root axis, to which the two cotyledons are attached. The part of the axis directed towards the pointed end is the **radicle** (young root), and the portion lying within the two cotyledons is the **plumule** (young shoot) (VanDerZanden, 2008).

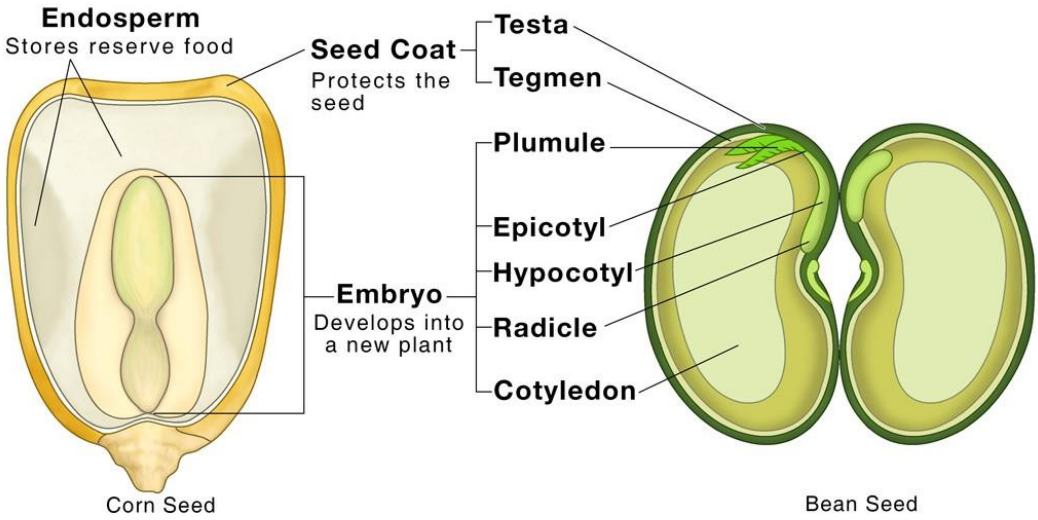


Fig 38: Structure of a seed

6.4 Germination

When a seed is provided with moisture, proper temperature, and air (oxygen), the dormant embryo (young plant) starts growing. This process is called germination. There are several types of germination, but here we are considering only epigeal and hypogeal germination.

6.4.1 Epigeal Germination.

The embryo of the sown seed, for instance, a melon *(Cucumis melo),* absorbs moisture and swells. Pressure develops from inside, due to which the seed coat ruptures and the radicle (young root) first emerges out of the seed coat through the micropyle and goes down into the soil. It becomes the primary root and soon gives out lateral roots and fixes the young seedling in the soil. The portion of the axis below the cotyledons is known as the hypocotyl; this grows relatively fast and pushes the cotyledons *above* the surface of the soil, hence the term *epigeal* germination. Sometimes the ruptured seed coat is also carried along with the cotyledons. When the cotyledons are exposed to sunlight or artificial light, they become green and, through photosynthesis, manufacture food material for the

young seedling. Meanwhile, the plumule elongates and gives out lateral leaves. This type of germination is observed in muskmelons, gourds, luffa, beans, and cucumbers.

6.4.2 Hypogeal Germination.

A fairly fresh mango seed *(Mangifera indica),* presoaked overnight, is sown in the soil. The huge embryo imbibes moisture and the cells of the embryo become turgid. The pressure exerted by this turgidity splits the hard endocarp, which opens at the pointed end. First, the radicle comes out and goes towards the force of gravity in the soil. It establishes itself in the soil by sending out small hairs and lateral roots to absorb water and dissolved mineral salts. The **epicotyl,** the part of the axis situated above the cotyledons, grows rapidly and carries the plumule above the surface of the soil. The large cotyledons, which contain the reserve food material, do not come above the surface of the soil; they remain *underground* (hence the term *hypogea/*germination), providing nutrition to the growing tissue, and ultimately disintegrate. The **plumule** (young shoot) first gives out brownish leaves, which turn green when they are exposed to sunlight and start manufacturing food material like ordinary green leaves. In this way, the young seedling is established. Hypogeal germination is also found in litchi, groundnut, peas, gram, and jackfruit.

6.5 Vegetative Growth Patterns

Herbaceous plants are small plants with soft stems. Generally, they are classified according to their life span as: (1) annuals (2) biennials (3) perennials.

Annuals are those plants that germinate, attain their vegetative growth in one season or survive for a few months or a year, giving out flowers and bearing fruits and seeds within that period. Almost all seasonal flowers, cereals, and most vegetable and edible oilseed plants are annuals. **Biennials** are also herbaceous plants; they complete their vegetative growth in the first year. In temperate climates, they produce flowers, fruits and seeds in the second year, but in tropical climates, they complete their lifecycle in one year like annuals. Carrot, radish, turnip, cabbage, and beet are common biennials of Pakistan. **Perennials** survive for many years. They can be classified into two categories: (1) herbaceous perennials, and (2) woody perennials. Under favourable conditions, herbaceous perennials give out aerial shoots from dormant underground stems like rhizomes, corms, bulbs, and tubers. The aerial shoots, like annual plants, bear flowers and fruits containing seeds. During unfavourable seasons, the aerial parts die, but the underground parts persist and remain alive. When the season again becomes favourable, they will repeat the same pattern of growth. Ginger, turmeric, arrowroot, crocus and saffron tulip are examples of such perennials. Woody perennials may be shrubs or trees. Shrubs are woody, smaller than trees, and

bushy in habit. They give out several equally strong branches without a definite single trunk. They survive for many years. Usually they are grown as hedges, climbers, and ornamental plants, e.g. rose, shoe flower, night jasmine, crotons, duranta, and lantana. Perennial trees are bigger than shrubs and most have a single trunk that bears lateral branches in various patterns. Perennial species, therefore, adopt different shapes. Some grow tall and become cone shaped like casuarina, pinus, cedar, and eucalyptus. Others form a canopy-like crown, like mango, banyan, and peepal.

6.6. Reproductive Floral Organs

Flower has the following organs: **Carpel** or **pistil,** female reproductive organs that contain the **Stigma,** where pollen sticks for pollination, **Style** is the long tube that connects the stigma to the ovary, **Ovary** is an enlarged structure at the base of the carpel/pistil where the ovules are located. On maturation, it will become the fruit. **Ovules** contain the female gametophyte, which becomes the seed (VanDerZanden, 2008).

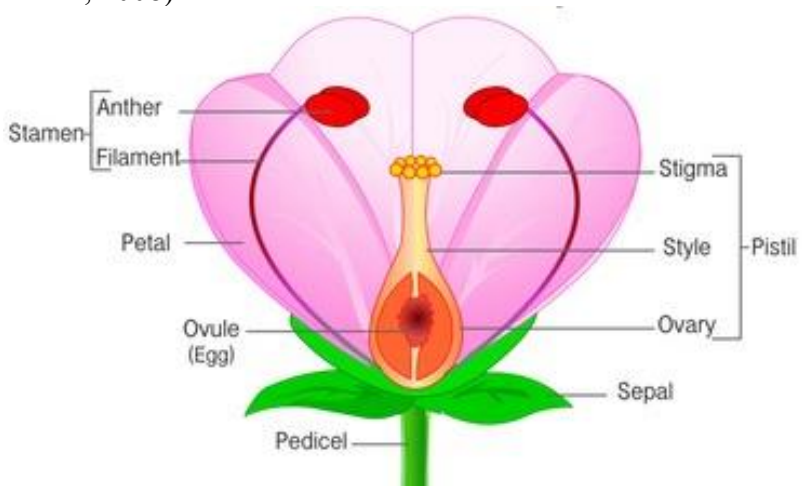


Fig 39: Structure of a flower

6.7 Reproductive Phase

6.7.1 Floral Development

The reproductive phase usually starts when the plant reaches maturity. Most of the apical meristems on the branches cease to initiate leaves and start producing floral parts in accordance with the traits of the species. The formation of flowers is usually the final event during the activity of the apical meristem. In annual plants, the beginning of the reproductive phase is an indication of the completion of the life cycle. In perennial plants, flowering is repeated each season. Flowers may occur at the apex of the main central shoot, at the lateral branches, or on both in the form of solitary blooms or an inflorescence. Flowering does not continue

indefinitely, however, the plant gradually, season by season, flowers, produces fruit, and ultimately reaches senescence. Senescence varies in different plants and depends upon environmental factors and the longevity of particular species. Initiation of lower buds in temperate-region species. The beginning of flower buds in temperate-region fruit species such as apples, peaches, pears, cherries, or plums starts between late spring and late summer during the year preceding the bloom. Flowering starts after the new shoots have reached a certain diameter and a good number of their leaves have matured. The fruit yield depends on the number of buds modified from vegetative to reproductive forms. This state depends on the health of the plant and the nutrition provided to it. Plants that are pruned, supplied with nitrogen fertilizers and heavily watered will generally produce long, fleshy vegetative shoots. Buds appearing on the shoots do not form flower buds for the following year. On the other hand, weak thin shoots, especially on older trees that have low vigour, produce few flower buds, particularly when the number of leaves is reduced by insects or diseases. Serious and lingering drought during the optimum period of bud initiation in the beginning of summer can produce water shortage in the trees, which hampers flower bud formation. A small water deficiency is not harmful; rather, it enhances flower initiation, decreases shoot elongation, and causes carbohydrate storage. It is quite clear that the care fruit plants receive greatly affects their yield. Once the flower parts are fully formed in the buds of deciduous fruit trees, the buds enter a physiological rest period. During that period, they will not open even if the plants are provided with favourable temperature, moisture and light conditions. The same is true for vegetative buds on the same tree which do not differentiate into flower buds. The initiation of this rest period varies with species and depends upon the health of the plant. The beginning of the rest period ranges from midsummer to late autumn. The physiological rest condition probably begins due to the storage of natural growth retardants like abscisic acid and the loss of growth-stimulating agents like gibberellin. Chilling of vegetative and flower buds by freezing temperatures in winter is required for the reversion of the rest effect. When the chilling period is prolonged, bud formation ceases. The advent of warm spring temperatures and sufficient soil moisture stimulates the vegetative and flower buds, which grow with vigour. Initiation of lower buds in subtropical species. In some subtropical fruits like citrus species and olives, flower bud induction and development are quite different. The olive tree *(Olea europaea)* survives in parts of the world where there is a lingering growing season and minimum winter temperatures higher than -9°C. Olive varieties generally thrive well where there are chilling temperatures in winter, and produce a good number of flowers and fruits.

Some freezing days during late winter directly influence the vegetative growing points so that they are modified into flower buds. Without freezing temperatures,

almost all the buds remain vegetative. Because of this plant habit, olive trees are not grown in warm parts of the world.
In the citrus species grown in subtropical environments, flower bud initiation starts in mid-winter and clear evidence of flower parts appears about one month later. In regions where there is a cool summer and moderate winter, some varieties of citrus bear flowers throughout the year, but the most prolific blooming is in spring. In tropical regions close to the equator, citrus flower buds initiate and bloom throughout the year. This applies to citrus fruit such as oranges, lemons, and pomelos. For these fruits, freezing temperatures during winter is not required to break bud dormancy. Initiation of flower buds in some tropical fruit species. The beginning of flowering in mango *(Mangifera indica)* appears to depend on environmental factors that retard growth, like a lengthy dry or cool period. Hormones produced in the leaves are transported to the shoot to initiate flowering in the buds. This begins in late winter or early spring. The initiation of flowers in pineapple plants *(Ananas comosa)* can be brought about by applying ethephon to the growing points, which liberates ethylene. In this case, the induction of flowering is stimulated by the hormone. The initiation of flowering in coffee trees *(Coffea arabica)* begins with the appearance of the flower primordia. The flowers bloom almost one month later. The period of flowering depends upon the environmental conditions prevailing at that time. After a long dry period, flowering begins within one month after the start of the rains. With sufficient soil moisture and favourable growing temperatures, flowering and fruiting take place intermittently throughout the year.

6.7.2 Flower Morphology.

The flower is the reproductive phase of the plant, which is responsible for the production of fruit and seeds. Parts of the flower generally include calyx (sepals), corolla (petals), androecium (stamens) and gynoecium or pistil (carpels).

6.7.3 Gametogenesis.

Gametogenesis is the formation of male and female gametes in the flower. The process of gametogenesis varies significantly among major classes of plants. It comprises two processes: (a) microsporogenesis and (b) megasporogenesis. In angiosperms, **microsporogenesis** takes place in the anthers of flowers. In the beginning, some central cells of the pollen chamber or pollen sac are activated; these cells are called microsporocytes or pollen grain mother cells and are diploid (2n). The nucleus of each microsporocyte enlarges, and meiosis or reduction division takes place. Two nuclei are formed, each of which has half the number of chromosomes of the original cell [haploid (n)], Immediately after this, the two newly formed nuclei divide mitotically and form four nuclei, but this time the number of chromosomes is not reduced; each has a haploid (n) number of

chromosomes. A cleavage of the cytoplasm develops, separating the four nuclei into four clear compartments or pollen cells. The original one of the pollen mother cell degenerates. Each pollen cell gets nourishment from surrounding tapetum cells and develops a thick outer wall called the exine and a thin inner wall known as the intine. Meanwhile, the nucleus of each pollen grain again divides mitotically and two nuclei are formed. One of these is called the vegetative nucleus or tube nucleus, and the other is known as the **generative nucleus**. In this form, the mature pollen grains are released from the anther when dehiscence takes place. The formation of pollen grains or microspores in the above manner is called **microsporogenesis**.

The type of development that takes place in the female part of the ovule (ovary) to give rise to female reproductive cells within the ovule is known as **megasporogenesis**. Inside the ovule at the early phase of the development of the nucleus, one of the cells of the leonucleus becomes active and larger than the other cells. It is called the megasporocyte or embryo sac mother cell, and is diploid (2n). Meiosis takes place and it divides into two cells, each containing a haploid number of chromosomes (n). The two newly formed cells now divide mitotically, i.e. their chromosome number remains haploid (n). In this way, a vertical row of four haploid cells called megaspores is formed. After this, the upper three disintegrate, but the lowest one survives and becomes the embryo sac. Its nucleus divides three times mitotically and eight haploid nuclei are formed. Three of these migrate towards the chalazal end and are known as antipodal nuclei or cells. Another three go towards the micropylar end. Of these three, the central one becomes the ovum or egg or female gamete, and the two lateral ones are called synergids. The remaining two nuclei fuse in the middle of the embryo sac and form the polar nuclei, which fuse and form a diploid nucleus (2n).

6.8 Pollination

The transfer of pollen grains from the anther to the stigma by a pollinating agent is called **pollination.** There are two main mechanisms of pollination:(a) autogamy or self-pollination, and (b) allogamy or cross-pollination. **Autogamy or self-pollination.** Pollination occurring within a hermaphrodite or bisexual or perfect flower, or between two such flowers situated on the same plant of the same variety or cultivar, is known as self-pollination. **Allogamy or cross-pollination.** The transference of pollen grains by pollinators such as bees, butterflies, moths, wind, water, squirrels, birds, bats, sand animals, or even humans from the anther of one flower to the stigma of another flower situated on a different plant of the same species, or on cultivars of related species, is called cross-pollination. Two parents are involved in this process, and two different haploid (n) sets of chromosomes are brought together. In this process, the combination of two sets of parental traits or characters is possible. The production of hybrid offspring is thus

possible and probable. In comparison to inbreeds, hybrids are healthier and higher yielding; therefore, horticulturists use this method to get new varieties or cultivars of fruits, flowers, and vegetables. Insect-pollinated plants generally have showy, coloured flowers, scent, or nectar, e.g., queen of the night, jasmine, rangoon creeper, poinsettia, larkspur, salvia, snapdragon, and garden nasturtium. Wind-pollinated plants usually do not have showy flowers and do not possess scent. The anthers produce pollen grains in great quantity. These pollen grains are light in weight and dry, so that they are carried easily by the wind to great distances. Papaya, maize or corn, date palm, and coconut are wind-pollinated species. Water-pollinated plants generally have large flowers and leaves that float on the surface of the water. The female stigma receives floating pollen grains, as in the water lily and giant water lily, while animal and bird-pollinated plants usually have abundant nectar. Bats, squirrels, and birds visit flowers for nectar, and pollen grains stick to their bodies. When they go from one flower to another and from one plant to another, pollen grains are carried from one plant to another and cross-pollination takes place. The silk cotton tree, coral tree, and rose apple are pollinated by animals.

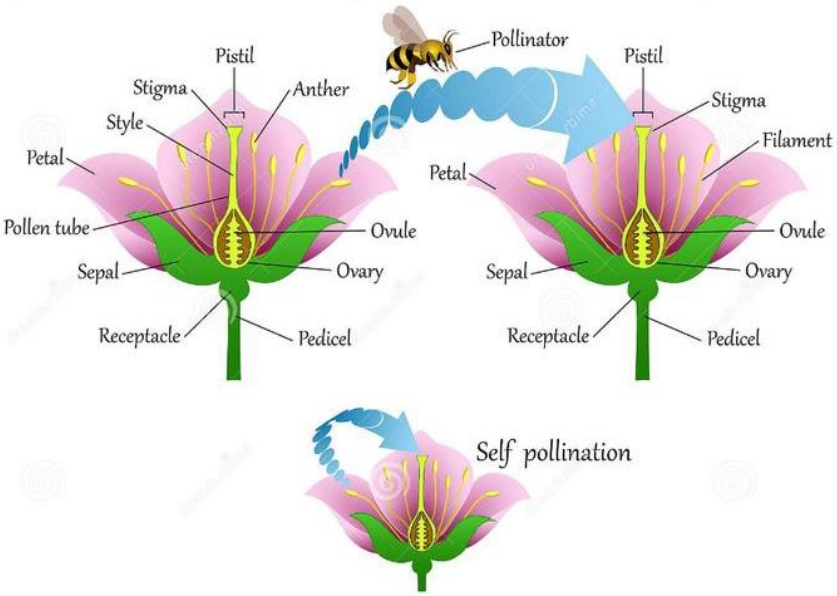


Fig 40: Pollination

Advantages and disadvantages of self and cross-pollination

Self-pollination has the advantage that it takes place in bisexual flowers, where both male and female parts mature at the same time and there is a great possibility of fertilization and fruit formation. There are a number of suggested advantages of cross-pollination.

(i) Hybrids possess greater adaptability to the environment.
(ii) (ii) They have better germinating ability.
(iii) (iii) Offspring produced are more capable of surviving.
(iv) (iv) Variation is increased.

Disadvantages are:

(i) In self-pollinating species, the vigour of the offspring may decrease generation by generation.
(ii) (ii) There is a possibility that pollination may fail to occur.

6.9 Fertilization and Development

a. Fertilization

Fertilization is the union of male and female gametes (sperm and ovum). After the transfer of pollen grains to the receptive stigma, they are invigorated, and the inner wall (in tine) of each starts growing through one of the germ spores and forms a pollen tube. The receptive stigma secretes a viscous sugary substance that accelerates the growth rate of the pollen tube inside the style. It carries the tube nucleus and the generative nucleus. The vegetative or tube nucleus disintegrates, and the generative nucleus divides mitotically into two male gametes or sperms. In some cases, the generative nucleus divides even before pollination. The pollen tube generally grows and goes towards the micropylar end of the ovule, carrying the two male gametes through the micropyle into the embryo sac. The tip of the pollen tube dissolves, setting free male gametes inside the embryo sac. One of them fuses with the egg or ovum (n); this is known as fertilization. The fertilized ovum becomes diploid (2n) and eventually develops into the embryo (young plant) of the second generation. The other male gamete unites with the polar nuclei (2n) and becomes triploid (3n). The union of the second male gamete with the polar nuclei is known as **double fertilization**. These three nuclei collectively develop into the endosperm, the food for the young embryo. Meanwhile, the synergids and antipodal nuclei degenerate. The actual function of these is not yet fully understood. The whole ovule ultimately develops into the seed of the second generation and the ovary into fruit. In some cases, other parts of the flower, especially the receptacle, also grow along with the ovary and form the fleshy edible part of the fruit. Sometimes the fruit is formed without fertilization; this process is known as **parthenocarpy** and such a fruit is called **parthenocarpic fruit**. Such fruits do not contain seeds, like some banana cultivars, grapes, mulberries, and pineapple (Moore and Bradley, 2022).

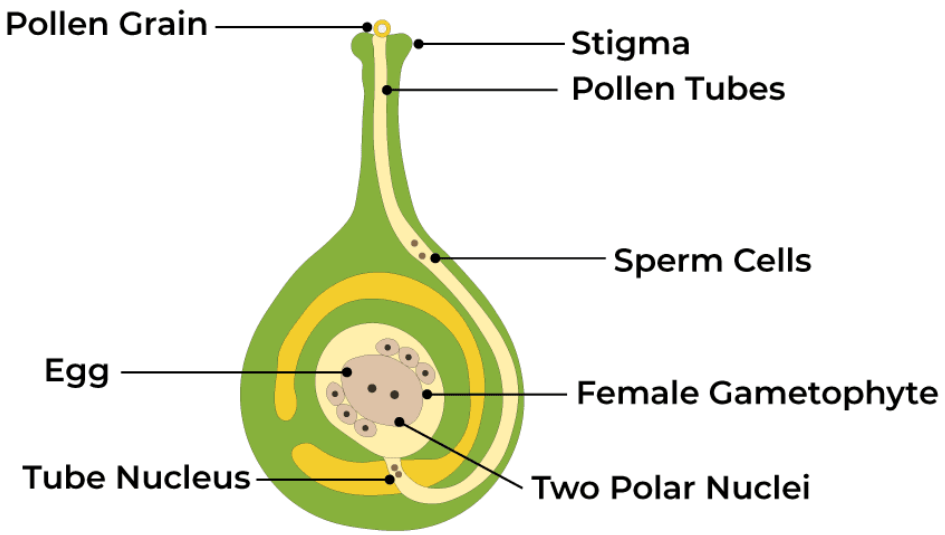


Fig 41: Fertilization in plants

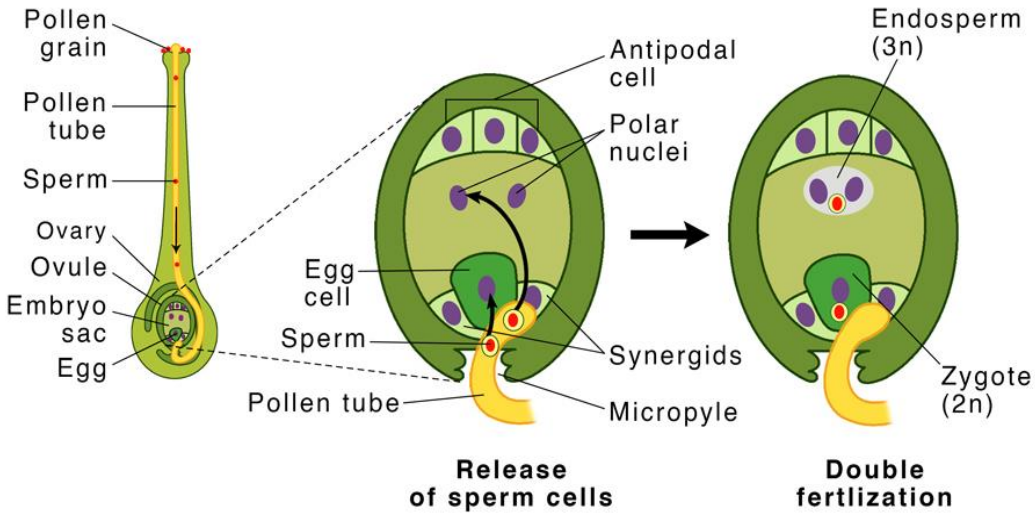


Fig 42: Double fertilization in plants

b. Development of the embryo

In dicotyledonous plants, when the processes of fertilization and double fertilization are over, the fertilized ovum is covered by a cellulose wall and

becomes a zygote. The zygote remains inactive for several days inside the endosperm. Essential changes, such as the synthesis, multiplication, and organization of ribosomes; a decrease in the size of the vacuoles; formation of the endoplasmic reticulum; and other changes in cell organelles, appear to make the zygote ready for intensive metabolic activity. It then divides mitotically into two upper and lower cells. The lower cell divides in one plane, forming a row of cells called the suspensor. The suspensor becomes larger, penetrates deeper into the endosperm, and obtains food material for the developing young embryo. During the subsequent processes of development, the suspensor becomes disorganized. The upper cell is known as the embryonal cell. It increases in size and divides mitotically into three planes, forming eight cells. Four of these cells divide and form the posterior octant, and the other four cells opposite the micropylar end form the anterior octant. Each octant then divides, by a wall parallel to its curved surface, forming a superficial layer of cells and a central mass of cells that forms an embryonal mass. The superficial cells divide radially only and form a single layer of the root apex and stem apex. The embryonal mass tissue divides further, forming various tissues, each of which differentiates into a specialized part of the embryo, such as the plumule, two cotyledons, the hypocotyl, and the radicle.

Further cell divisions of the stem apex give rise to a globular mass of cells filled with cytoplasm. Its surface cells form the protoderm, which is the precursor of the epidermis. The central core of cells becomes elongated and forms the precambium, which is the beginning of the vascular system. The remaining cells in the center of the globule divide actively and give rise to the ground tissue system. The differentiation of tissues and organ formation begins with the appearance of the cotyledons. The initial embryo becomes almost heart-shaped. At the central position of the two cotyledons, a cluster of cells becomes organized and gives rise to the apical meristem. Another cluster of cells at the opposite side of the embryonic axis forms the root meristem. These two meristems are situated in a position inside the endosperm that permits their continuous growth. Vitamins, auxins, and cytokinins needed for the normal development of the young embryo are provided by the endosperm. The apical meristem of the shoot gives rise to new organs and tissues,such as the shoot apex and young leaves. The initial leaves are close to each other because the internodes are short. The leaves are situated at regular intervals surrounding the stem. In due course of time, the shoot is exposed. Under a microscope, it looks like a dome-shaped mound or a flattened cone, or in angiosperms, depressed in shape like a saucer. When a longitudinal section is observed under a microscope, this region appears very organized. One or more layers of cells cover the surface, and in the axils of the leaves, the primordia and small pockets of meristematic tissues are visible. These develop into small shoot apices and eventually into axillary buds. The arrangement of cells is more regular in the root apex than in the shoot apex, with clearly defined layers

which correspond in number and arrangement to the regions of the mature root. The apices of the root and shoot possess sufficient food material for growth. The root apex controls its own activity and has the potential of forming the mature root (VanDerZanden, 2008).

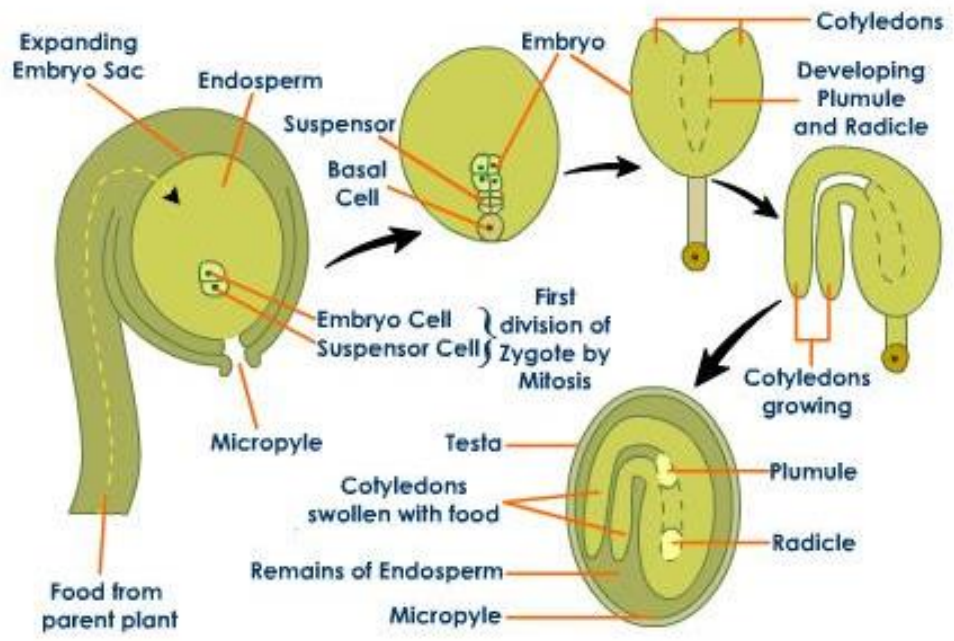


Fig 43: Development of the embryo in plants

The modification of vegetative primordia into reproductive primordia is brought about by complex biochemical changes that are not fully understood. This mysterious change alters the mode of differentiation from vegetative bud and stem tissues to the tissues that form the reproductive organs, such as gynoecium (pistil) and androecium (stamens) and accessory parts of the flower, like sepals and petals. When a meristem is being altered from the vegetative to its productive form, microscopic modifications in its structure become visible. This structural change is permanent and flower formation continues until the flower is fully mature. At this juncture, the flower is ready for the development of the fruit. There are two main patterns of endosperm development: (i) nuclear, and (ii) cellular.

i. **NUCLEAR PATTERN.** In this pattern, a triploid (3n) endosperm nucleus divides a number of times without corresponding cell-wall formation. As a result, several hundred nuclei are generally formed, and a large vacuole is developed in the embryo sac. Cytoplasm along with nuclei are pushed towards the border of the

embryo sac and the nuclei are almost uniformly distributed. Cell wall formation is centripetal, and in this way, a mass of cells is formed, each of which has a nucleus and a cell wall and is filled with food substances. This accumulated mass of cells is known as the endosperm. It grows and fills up the embryo sac.

ii. CELLULAR PATTERNS. In this pattern, a triploid (3n) endosperm nucleus divides several times, forming numerous nuclei, and around each nucleus a cell wall is formed. The wall may be longitudinal, transverse, or oblique, depending upon the plant species. In this way, numerous cells are formed, each having a nucleus and food materials. The tissue of the seed is called endosperm. In non-endospermic seeds such as garden peas, French beans, gram, sunflower, mango, orange, and guava, the cotyledons store up the endosperm and become thick and succulent, while in endospermic seeds such as papaya, palm, lilies, custard apple, four o'clock plant, wheat, maize, rice, and barley, there is a separate chamber surrounded by the seed coat and fruit wall (pericarp). The accumulated food, whether it is in the cotyledons or in the endosperm, is utilized by the embryo during germination. The two integuments of the ovule change into the two parts of the seed coat: the outer one becomes the testa and the inner one the tegmen. In some plants, such as the four o'clock *(Mirabilis jalapa)* and coffee, the nucleus also survives and develops into a nourishment-providing tissue like endosperm which is known as periderm. The coffee bean consists of periderm tissue. The ovule finally becomes the seed and the ovary the fruit.

6.10 Fruit Growth.

The treatment of fruit growth here is mostly restricted to succulent, fleshy fruits because of their horticultural and commercial importance. Generally, the growth of fleshy fruits adopts two patterns. In one set of fruits like tomatoes, apples, pears, and lemons, cell division and cell enlargement are rapid in the beginning and gradually slow down as the Fruit approaches maturity. The other group of fruits, e.g. mangoes, plums, Indian plums, pears, and apricots, exhibit continuous cell division at the initial stage, slow down during stone (endocarp) formation, and again resume continuous cell division and enlargement until the fruit matures. In some cases, like apples and pears, some accessory parts, like the receptacle, also grow along with the fruit. These form the succulent edible part of the fruit and contain more intercellular spaces than other parts of the fruit. The period of growth varies in different types of fruits, generally ranging from four to five months. Fruit development is regulated by numerous internal and external factors. The most important among them are the pollination effect, fertilization effect, and development of the embryo and seed. Growth-regulating substances such as hormones, auxins, gibberellins, and cytokinins greatly influence fruit size and

weight. Their action on growth is mostly physiological; it varies in different types of fruits and is very complex.

Pollination is one of the most essential steps in fruit development. It performs two separate functions: one is the procurement of male gametes or sperm necessary for fertilization; the second is the provision of an enzyme that alters auxin precursors available in the stigma into auxins. The growth of the pollen tube inside the style is affected by the availability of proper osmotic concentration and is also accelerated by the presence of certain inorganic chemicals like manganese sulphate, boron, and calcium. The presence of sugary substances secreted by the female organs enhances the growth of the pollen tube. When the pollen tube does not grow rapidly inside the style, abscission of the entire flower and ultimately the failure of fruit development are likely. This is generally overcome by the application of CL-naphthalene acetamide, one of the set of auxins. There is an interesting phenomenon known as **metaxenia.** The term refers to the direct effect of pollen grains on the female tissues of the ovary of a related cultivar of the same species. This inference is based on the observation that the hormone content of the ovary increases after pollination.

In some fruits and seed coats, the skin colour is observed to be affected by the source of pollen; this happens with fruits of the Cucurbitaceae family, for example. In oranges, the colour and flavour of the fruit are influenced by the pollen parent. In dates, the size and the time of ripening are influenced by the kind of pollen. Meta xenia differs from **xenia,** the direct influence of pollen grains on endosperm tissue colour, observed in maize, for example.

The development of the fruit is also affected by a stimulus from the developing seeds within the fruit. Uneven distribution of seeds causes irregularly shaped fruits. In fruits such as tomatoes and strawberries, a direct relation exists between the number, weight, and size of seeds. With strawberries, for example, if all the achenes except one are removed, the receptacle tissue that is immediately below that particular achene enlarges. When more than one achene is present, only the portion of the receptacle tissue that has achenes will develop. The growth-inducing effect of the seeds can be restored in the seedless part of the receptacle by the application of auxins. With tomatoes, when the liquid extract obtained by squeezing pollen grains or immature seeds is applied to the stigmas of unpollinated pistils, it accelerates fruit growth. This effect of pollen or seed extract can be duplicated by applying a paste containing an auxin. The stimulating effect of seeds or pollen on the growth of other fruits, such as peppers, eggplant, and figs, is also altered by the application of auxins. In addition, fruit setting is stimulated in grapes, apricots, apples, and pears by the use of gibberellin. Similarly, cytokinin enhances fruit setting in grapes.

Auxins are usually used with apples, grapes, and pears; they are especially effective on the stone fruits like peaches, apricots, olives, plums, and cherries.

The extent of action is related to the concentration of the chemical applied, the stage of development of the fruits, the variety or species, and the temperature and humidity prevailing at the time of application. The adequate availability of nutrients and moisture at appropriate stages of development greatly influences the number and size of fruit. For example, it has been calculated by horticulturists that on a healthy mature apple tree, about 40 leaves provide sufficient nutrients for the normal growth of one apple. When this ratio is abnormally altered, the quality and size of fruits are affected. If the number of fruits is high, their size will be reduced. Therefore, fruit growers generally artificially reduce the number of fruits in order to maintain size and quality. This reduction of crop load is called fruit thinning. Crop bearing may also be decreased with chemicals. However, the mode of action of chemicals such as naphthalene acetic acid (NAA) and its derivatives is not clearly understood. Probably it retards the process of fertilization, or causes inhibition of embryo development or abortion of the embryo after fertilization. The result is natural fruit thinning.

6.11 Maturity, ripening, and senescence

a. Maturity. Maturity and ripening are two separate processes. Maturity of fruit is the final stage of development that must take place when the fruit is still attached to the mother plant. The enlargement of cells and storage of carbohydrates is taking place. Aroma and taste-producing substances are being accumulated, and acidity is decreasing. Generally, the fleshy edible portion is not yet softened.

b. Ripening of fruit involves certain biochemical changes that take place in the fruit after full maturation. The softening of the edible portion is near completion. Production of the fruit's characteristic aroma and sweet juice increases. Ripening may take place before or after harvesting. For example, a popular grafted mango variety, Sindri, grown in Sindh, is usually harvested before it is ripe on the tree. Generally, the fruit is considered to be mature and ready for harvesting when one or two naturally ripe, yellowish mangoes drop from the tree. The harvested mangoes are mature, but are still green, sour, hard, and not ready to be eaten. The harvested green fruit is kept in wooden crates or porous new earthen pots between layers of wheat or rice straw, hay, grass, old newspapers, etc. These crates or earthen pots are stored in closed storage rooms for ripening, which is usually complete in a week. The ripened fruit possesses an attractive yellow colour and aroma, and becomes sweet, juicy, and tasty; at this point, it is brought to market and fetches a good price. Generally, Sindri mangoes are transported to big cities like Karachi, Lahore, Hyderabad, and Islamabad, and exported to the Middle Eastern countries, packed in wooden crates in the above manner. Non-grafted varieties of mango are harvested for making pickles before maturity, when the endocarp (stone) becomes hard.

Ripening. Physiological changes indicate the termination of the mature stage and the initiation of senescence of the fruit. The period in which a number of specific biochemical changes a significant and abrupt increase in natural respiratory rate, and autocatalytic production of ethylene, take place before senescence is called the **climacteric**. After the climacteric, the rate of respiration again decreases and reaches a level equal to or less than the rate prevailing before the climacteric. For example, in some varieties of apple, pear, and banana, the pigment changes from green to yellow. The ripening of pears synchronizes with the end of the climacteric. With apples and bananas, the stage of ripening at which the fruit is best to eat is reached immediately after the climacteric.

There are different views regarding the climacteric increase in the rate of respiration. One idea is that the acidity of the tissue cytoplasm decreases to a critical stage that increases the permeability of the cell membrane. Thus, fructose already stored in the vacuoles possibly enters the cytoplasm and becomes available for the enhanced rate of respiration. A second view is that adenosine diphosphate (ADP) and adenosine triphosphate (ATP) play a role in energy production during respiration. A portion of energy is kept for the chemical change of ADP to ATP. It is supposed that during fruit maturation, cells enlarge quickly and require more energy for protein synthesis; as the fruit matures, ADP is readily made available for the increased rate of respiration.

Temperature has a significant effect on fruit maturation and the climacteric. For example, the rate of respiration of the apples at 22°C is five times more than that of those at2°C; and the time required to reach climacteric is 25 times more for the apples kept at 2°C. Fruit ripening is a DNA-regulated activity similar to other plant development processes. There is an increase of RNA and enzymes such as hydrolase, synthetase, and oxidase in climacteric fruits. Ethylene plays an active part in fruit ripening and accelerates the process; ripening can be retarded by the removal of ethylene from the tissues of pre-climacteric fruits. However, the mode of action of ethylene on fruit ripening is not fully understood.

c. Senescence. Senescence is a physiological aging activity in which plant tissues degenerate and ultimately die. The activity is one of the most mysterious plant growth processes, and takes place in almost all organs of the plant. It can be considered under two categories: partial senescence and complete senescence.

d. Partial senescence. Partial senescence involves the degeneration and death of aerial plant parts like leaves, branches, flowers, and fruits, but not underground plant parts e.g. the deterioration of cotyledons after germination, observed in almost all plants. With deciduous plants in unfavourable seasons, especially in winter, the leaves fall. In the commercially important woody perennial shisham or *tali (Dalbergia sissoo),* the leaves become senescent, die, and fall off in winter. The rest of the plant survives, gives out new leaves in spring, and bears flowers and fruits in the ensuing summer. Shoots of herbaceous perennial plants die

during unfavourable seasons, but the underground parts survive and remain viable in the soil. This happens with the corms of taro *(Colocasia esculenta),* gladiolus, crocus *(Colchicum autumnale),* tubers of potato *(Solanum tuberosum),* and Jerusalem artichoke *(Helianthus tuberosus);* the bulbs of onion *(Allium cepa),* garlic *(Allium sativum),* and lilies; and the rhizomes of turmeric, ginger, and arrowroot.

e. Complete senescence. This is the aging process in which all parts of the plant except the seeds ultimately die. It is observed in almost in all cereals, pulses, vegetables, and ornamental seasonal flowers. In other words, annual or seasonal plants complete their life cycle after the maturity of their fruits or seeds. In perennial shrubs and trees, a gradual aging process takes place. Their older organs degenerate and ultimately die, and new shoots arise, mature, and bear flowers and fruits. In this manner, plants survive for many years. In addition, some perennial woody plants are invigorated by severe pruning and by the provision of fertilizers to stimulate the growth of adventitious buds around the pruned branches. For example, in ber *(Zizyphus mauritiana),* after the fruiting season is over in late spring, the old branches are pruned in early summer. New adventitious buds arise around" the pruned branches in summer, mature in late summer to autumn, and bear flowers in the form of inflorescence in the axils of new leaves on current shoots in the ensuing winter. Therefore, in this plant regular pruning is necessary to induce healthy growth and obtain maximum fruit yield. Considerable study has been done on the senescence of different parts of plants, especially on abscission of leaves. It is thought that during senescence photosynthesis, starch, chlorophyll, DNA, RNA, proteins, gibberellins and auxins decrease. There are different hypotheses regarding the cause of the senescence of annual or seasonal plants. The most important relates to the quantities of nutrients produced by the plants during various activities. A considerable amount of nutrition is consumed during flowering, fruiting, and seed formation. Therefore, after these processes take place, the plants deteriorate and finally die due to a lack of sufficient nourishing substances.

6.12 Self Assessment Questions

Fill in the blanks with appropriate words.

i. ……. is the sum of all the changes that an organism goes through in its life cycle, including growth and differentiation.

ii. During the initial stages of growth, …… is not very essential.

iii. The …… is a container in which a tree embryo develops and reaches maturity.

iv. The transfer of pollen grains from the anther to the stigma by a pollinating agent is called …….

v. The seed is one of the most important products of the plant; it maintains the continuity of the……..

vi. When a seed is provided with moisture, proper temperature, and air (oxygen), the dormant embryo (young plant) starts……...

vii. ……. survive for many years

viii. The union of the second male gamete with the polar nuclei is known as……..

ix. The type of development which takes place in the female part of the ovule (ovary) to give rise to female reproductive cells within the ovule is known as ……

x. Ovules contains female……..., becomes the seed.

Answers

i. development
ii. light
iii. seed
iv. pollination
v. species
vi. growing
vii. Perennials
viii. double fertilization
ix Megasporogenesis x. gametophte

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Unit: 7

SYSTEMS OF PLANTING ORCHARDS

Written By: Dr. Zaid Mustafa
Reviewed By: Dr. Ayesha Maryam

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INTRODUCTION

Orchard layout refers to the systematic arrangement of plants in the field to maximize productivity and facilitate management. A suitable planting system should ensure optimum plant population, adequate space for tree growth, easy cultural operations, and effective supervision. Several systems of orchard planting are adopted depending on crop type, land conditions, and management goals. The most common system is the square system, where equal spacing is maintained between plants and rows, making it simple, long-lasting, and easy for intercultural operations, though it leaves unused space initially. The rectangular system allows more plants per unit area and better light penetration, but it is less suited for long-term plantations. The hexagonal system accommodates 15% more plants than the square system and permits cultivation in three directions, though it is complex to lay out.

Other systems are modifications that maximize land use. The quincunx system adds filler crops in the center of squares to utilize empty space and provide early returns, though fillers may later compete with permanent plants. The triangular system enables 50–60% more plants per acre than the rectangular system, but it can cause crowding in later stages. On hilly and undulated terrain, the contour system is followed, where trees are planted along contours to prevent erosion and conserve soil moisture. Thus, orchard planting systems balance between land efficiency, ease of management, crop requirements, and long-term sustainability.

OBJECTIVES

- To explain the importance and principles of orchard layout and planting systems
- To describe the characteristics, advantages, and limitations of different planting systems
- To analyze how planting systems influence plant population, orchard management, and productivity
- To highlight the suitability of different systems for plains, fertile lands, and hilly areas

LEARNING OUTCOMES

By the end of this unit, students will be able to:

- **i.** Define orchard layout and explain its role in maximizing yield and orchard efficiency
- **ii.** Differentiate between square, rectangular, hexagonal, quincunx, triangular, and contour planting systems
- **iii.** Compare the advantages and disadvantages of each planting system in relation to crop and site conditions
- **iv.** Evaluate the impact of planting systems on intercultural operations, light penetration, and crop longevity
- **v.** Recommend suitable planting systems for plains, fertile irrigated lands, and sloping hilly terrains

7.1. Systems of Planting Orchards

A number of different systems for planting orchards are used with respect to different crops and the requirements of the orchard (Harendra, 2024). The arrangement of plants in the orchard is known as lay-out. The following points need to be considered before choosing a planting system and its layout.

1. It should accommodate the maximum number of plants per unit area.
2. It should allow sufficient space for the development of each tree.
3. It enables equal distribution of area under each tree.
4. The intercultural operations, such as ploughing, spraying etc are easily carried out.
5. It makes supervision easy and effective.

First of all, laying out is done on paper and then practically in the field. At first, seedbeds are produced/prepared very carefully and then plants are transplanted in a suitable system of plantation. There are the following different planting systems which can be used in a given site.

a. Square System
b. Rectangular System
c. Hexagonal System
d. Quincunx System
e. Triangular System
f. Contour System

7.2 Sequence System

It is the basic system of layout. In this system, plant-to-plant and row-to-row are kept equal (the same). Plants are planted at each corner of each square, regardless of the planting distance. It is the most desirable system for long-lived permanent trees of important fruits like mango, citrus, guava, apple, or pear and is mostly followed in the plains areas of Pakistan. The advantages and disadvantages of this system are as follows

Advantages

1. Most commonly followed and simplest of all and easy to lay out.
2. Plants will live for a longer period of time.
3. There is a possibility of intercropping in two directions.
4. Cultural operations like fertilization, pest control, spraying, irrigation etc., are easy to perform.

Disadvantages

1. Some space in the early stages is left unutilized.
2. Fewer trees in one acre

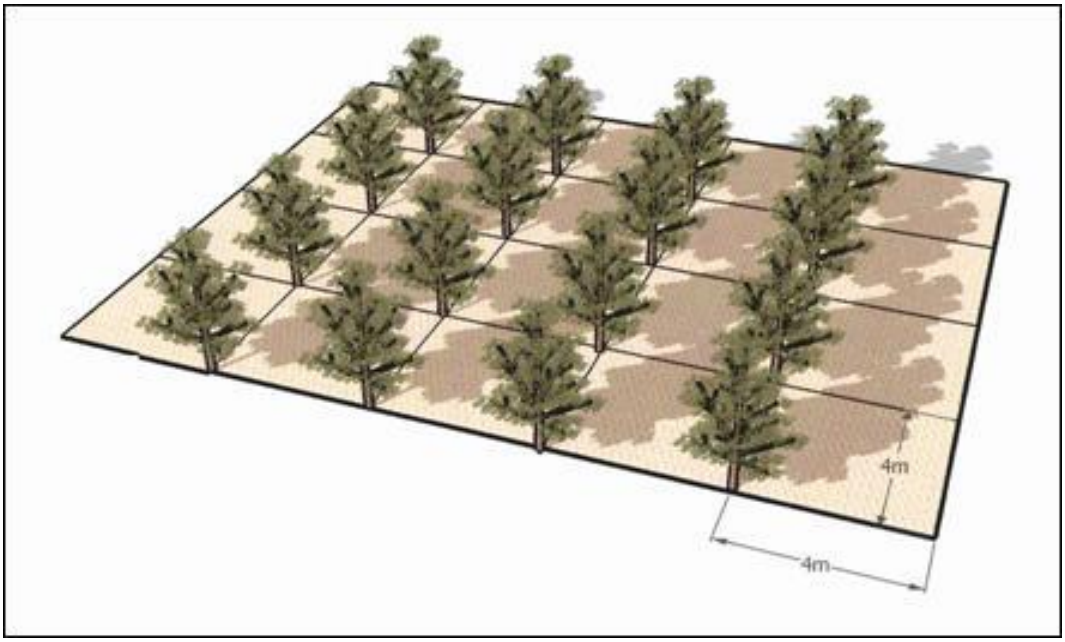


Fig 48: Square System

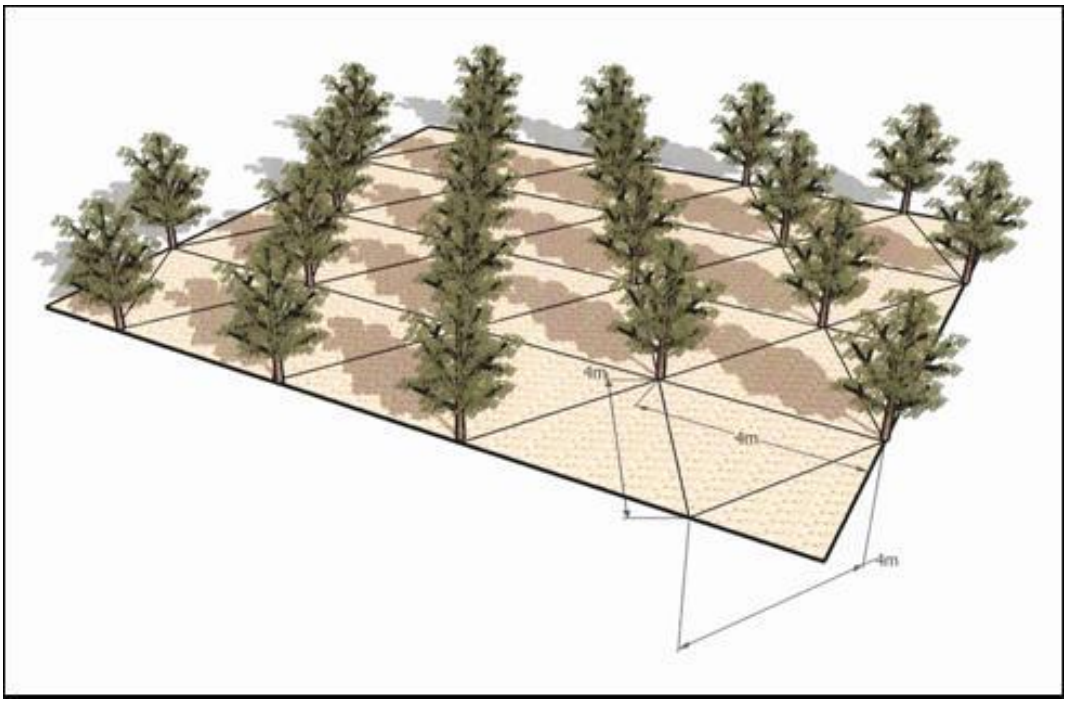


Fig 49: Rectangular System

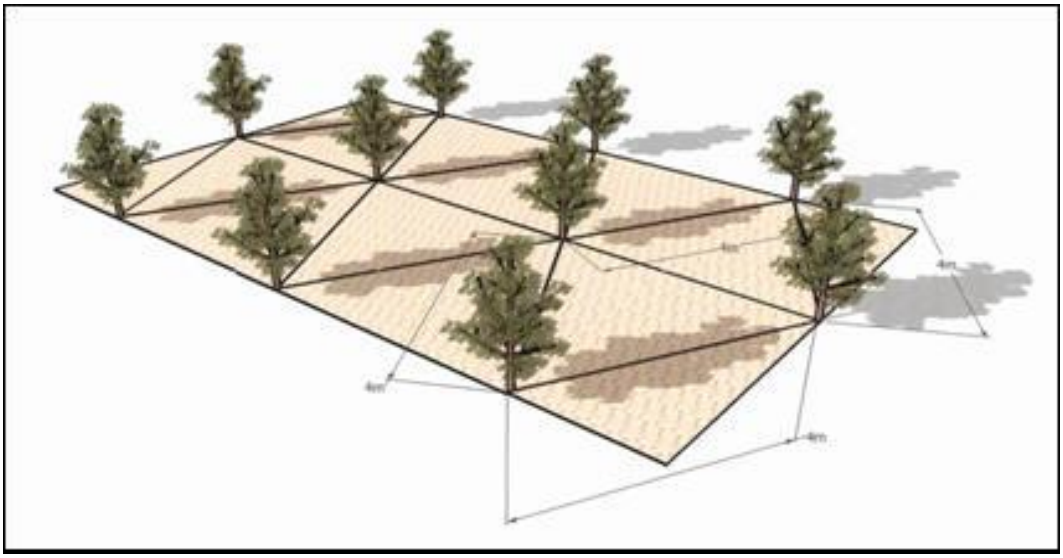


Fig 50: Hexagonal System

1. crop is allowed to continue after the growth of the main crop.

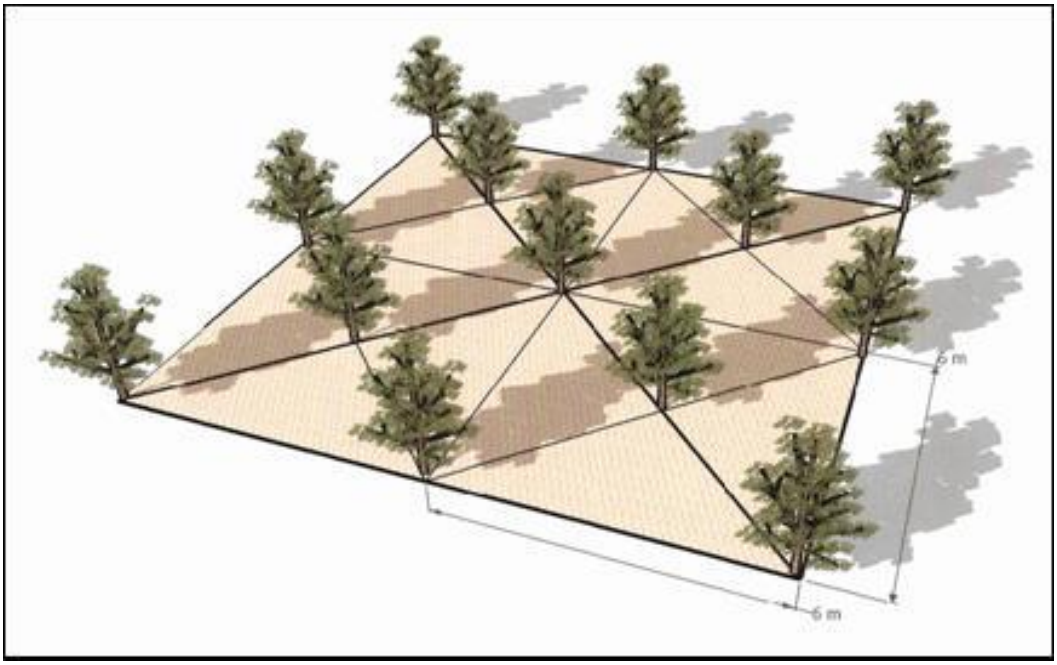


Fig 51: Quincunx System

1. It is not a popular system of layout

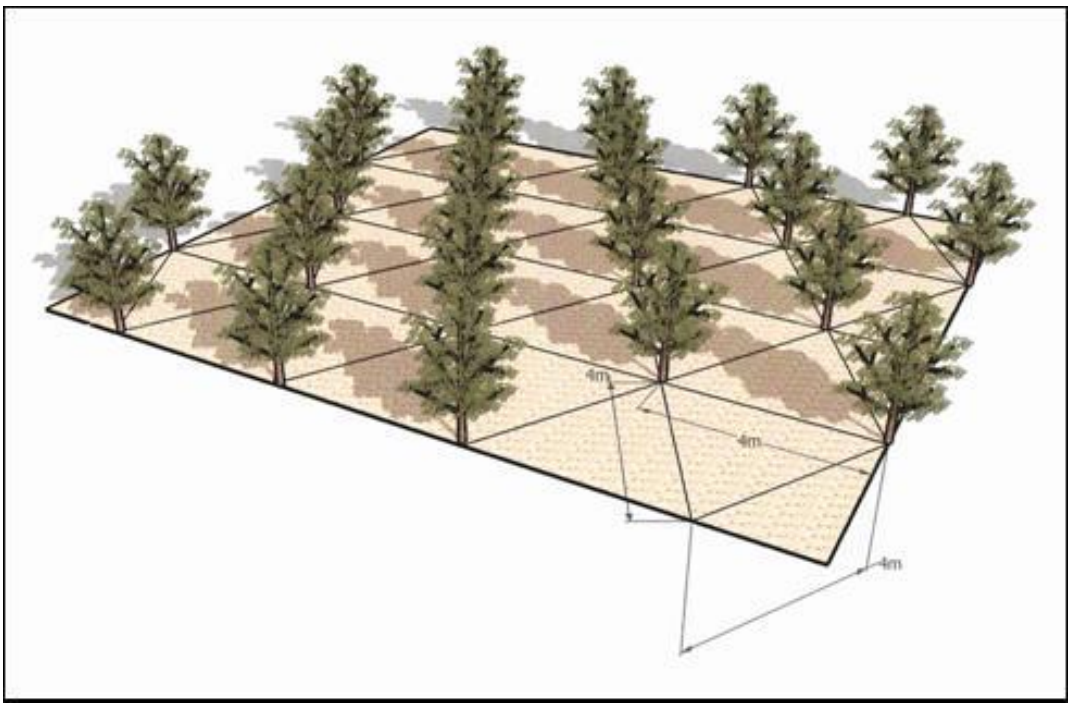


Fig 52: Triangular System

7.3 Rectangular System

It is similar to the square system, except that the distance between plants in the row and the distance between rows are not the same, but different. Row- to -row distance is more than that from plant to plant in the row. The advantages and disadvantages of this system are as follows.

Advantages

1. The number of plants per unit is increased, which results in maximum return in the early years of plantation.
2. An irrigation channel can be made lengthwise and breadth-wise.
3. Light can penetrate into the orchard through the large interspaces between rows.
4. Intercropping is possible.

Disadvantages

1. It is not good for long-term plantations.
2. Crowding will occur on two sides of the plants.
3. Only one way cultivation is possible.

4. When plants intermingle with each other, it is recommended to harvest (uproot) every alternate plant or perform processing operations.

7.4 Hexagonal System

This is also called an equilateral system. Sometimes a seventh tree is planted in the center of the hexagon, and then it is called the septule system. In this system, the trees are planted in each corner of the equilateral triangle. This system differs from the square system in which the distance between the rows is less than the distance between the trees in a row, but the distance from tree to tree in six directions remains the same. This system is usually employed where land is expensive and is very fertile with good availability of water. The advantages and disadvantages of this system are as follows.

Advantages

1. 15% more plants can be accommodated as compared with the square system
2. Cultivation can be done in three directions
3. More income can be obtained

Disadvantages

1. It is difficult to layout
2. Intercultural practices could be difficult
3. Fillers cannot be planted

7.5 Quincunx System

This is the modification of a square system of layout designed to make use of the empty space in the center of each square by planting another plant, which is called a filler tree. Generally, the filler tree will be quick-growing , shorter duration and not be of the same kind as those planted on the corner of the square. Guava, phalsa. Plum, papaya, peaches, kinnow are important fillers. The filler tree is removed when the main fruit trees grow to full stature and start bearing. The advantages and disadvantages of this system are as follows:

Advantages

1. No unused space will be left.
2. 60-75% more plants can be planted the square system.
3. Early production due to filler will be better than intercropping.

Disadvantages

2. Fillers may adversely affect the growth of permanent plants due to competition of light, nutrients and insect attack, so it is recommended that when permanent plants start bearing fillers, they should be removed.
3. Intercultural practices will become difficult.

Spacing of the main crop is reduced if the filler

7.6 Triangular System

This system is a modification of the rectangular system. After laying out different rectangles, a plant is planted in each rectangle, thus making a triangle. The advantages and disadvantages of this system are as follows

Advantages

1. 50-60% more plants can be planted/accommodated in this system as compared to the rectangular system

Disadvantages

2. Crowding will occur at later stages of the orchard

7.7 Contour System

It is generally followed on the hills where the plants are planted along the contour across the slope. It is particularly suited to land with undulated topography, where there is greater danger of erosion and irrigation of the orchard is difficult.
The trees may not be set at equidistance. The number of plants per unit area will generally be less than in other systems.

7.8 Self Assessment Questions

Fill in the blanks with appropriate words.
i. A number of different systems for planting ……. are used with respect to different crops and the requirements of the orchard
ii. The arrangement of plants in the orchard is known as……...
iii. ..... System is the basic system of layout. In this system, plant-to -plant and row-to-row are kept equal (same).
iv. In ……system row to row distance is more than that from plant to plant in the row.
v. …….. system differs from the square system in which the distance between the rows is less than the distance between the trees in a row, but the distance from tree to tree in six directions remains the same.
vi. In the hexagonal system……more plants can be accommodated as compared with the square system

vii. Cultivation can be done in …….. directions if the layout of the orchard is hexagonal.
viii. ……..is the modification of a square system of layout distinguished to make use of the empty space in the center of each square by planting another plant, which is called a filler tree.
ix. …….. is generally followed on the hills where the plants are planted along the contour across the slope.

Answers
i. orchards
ii. lay-out
iii. Square
iv. rectangular
v. Hexagonal
vi. 15%
vii. three
viii. Quincunx system
ix. Contour system

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Harendra. (2024). Different planting systems. Ecofarming. E-ISSN: 2583-0791. http://www. ecofarming.rdagriculture.in



Fig 53: Contour system

Unit: 8

PLANT PARTS

Written By: Dr. Zaid Mustafa
Dr. Sakeena Tul Ain Haider
Reviewed By: Dr. Ayesha Maryam

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INTRODUCTION

The root system and shoot system together form the structural and functional framework of plants. Roots develop from the radicle and are responsible for anchorage, absorption of minerals and water, conduction of food and nutrients, and storage. They may form a tap root system (in dicots) or an adventitious/fibrous root system (in monocots). Roots are further modified for food storage in different forms, such as conical (carrot), fusiform (radish), and napiform (turnip). The shoot system, arising from the plumule, includes stem, leaves, and branches. Stems provide support, conduction, and bear nodes, internodes, buds, leaves, flowers, and fruits. Depending on plant type, stems may be aerial, erect, weak, reduced, or underground modified (e.g., rhizome, tuber, corm, bulb) and often serve food storage and vegetative propagation.

Leaves act as the major photosynthetic organs, structurally adapted for maximum light absorption, with venation patterns differing between dicots and monocots. Flowers are specialized reproductive structures made of sepals, petals, stamens, and pistils. Their classification depends on the presence or absence of these parts, and plants may exhibit sexual variations such as monoecious, dioecious, or andromonoecious types. Collectively, these systems ensure plant survival, growth, food production, and reproduction while showing remarkable modifications for adaptation.

OBJECTIVES

- To understand the structure and functions of the root system and its types
- To study the modifications of roots for storage and adaptation
- To explore the shoot system, stem types, and modifications for support, storage, and propagation
- To describe the structure, forms, and venation of leaves
- To explain the structure, classification, and types of flowers based on reproductive parts
- To highlight the importance of these plant systems in growth, reproduction, and adaptation

LEARNING OUTCOMES

After studying this topic, students will be able to:

i. Differentiate between tap root and adventitious/fibrous root systems
ii. Recognize various root modifications (conical, fusiform, napiform) and their significance
iii. Describe the shoot system, stem types, and underground stem modifications (rhizome, tuber, corm, bulb).
iv. Explain the role of leaves in photosynthesis and identify venation patterns in dicots and monocots
v. Classify flowers as complete, incomplete, perfect, imperfect, monoecious, dioecious, or andromonoecious
vi. Analyze how structural modifications of roots, stems, and leaves contribute to plant survival and adaptation

8.1 Plant Parts

Plants have two basic parts i.e., **underground parts,** which make the root system of plants and **above-ground** parts, which make the shoot system of plants. Root and shoot constitute the vegetative part of the plant, while flower, fruit and seed constitute the reproductive part of the plant.

8.2 Root System

It develops directly from the radical of the seed, and helps the plant in anchorage, transport of minerals and water (to upper ground parts through roots and prepared food from leaves to roots) and storage of food.

8.2.1 Characteristics of Root

The root is an organ of a plant that is in the soil. It is non-green in nature and does not bear leaves and buds. Normally, a plant bears a tap root or primary root system from which, after branching and re-branching, secondary and tertiary roots arise. The tap root and all its lateral branches collectively form a root system (Fitter, 2002).

8.2.2 Functions of the Root System

1. Root system helps the plant to firmly anchor in the soil.
2. It provides support to plants and laterals.
3. It acts as a reservoir of food storage.
4. Basic and functional unit of conduction in plants, which transfers minerals and water to the upper ground parts through roots and prepares food from leaves to roots.

8.2.3 Types of Root Systems

There are two major types of root systems

a. Tap root system: It develops directly from the radical of the seed and consists of main or primary roots along with secondary and tertiary roots, e.g., citrus, mango.

b. Adventitious roots/fibrous roots system

It develops from any other part of the plant except the radicle of the seed, and most of the monocots have adventitious roots, e.g., date palm.

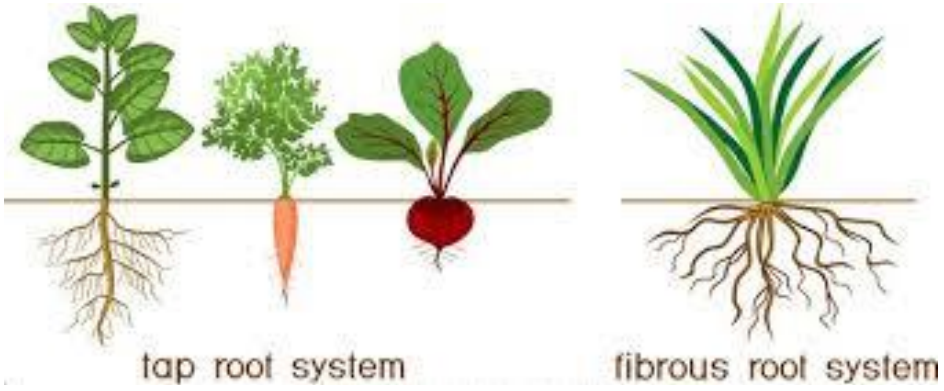


Fig. 57: Tap root system and fibrous root system in plants

8.2.4 Modification of roots

On the basis of different morphological forms, plants may have the following types of root systems

1. **Fleshy tap roots:** the roots become swollen or fleshy due to the storage of food in the form of starch. They may assume many types, like
2. **Conical:** Swollen at the top and tapering toward the end, e.g., carrot
3. **Fusiform:** swollen in the middle and tapering toward both ends, e.g., radish
4. **Napiform**: spherical and tapering toward the end, e.g., turnip

8.3 Shoot System

The stem, along with its branches and leaves, is called the **shoot system.** The most prominent ascending and aerial part of a plant that develops from the plumule and epicotyl is called the **stem.** It provides support to vegetative and reproductive shoots. It bears nodes and alternating internodes. Internode is the part of the stem between two successive nodes. Leaves and branches are developed on nodes. Buds are present on the **Apex** called apical/terminal buds, while **Leaf axils** are known as axillary/lateral buds. **Bud** is a condensed shoot having a short stem, which is covered by a number of delicate rudimentary leaves. Stem and its branches arise from a bud. Cabbage is an example of the largest vegetative bud in the plant kingdom.

8.3.1 Function of Stem

To provide support and conduct in plants are major functions of a plant stem. **a) Support:** Stems provide mechanical support and raise leaves into the air and facilitate photosynthesis. Flowers and fruits are also produced in positions that

facilitate pollination and seed dispersal. b) **Conduction: The** Stem also provides a pathway for water and mineral nutrition movement from root to aerial plant parts like leaves, etc. and prepares food from one tpart of the plant.

8.3.2 Forms of stem

Plants have different forms of stems that give different structures and shapes to the plant. The most important form of stem is:

i. Arial stem

The stem that remains outside the soil surface is known as arial stem,

ii. Exert stem

It grows upward/upright without any kind of support above the soil surface.

iii. Weak stem

It is incapable of growing straight upright under national conditions; trailing and climbing support is required.

iv. Reduced stem

Sometimes the stem is reduced to an extremely small remnant, persisting at the upper end of the root, to form a reduced stem, e.g., Carrot, radish, etc.

v. Underground modified stem

When leaves and roots are not storage organs in a plant, the stem modifies and acts as the chief storage organ, which is known as an underground modified stem e.g., rhizome, ginger, potato etc.

8.3.3 Stem Modifications

Mostly stemsare arial, upright and produce leaves, flowers and fruit; however, in some cases stems get modified to carry out some functions like **Permination:** the process of living together through a number of years, like a perennial plant and support vegetative propagation, synthesis and storage of food. Stem modifications are broadly classified as

- Underground stem modification
- Above-ground stem modification

8.3.3.1 Underground Stem Modification

Underground stems can be modified into the following different forms

a. Rhizomes
b. Tubers
c. Corm
d. Bulb

a. Rhizomes

It is a specialized stem structure in which the main axis of the plant grows horizontally at or just below the ground surface. It is perennial, non-green, fleshy below ground, with a brown coloured stem which may mistakenly be taken for a

root but is distinguishable from the root because it bears nodes and internodes. The brown scale leaves are present on nodes, and apical and lateral buds are present. Rhizomes are horizontal and struggling (spreading out in different directions), e.g., Ginger, turmeric, etc.

b. Tubers

It is a special kind of swollen modified stem that functions as an underground storage organ. Tuber has all the parts of a typical stem, but is very much larger; external eyes are present as nodes, containing one or more small buds. Adventitious branches arise from the underground part of the stem of the potato plant, and the apices of the branches develop into tubers. Tubers are formed by the swelling of branch apices due to the accumulation of starch. **Shape:** oval, spherical and protected by corky skin, e.g., potato

c. Corm

A corm has a solid stem structure with distinct nodes and internodes. The bulk of the corm consists of storage tissues composed of parenchyma cells. Dry leaves bear persist on the mature corm, attach to each node and encircle the corm. The covering is known as a tunic, which protects it from injury and water loss. At the apex of the corm, there is a terminal shoot that will develop into leaves and a flowering shoot, e.g., gladiolus

d. Bulb

Underground structure produced mainly by monocots. It has a short, modified stem enclosed in fleshy leaves (scales) modified for food storage. From the reduced stem, adventitious roots arise towards the lower side, e.g. onion

8.3.3.2 Above-ground Stem Modification

Above-ground stem can be modified into the following different forms

a. **Crown**

It is a compressed stem. Its position is just above or just below the soil surface, and leaves and flowers arise from the crown of the bud. In addition, fleshy buds from the crown may produce a whole new plant referred to as a crown division.

b. Stolon

These are stems that grow horizontally along the ground. A runner is a stolon with a long internode originating at the base or crown of a plant.

c. Spur

These are the stems of woody plants, whose growth is restricted, characterized by shortened internodes, e.g., apple, pear, etc.

8.4 Leaf

Leaves are photosynthetic organs upon which higher plants depend for the formation of carbon-containing compounds. A leaf is basically a flat appendage of a stem arranged in such a pattern to present a large surface for the efficient

absorption of light energy. The leaf blade is usually attached to the stem by a stalk or petiole. The leaf-like outgrowth of the petiole, commonly known as a stipule, is present (Kriska, 2025).
Leaf venation: The vascular system in leaf form a branching network of veins, the venation is net-like in dicots and parallel in monocots. Modification: It may be a stem-like fleshy structure, e.g., sensevieria (Tendrils of pea)

8.5 Flower

Flowers show variety in structure, composition and size. The major parts of a flower are sepals, petals, stamens and pistil. Sepals are collectively known as the **calyx**. These enclose the flower in bud and are usually small green leaves or a structure below the petals. Petals are collectively called a **corolla.** These are the prominent portions of the flower, highly coloured and rarely with green pigment. Petals may contain perfume glands as well as nectar glands which produce sugary substances. Stamens are also known as **Androcium** (male flower part). Each stamen consists of a pollen-bearing anther supported by a filament. Pistil, also known as **Gynoecium** (female flower part). It consists of ovule bearing base (ovary) supporting an enlarged region (style) whose exposed tip is called (Stigma).Ovule gives rise to a seed and a mature ovary is called a **fruit.** Flower parts are born on an enlarged portion of the flower supporting stem, known as the **receptacle** and the arrangement of flowers on plants is known as **inflorescence**.

8.5.1 Types of flowers

A flower can be of the following types;

a. Complete flower:

The flower having sepals, petals, stamens and ovary is known as a complete flower.

b. Incomplete flower:

When a flower lacks one or more of these parts i.e., sepals, petals, stamens and ovary. It is known as an incomplete flower. It may be an imperfect or perfect flower.

c. Imperfect flower:

A flower with a single sex organ (stamen or pistil) is known as an imperfect flower. It may be a pistillate or staminate flower.

i. **Pistilate flower: a** flower having a gynoecium only
ii. **Staminate flower: a** flower having an androecium only

d. Perfect/ Bisexual/ Hermaphrodite flower

A flower having both androecium and a gynoecium

i. **Monoecious**:

Both staminate and pistillate flowers are on the same plant e.g. cucurbits

ii. Dioicous:
Staminate and pistilate flowers are on different plants e.g. date palm
iii. Andromonoecious:
The plants having perfect and staminate flowers, e.g. muskmelon

8.6 Self Assessment Questions

Fill in the blanks with appropriate words:
i. Plants have two basic parts i.e. underground parts which make the root system of plants and above-ground parts which make……system of plants.
ii. The flower having sepals, petals, stamens and ovary is known as……..
iii. A flower having both androecium and a gynoecium is called …….
iv. Root and shoot constitute the vegetative part of the plant, while flower, fruit and seed constitute ……...part of the plant.
v. ……..are photosynthetic organs upon which higher plants depend for the formation of carbon-containing compounds.
vi. Pistilate flower having ……. only
vii. ……. develops directly from the radical of the seed, and helps the plant in anchorage, transport of minerals and water and storage of food.
viii. Tuber has all the parts of a typical ……but is very much large, external eyes are present as a node, containing one or more small buds.
ix. The stem which remains outside the soil surface is known as ……..stem,
x. **…….**is a condensed shoot having a short stem, which is covered by a number of delicate rudimentary leaves.

Answers

i. shoot
ii. complete flower
iii. Perfect/ Bisexual/ Hermaphrodite flower
iv. Reproductive
v. Leaves
vi. gynoecium
vii. Root
viii. stem
ix. arial
x. Bud

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Unit: 9

PLANT ENVIRONMENT

Written By Dr. Zaid Mustafa
Dr. Sakeena Tul Ain Haider
Reviewed By Dr. Qasim Ali

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INTRODUCTION

Climate factors (temperature, light, humidity, and precipitation) and soil properties (structure, texture, and fertility) are the two main components of the plant environment. Temperature regulates growth, flowering, and fruiting, with species-specific tolerance ranges. Light provides energy for photosynthesis and influences photoperiodism, germination, and morphology. Humidity and precipitation govern plant-water relations, affecting transpiration, soil moisture, and water availability. Together, these climatic variables determine crop adaptation, productivity, and stress responses.

Soil acts as a medium for anchorage, water and nutrient supply, and microbial activity. Its structure, texture, and fertility control root growth, aeration, and water-holding capacity, ultimately influencing plant health and yield. Sustainable management practices such as mulching, hardening, irrigation, organic matter addition, and crop rotation are crucial to optimize climate–soil interactions and maintain long-term productivity.

LEARNING OBJECTIVES

- To understand the role of climate (temperature, light, humidity, and precipitation) and soil (structure, texture, and fertility) in plant growth.
- To identify plant responses and adaptations to varying environmental conditions.
- To explore management practices that optimize crop performance under different climates and soils.

LEARNING OUTCOMES

By the end of this unit, students will be able to:

i. Explain the factors affecting climate and soil plant physiology, distribution and productivity.
ii. Differentiate between crop requirements and stress tolerance under varying environments.
iii. Assess soil properties and climatic conditions for suitable crop selection.
iv. Recommend cultural and management practices to mitigate adverse climate and soil effects.

9.1 Plant Environment

The climate (temperature, light, humidity, precipitation etc) and soil, (structure, texture, fertility etc.) are two major components of plant environment (VanDerZanden, 2008). Details are as follows:

9.2 Temperature

The narrow range of temperature in which plants can grow makes temperature one of the most limiting factors in crop cultivation. The optimum temperature for growth of most horticultural plants lies between 15° and35°C. The tolerance limits for maximum and minimum temperature vary with species. Tomatoes or example, cannot withstand freezing temperatures, whereas a hardened apple tree will not be harmed at -35°C. Tropical plants like bananas will suffer chilling injury at 4°C. The dramatic increase in the production of vegetables and bananas in the frost-free zone of lower Sindh is a vivid example of the exploitation of plant-temperature relations (Javed et al., 2022).

The **temperature** of a substance may be defined as a measure of the relative speed with which its molecules are vibrating. All vibrations cease at absolute zero (-273°C). Temperature reflects the intensity of heat, which is a qualitative indicator without any regard for the quantity of heat present in a body of matter. It is necessary to discuss a few important aspects of heat energy at this point.

Heat is a form of energy that causes an increase in the temperature of matter when transferred into it. A Corresponding reduction in temperature takes place when heat is removed, provided the matter does not change states during the process of heat transfer. The changes of state of ice to water, or water to water vapor, involve the transfer of heat without a change in temperature.

The number of calories of heat required to change the temperature of 1 g of a substance by 1°C is called **specific heat**. Substances with a high specific heat undergo a relatively small change in temperature in response to a given amount of heat energy. Because of its high specific heat, water has a strong modifying effect on temperature change. This has great significance for plants, especially for frost protection. The amount of heat absorbed in changing 1 g of a substance at its melting point from the solid to the liquid state, or released when the substance changes from the liquid to the solid state, is its **heat of fusion**. To change 1 g of a substance at its boiling point from the liquid to the vapour state, the heat requirement is called the **heat of vaporization**. Like specific heat, the heat of fusion and heat of vaporization of water are very high compared to those of other substances.

9.2.1 Temperature Measurement

The freezing point of water is 0°C, and its boiling point is 100°C on the Celsius (centigrade/metric) scale. On the Fahrenheit scale, the freezing point is 32° and

the boiling point is 212°. The Kelvin absolute temperature scale begins at absolute zero, at which point matter contains no heat energy. It is equivalent to -273°C or -460.4°F. Ice melts at 273°K and water boils at373°K. The following equations can be used to convert temperatures from one scale to another.

°F= (9/5°c) + 32
°C= 5/9 (°F - 32)
°K= °C + 273
°C= °K – 273

9.2.2 Factors Influencing Temperature

The following factors can influence the temperature on the Earth

i. Solar radiation. Our main source of heat is the sun. The sun is located at a mean distance of 1.5 x 108 km from the Earth, and has a diameter of 1.4 x 106 km, which is about 100 times that of the Earth. Its estimated surface temperature is about 6,000°C, and it is constantly radiating energy in all directions. The minute fraction of the sun's radiation thatreaches the Earth and its atmosphere is enough to sustain all life. Of the incoming solar energy striking the outer atmosphere, 10% is ultraviolet, 40% visible, and 50% infrared radiation. Most of the DV radiation is absorbed by the ozone layer in the upper atmosphere. Living organisms cannot withstand large amounts of UV radiation. Water vapor and CO_2 absorb part of the infrared radiation. Smoke, dust particles, and water droplets in the atmosphere scatter light of differing wavelengths, depending on their size and concentration. It is estimated that 34% of the solar radiation received by Earth is reflected back to space by atmospheric clouds, 19% is absorbed by the atmosphere, and 47% reaches the Earth directly or as diffused radiation.

ii. Latitude. In general, temperature increases with decreasing latitude. These temperature differences are caused by differences in the amount of radiation received from the sun (insolation). The Earth's axis of rotation is tilted at an angle of 23Y2° to its plane of rotation around the sun. At any given time, only half of the Earth is illuminated, and the portion illuminated is continually changing. At the spring and fall equinoxes (March 21 and September 21, respectively), sunlight reaches the entire earth from the North to the South Pole. Thus, all points on the earth have 12 hours of daylight and 12 hours of darkness. However, at all other times of the year, insolation striking the earth's surface varies with latitude. The more vertical the sun's rays, the greater will be the concentration of energy per unit area. Thus, the intensity of solar energy reaching the earth at the equator, where the sun strikes the earth at an angle of 90°, is greater than at the poles, where the sun's rays strike the earth at a very small angle. As one moves away from the equator, the same amount of radiant energy is spread over an increasing surface area. As the angle of incidence decreases, the same amount of radiant energy is received by an increasing area, and consequently, its intensity is decreased. You can visualize this by shining a flashlight on a dark wall at an angle

of 90° and then tilting the flashlight to decrease the angle at which the light strikes the wall. Also, as the angle of the sun decreases, the depth of atmosphere through which its rays must pass increases. At 90°, the depth is 1 atmosphere; at 60° it is 1.2 atmospheres; at30°, 2.0 atmospheres; and at 10°, 5.7 atmospheres. As the depth of the atmosphere through which it must pass increases, the amount of solar, energy reaching the earth decreases because of increased absorption, reflection, and scattering by the atmosphere. The difference in the intensity of sunlight in the early morning and at noon is a result of these factors. Within Pakistan, however, latitude effects on temperature are negligible.

iii. Season. Seasonal effects on temperature are closely related to latitude. When one moves away from the equator, temperatures not only decline but vary more between summer and winter. These seasonal effects result largely from the tilt of the Earth's axis with respect to its plane of rotation and day length. At the equator, day length is 12 h during the entire year, and solar angle is always relatively close to 90°. As the distance from the equator increases, summer day length increases and winter day length decreases. Therefore, in spite of the low solar angle, areas at higher latitudes receive a moderately high amount of solar energy during summer. The average temperature difference between 0° and 900N latitude in July is 27°C. During winter, however, far northern latitudes have not only very low solar angles but very short days as well. Thus, the mean temperature difference in January between 0° and 900N latitude is68°C, much greater than that in July. All of Pakistan lies between 25°N and 35°N.

iv. Elevation. Atmospheric heat is received directly from the Earth's surface and only indirectly from the sun. The lower tropospheric air contains more water vapour and dust, therefore absorbs more terrestrial radiation, leading to higher temperatures at lower altitudes. Temperature decreases with elevation; for each 100 m increment in elevation, mean temperatures decline about 0.6°C. A zone of permanent snow exists above 4500 m in the tropics and above 3000 m in the temperate zones. The effect of elevation on temperature depends on the balance between incoming and outgoing radiation. The most important factor is atmospheric water vapour and its effect on radiation. Approximately half of the total water vapour in the atmosphere is in the lower 1800 m.; thus, the lower 0.2% of the atmosphere contains more than 50% of its total water vapour. Since water vapour slows the radiation of heat away from the Earth more than it blocks incoming solar radiation, atmospheric water vapor has a major impact on temperature at the surface of the Earth. Although a site at 1500 m receives somewhat more solar radiation than one at sea level, since there is much less water vapour in the air at the higher elevation, the rate of radiant heat loss is much greater and the effect is a lower temperature at the higher elevation. Pakistan is a land of contrasts, starting from sea level and rising to the highest mountain peaks. The influence of elevation on temperature plays a tremendous role in the different

agro-ecological zones and the horticultural crops grown in specific areas of the country. For annual crops like vegetables and seasonal flowers, the mean and extreme temperature values and the length of the growing season are important. Perennial plants like fruit trees and ornamental shrubs are affected by temperature during the whole year, and frost is a critical component.

v. Time of day. The temperature at any given time depends on the balance between incoming and outgoing heat. Plotting the energy received from the sun and that lost by the earth in relation to temperature shows that maximum temperatures occur not at the time of maximum insolation but rather when insolation has declined to where it equals radiational heat loss. Minimum daily temperatures occur in mid-afternoon, well past solar noon, and the daily minimum occurs just before sunrise. For the same reasons, annual maximum temperatures in the Northern Hemisphere occur in late July and August, well after the time of maximum solar radiation, and the annual minimum occurs in late winter, well after the period of minimal insolation. This relationship is called the tag effect.

Air temperature changes during the day and night: During the day, radiation from the sun passes through the atmosphere and is absorbed by solid surfaces on the Earth's surface. Much of this energy is converted to heat, which raises the surface temperature of the Earth. Soon after sunrise, the temperature of surfaces exposed to the sun becomes greater than the adjacent air temperature and heat begins to be transmitted to the air by conduction. As the air near the surface of the earth warms up, convection currents gradually begin, and heat is moved upward. As the day progresses, however, the warmest air is close to the ground and temperature declines with increasing distance from the earth's surface. After sunset, the Earth no longer receives solar radiation, but radiation of heat from the Earth continues. Thus, the temperature of many exposed surfaces falls below that of the adjacent air. This effect is particularly important with efficient radiating surfaces like leaves, which have a large surface area in relation to their volume. As the surface of a leaf becomes cooler than the surrounding air, heat is conducted from the air to the leaf, the reverse of the heat flow during the day.

Temperature Inversions: As the nighttime pattern of conduction continues, the air near the ground becomes cooler than the air above it. Since the cool air is denser than the warm air above it, no convection currents are formed and a temperature inversion results; that is, an inversion of the normal daytime situation. Maximum night time radiant heat loss occurs when there are long nights, clear skies, cool, dry air, and calm conditions. Since clouds block heat loss, temperatures drop much more slowly on cloudy nights. High humidity also restricts heat loss as can be seen by comparing the rapid cooling at night in dry areas like the Thal Desert with the hot nights in humid areas like the irrigated areas of Punjab.

vi. Topographic factors. Proximity to large bodies of water has a profound effect on temperature patterns. Since water has a higher specific heat and higher thermal

conductivity than soil, it absorbs heat to much deeper levels and warms and cools more slowly than soil. Temperatures vary less over oceans and other large bodies of water than over continents. The moderating effect of oceans and other large bodies of water on climate is called the oceanic effect. The differences between the yearly temperature patterns of Karachi and of Multan are largely a result of the oceanic effect.

vii. Slope. The direction in which a slope faces affects its temperature. In general, angles of the slopes being equal, a south slope is the warmest, followed by west, east, and north slopes. These temperature differences are the result of differences in the amount of solar radiation received by the soil. South slopes receive the most radiation because they are exposed to sunlight almost all day, even in winter when the sun is low in the sky. A west slope tends to be warmer than an east slope because it is warmed by the sun all morning. This difference is particularly marked in soil temperature, and thus low-growing crops, such as strawberries, are more affected than apple trees, which are more influenced by air temperature. Horticulturists should keep slope effects in mind when selecting sites for relatively tender, low-growing crops. Air drainage. During the night, the air near the ground is colder and therefore denser than the warm air above. Because it is denser, cold air flows downhill and collects in low areas from which it cannot drain, an effect called cold-air drainage. This leads to the formation of frost pockets, or depressions which collect cold air; the slope itself remains a relatively warm area, or thermal belt. Plants in frost pockets are in most danger of freeze damage. Therefore, in selecting planting sites, the location of the site to be planted in relation to the area into which cold air will drain should be kept in mind. Crops susceptible to freeze damage should be planted on sites that have good air drainage. Thus, apple growers often plant orchards on hillsides with less than ideal soil, just to have good elevation and associated air drainage. Early-blossoming cultivars may be planted at the top of a slope, and later -blooming varieties at the lower levels. The size of the area into which cold air drains is also important. The sides of a narrow valley are less desirable than the sides of a hill that rises up from a relatively large area into which cold air can drain.

viii. Soils. Different types of soil warm up at different rates in the spring. The rate of warming is determined by several factors, including colour, density, rate of heat conduction, air space, and water-holding capacity, which are the most important factors. Sandy soils with low water-holding capacity tend to warm up first in the spring and are often called early soils. Organic soils tend to warm up slowly and are thus classed as late soils. Loam, silt, and clay soils fall somewhere between sandy and organic soils, depending on the factors listed above.

9.2.3 Temperature Relations of Plants

The term cardinal temperatures designates several critical temperatures for plants. It includes the optimum temperature, at which a plant functions best; the minimum temperature, below which a plant cannot grow; and the maximum temperature, above which the plant cannot grow. Cardinal temperatures vary greatly among species according to their origin and adaptability. To describe tolerance for minimum temperature, plants are categorized as hardy, half-hardy, and tender.

Hardy plants can withstand minimum temperatures of -4 to -2°C.Peas, spinach, turnips, and cabbage are hardy plants. **Half-hardy crops** can survive minimum temperatures of -1 to 0°C.

Some half-hardy plants are carrots, beets, and lettuce. **Tender crops** cannot tolerate 0°C. Beans, corn, squashes, melons, cucumbers, and tomatoes fall in this category. These crops need a frost-free growing season or frost protection. A second classification involves the optimum growing season temperatures. There are two classes: **cool-season and warm-season crops**. The optimum temperature for cool-season crops is 18-24°C. Warm-season crops like temperatures of 25-35°C. Vegetable crops and annual flowering plants are traditionally classified as summer and winter groups according to their temperature requirements. However, most of the winter crops of the plains are grown at higher elevations during the summer months. Trees are classified as temperate, tropical, and subtropical/ semi-tropical according to their sensitivity and temperature requirements. However, some crops can be grown in areas not normally ideal for them by selecting special strains and using management practices to cope with unfavourable weather and temperature conditions. *Greenhouses* are used for controlled temperature production of high-value ornamental and vegetable crops. *Shading and mulching* can be used to avoid injury from extreme temperatures. With perennial plants, artificial control of temperature has limited scope.

Length of growing season and degree days. The suitability of an area for any crop is determined by the length of its growing season. The oldest and simplest method of calculating the length of the growing season is the average number of consecutive frost-free days. This varies from 100-120days in the Northern Areas, and keeps increasing progressively toward the lower parts of the country to almost 365 days a year in the lower tropical coastal regions of Sindh. Elevation and proximity to large bodies of water will have a marked influence on the occurrence of frost. The length of the growing season determines what cannot be grown, but it does not tell us what can be grown. For example, even though the growing season is long enough, the production of certain tender vegetables is not possible if the temperatures are not sufficiently warm. The concept of degree days is a means of correlating temperature with crop development. The calculation of degree days is a method of temperature summation that can be used to predict

successive planting and maturation dates. Degree days are calculated as follows. For each crop, a base (threshold) temperature is determined below which crop growth and development is minimal. For each day of the year, this base temperature (in °F) is subtracted from the maximum for that day. For example, with pea, the base temperature is 40°F (4.4°C), so for a day with a maximum of 50°F (10°C), 10 degree days would be accumulated. If the daily maximum is lower than the base temperature, no degree days are accumulated or subtracted. Peas require an average of 2000 degree days. For warm-season crops, the base temperature would obviously be higher than 40°F. Degree-day calculations yield approximations, as they do not consider the non-linear responses of plants to temperature as well as the effects of other important factors like latitude, illumination, daylength, nutrition, water, and disease and insect problems.

Freezes and frosts. There are two types of freezes. **Radiational freeze** occurs with calm conditions, radiational cooling, and temperature inversion. Its severity is directly dependent on radiant heat loss through temperature inversions. **Adiabatic freezing** occurs as a result of the entry of a large cold air mass. During wintertime in the mid to high latitudes of the temperate zone, large, dry cold air masses move southward from the circumpolar regions, causing sudden and drastic temperature drops. No temperature inversion is present; heat is lost directly to the cold air by conduction, and freeze damage may occur. The terms *freeze* and *frost* are often not discriminated; however, horticulturists soften the use of the words frost and freeze for radiational and advective freeze, respectively. Thus, **frost** refers to temperatures of 0°C or below associated with a temperature inversion. A white frost occurs where the dew point (temperature at which relative humidity reaches 100 percent) is above the minimum temperature and is obvious from the deposit of ice or frost (frozen dew) on exposed surfaces. A black frost results when the dew point is below the minimum temperature. The visible indication of cold injury is blackening of tender plants. Other forms of low-temperature injury include chilling injury, desiccation, and heaving. **Chilling injury** is plant tissue damage at the membrane level caused by temperatures slightly above freezing. Desiccation of tissue occurs because of decreased water uptake by the roots. **Winterkill** takes place in evergreen plants, which lose water by transpiration faster than it is replaced through the roots. The heaving of soil caused by alternate freezing and thawing damages the plant by ripping its root system. Mulching can effectively prevent heaving. Bark splitting can also occur as a result of low-temperature injury. Limbs can be broken by the weight of ice after heavy snowfalls.

High-temperature injury. Sunburn or 'burning up' of plants takes place during hot weather. High temperature results in excessive water loss and tissue desiccation. Warm, dry winds aggravate this situation. A significant amount of visible heat injury to fruit, leaves, and other tissues can occur when daily air

temperatures reach 40°C or higher. Temperatures during the summer months in the plains of Punjab are high enough to cause heat injury. Typically, heat injury occurs on a plant's most exposed south side. Bark splitting, yellowing and browning of leaves, visible spots on the peel of fruits, misshapen fruits, and effects on the quality of produce are common. Soil temperatures can also rise enough to interfere with root growth. Young plants can burn off at the soil line. Extremely high temperatures (46-54°C) may kill the plant.

Vernalization and chilling requirements. Temperature plays a crucial role in flower initiation and development in some plants. Biennial plants typically produce only vegetative growth in the first year; then, after extended exposure to cold during the winter (vernalization), flowering takes place in the second year. Some common crops that need low temperatures for flower induction are beets, cabbage, lettuce, radishes, and carrots. Most of the winter-hardy deciduous fruits have specific quantitative chilling requirements for successful flowering. A certain minimum number of hours of exposure to temperatures below 4.4 °C (40°F) are counted by an internal clock mechanism. Any hours of temperature above the critical temperature are to be deducted from the counts. Chilling requirements vary among species and among cultivars. Breeders have developed low chilling cultivars of apples, peaches, plums, almonds, and apricots that can fruit successfully in relatively warm regions.

9.2.4 Temperature Management

Plants show a marked response to changing temperatures. Extremes of temperature, even for short periods of time, can lead to irreversible changes, resulting in the death of the whole plant or parts of it. Exhausted fruit-bearing trees are very susceptible to low-temperature injury. Late-season growth on trees remains succulent and gets killed. There is no direct control of temperature under field conditions. Adaptations through selection of location, site, choice of plants, and appropriate cultural practices can modify the effects of extreme temperature.

9.2.4.1 Hardening

Broadly, hardening refers to processes that increase the ability of plants to survive environmental stress. In its restricted meaning, hardening refers to developing the ability to withstand cold injury. Physiologically, cold-hardiness is acquired in response to natural changes in temperature, water availability, and day length. The progressive onset of cooler weather and shorter days in the fall brings about dormancy and hardiness. Growth slows down and carbohydrates accumulate near the end of the growing season. Water moves from the protoplasm to the vacuoles. The changed carbohydrate and water relations leave a larger proportion of water bound to protoplasmic proteins and other colloidal materials, which stabilizes cell structure and imparts hardening. Nursery plants are hardened before transplanting

to enable them to withstand the stress of transplanting. There are several ways to do this. The simplest method is to withhold water and excessive nitrogen fertilization. Sufficient growth during the growing season is necessary to accumulate carbohydrates. Gradual exposure of nursery plants to cold, along with withholding water or root pruning, can sufficiently harden the plants in about 10 days. Hardened nursery plants look stocky in contrast to tender and leggy unhardened plants. Many vegetable nursery plants develop a dark-green colour and a waxy covering on the leaves upon hardening. Over-hardening must also be avoided, since prolonged hardening can interfere with the subsequent development of seedlings after transplanting. In cruciferous vegetables (cole crops), over-hardened seedlings bolt without producing heads.

9.2.4.2 Mulching

Surface covers used as insulating agents to regulate soil temperature are called mulches. Mulching materials include a variety of plant refuse, straw, hay, organic manure, paper, and plastics. Stable soil temperature improves root growth and increases nutrient availability both in summer and winter. It encourages early production of the crop as well (FAO, 2020). The stable soil temperature also prevents heaving. Additional benefits of mulching are

i. Moisture conservation,
ii. Weed control,
iii. Erosion control
iv. Clean harvest from vine crops like strawberries.

Some problems associated with mulching include the

i. Harbouring of plant pests
ii. Weeds
iii. Disease
iv. Producing microbes
v. Rodents

Inflammable mulching materials can be a fire hazard. Frost control. There are three approaches to frost control: (a) avoidance, (b) reduction of heat loss, and (c) addition of heat. For a successful control strategy, the conditions of occurrence of frost and the mechanisms of injury must be thoroughly understood. Spring frost can be avoided by planting annual crops late. But this approach has its own problems. Predicting the last frost-free date is a matter. If statistics and can be inaccurate. Areas with a short growing season get early fall frost, and late planting will further reduce the growing season. Starting nurseries under protection and transplanting after the frost-free period begins avoids the danger of frost. A futuristic approach to escaping freeze damage involves interfering with the transition of liquid water to ice crystals. The transition of water to ice requires ice-nucleating particles that include certain bacteria (Pseudomonas and Erwinia).

Elimination of ice-nucleating bacteria by bactericides or the use of non-nucleating ('ice-minus') bacteria as antagonists can reduce frost damage. 'Ice-minus' bacteria exist naturally and can also be genetically engineered (IFOAM. 2003).



Fig. 58: Different kinds of mulching in plants

Heat moves up through the soil by conduction, the rate of conduction varying with the soil type. Mineral soils conduct heat better than organic soils. Conditions leading to rapid and prolonged surface cooling are conducive to radiational frost. For example, the introduction of cold polar air followed by clear, dry, calm nights

facilitates upward radiation, causing temperature inversions. The absence of wind leaves the coldest air undisturbed next to the ground. Clouds and humidity cause re-radiation back to the earth and prevent frost.
Reduction of heat loss can be achieved by any method that will increase daytime absorption of heat by the soil or prevent its loss at night. Anything that prevents the accumulation of radiation during the day will increase the chances of frost. Thus, clean cultivation, which allows the direct penetration of heat into the soil, is better for frost control than mulched or sodded fields. Covering individual plants and the use of plastic tunnels, cold frames, and a variety of mulches can prevent heat loss at night. Replacing air spaces in the soil with water reduces the danger of frost. The addition of heat may be accomplished in a number of ways, e.g., by using heaters, flooding, or spray irrigation, and by mixing the air with wind machines. However, the cost of energy for artificial heating and running wind machines may be prohibitive. Smudging (use of smoky heaters), an effective method of frost protection, is now illegal in some parts of the world because of the air pollution that it causes.

9.3 Light

Sunlight is the *ultimate source of energy* on the Earth. Green plants convert solar energy into chemical energy by photosynthesis. The stored chemical energy of plants is utilized in different forms by non-photosynthetic organisms. In addition to photosynthesis, light affects other plant processes, including seed germination, vegetative and reproductive growth, and plant morphology. To understand the effects of light, it is necessary to present some basic terminology and definitions. Physicists describe the movement of light in terms of both wave motion and of discrete particles, but for most practical purposes, the wave description is used. **Wavelength** is the distance between successive crests or troughs of a wave, and **frequency** is the number of crests passing a given point in a unit of time. Frequency and wavelength are inversely related: the higher the frequency, the shorter the wavelength, and conversely. Shorter waves are emitted at a higher frequency and have higher energy, while longer wavelengths have a lower frequency and lower energy. Visible light is the portion of the electromagnetic spectrum to which the human eye is sensitive. It ranges between 380 and 760 nm, and the sensitivity response peaks at 555 nm. **Photosynthetically active radiation (PAR)** also lies within the visible portion of the light spectrum but peaks in different ranges. The spectrum of solar radiation is also called the electromagnetic spectrum. About 50 percent of the total radiation received on earth is in the visible wavelengths. The air acts as a filter that admits the visible waves and restricts the penetration of high-energy waves.

9.3.1 Light Measurements

Radiant energy is measured and expressed variously. A light meter used to determine the proper exposure time for photography is familiar to all of us. A **foot-candle (ft-c)** is defined as the illuminance from a standard candle received on a one-foot square surface one foot from the candle. This has been replaced by a more reproducible reference unit, called one lumen (lm) per square foot. The metric unit of light is the **lux (Ix)**, which is defined as one lumen per square meter. Thus, one ft-c equals 10.76 lux. A few examples from everyday life are: full sunlight at noon in summer is about 10,000 ft-cor 108,000 lux; full moonlight is about 1/50 ft-c. About 20 ft-c is considered adequate for reading; a 40W fluorescent tube emits about 25 lux.

The ft-c and lux have been widely used by researchers because of the simplicity and availability of low-cost measuring instruments. The trend in agricultural research is to express radiant energy in terms of PAR, which is the part of the spectrum primarily absorbed by chlorophyll molecules. It is measured by sensitive instruments and expressed in micro-einsteins per square meter per second ($\mu E\ m^{-2}\ sec^{-1}$) in the wavelength range of 400-700 nm. An **einstein (E)** is the energy in one mole, or Avogadro's number (6.02 x 1023) of photons. In Pakistan, we are fortunate to have ample sunshine throughout the year. Light is never considered to be a limiting factor in the cultivation of horticultural crops in this country.

9.3.2 Plant Responses to Light

Photosynthesis and photomorphogenesis are the two major categories of plant responses to light. Chlorophyll *a* and *b* molecules present in the green pigmented plant parts are responsible for photosynthesis; whereas **phytochrome,** a photoreceptive pigment ubiquitously present in all plant parts, is involved in photomorphogenesis. Phytochrome has two forms, which have different absorption peaks and are photo-reversible. The red-absorbing form (Pr) has an absorption peak at 660 nm and is readily converted to the far red-absorbing form (Pfr) with an absorption peak at 730 nm. A brief description of important photomorphogenic responses is as follows.

9.3.2.1 Photoperiodism.

The response of plants to the relative length of daylight or darkness is known as **photoperiodism**. The effect of day length on the growth and reproduction of plants was studied by Garner and Allard in America. They have classified plants mainly into three categories, according to the effect of photoperiod: (i) short-day or long-night plants, e.g.: cosmos, soybean, chrysanthemum, and poinsettia; (ii) long-day or short-night plants, e.g. spinach, althea, winter wheat, and oats; (iii) day-neutral plants, e.g. cucumber, kidney bean, pea, and tomato. The dividing line

between day lengths favourable to vegetative growth and those inducing flowering and seed formation is called the critical light period for a specific plant.
The period of day length from sunrise to sunset differs throughout the world depending on the time of year and geographical zones, except on the spring and fall equinoxes, when days and nights are of equal length throughout the world. Generally, 12 to 14 hours of continuous sunlight or artificial. Illumination is the critical light period for a particular plant. One hour or even a half-hour difference may cause major physiological changes in the plant. The phenomenon of photoperiodism is important in controlling the flowering of a good number of horticultural and agricultural plants. Shortening of the period of daylight by artificially shading the plant with coarse black cloth or black plastic, or lengthening the period of daylight by electric illumination, can induce early flowering.
Photoperiodism is the developmental response of plants to the relative lengths of light and dark periods. Flowering, tuber and bulb formation, and dormancy/rest periods are important developmental processes controlled by photoperiodism. Photoperiod/day length varies with latitude.
a. Flowering: Three distinct responses are known: short-day, long-day, and day-neutral plants.
i. Short-day plants flower only when the day length is less than the critical length, which varies among species and varieties. The plant remains in a vegetative state if the days are longer than the critical length. Some common short-day plants are chrysanthemum, poinsettia, and soybean. ii. **Long-day plants** flower only when days are longer than the critical day length. Some long-day plants are spinach, beets, and radishes.
iii. Day-neutral plants will flower with any day length, provided the plant is otherwise ready to reproduce. Some species flower after a certain number of nodes have developed on the stem, regardless of the light conditions. Common examples of day-neutral plants are tomato, dandelion, rose, and African violet.
These definitions must be understood precisely. A short-day plant is not necessarily one that requires a shorter day length than long-day plants. In fact, a short-day plant might require a day length longer than a long-day plant. It is classified as short-day because it *flowers* below a critical day length. Similarly, for *flowering* a long-day plant requires a photoperiod longer than the critical daylength. Also, it must be noted that most light-sensitive plants will ultimately flower even if not provided the right kind of photoperiod; however, this will occur after a prolonged period of time. It has been shown through grafting experiments that if bark from a plant induced to flower is grafted to an uninduced plant, the latter will also be induced to flower. Such experiments have led to the hypothesis of a flowering hormone or florigen. This means that flowering plants responding

to external as well as internal stimuli produce endogenous compounds responsible for the induction of flowering.

b. Tuber and bulb formation: Flowering, tuberization, and bulb formation have evolved for a common function, i.e. reproduction and survival during times that are unfavorable for growth. Bulbs and tubers are storage organs that start development when they receive a light stimulus. Most potato cultivars form tubers under short-day conditions; tuber formation can be stopped by providing light during the night, thus disrupting the short-day conditions. Interestingly, the potato is a long-day plant for flowering purposes. Both of the processes have their own evolutionary significance. The formation of onion bulbs requires long photoperiods, ranging from 12 to 15 hours depending upon the cultivar. Both bulb formation and flowering are long-day responses in onion.

c. Bud dormancy: The induction of dormancy of vegetative buds or the rest period in deciduous trees is directly related to the shortening of days during late summer and before the onset of cold winter weather. As the days lengthen in spring, dormancy is broken and fresh growth begins. This is a protective mechanism that tides the plant over adverse weather conditions. Otherwise, growth might begin in the middle of winter during unseasonal warm weather, and be killed later by the resumption of cold weather. In most deciduous trees, this is controlled precisely by the number of hours of cold after which dormancy will break, technically referred to as the chilling requirement.

d. Seed germination

The seeds of some plants will not germinate without exposure to light. Many weeds have this property and germinate only when near the soil surface or where the soil has been disturbed; this gives them an advantage over other plants, since their seeds germinate under conditions conducive to their survival and growth. Lettuce is a well-known example of this characteristic.

If lettuce seeds absorb water in the dark, only a few will germinate. If the seeds are exposed to red light (660 nm) after absorbing water, germination will be nearly 100 percent. If, however, they are then exposed to far-red light (730 nm), the stimulatory effect of the exposure to red light is reversed. Germination of certain species, e.g. the American elm and some cucurbits, is inhibited by light, and the seeds of many plants are unresponsive to the presence or absence of light.

e. Phototropism

The recurring cycle of daylight and dark periods of regularly changing duration is crucial for the normal growth and reproduction of plants. The number of daylight hours is referred to as the **photoperiod.** Plants generally bend in the direction of the most intense light, since the bending of the plant causes it to receive light more evenly on all sides. This response is called (positive) phototropism. Shoots and roots have positive and negative phototropism, respectively. Polarity for the

phototropic response is at the molecular level and can be found even in embryonic tissues of the radicle and plumule.

9.4 Precipitation

Precipitation is defined as any form of water - liquid or solid - that falls from clouds and reaches the ground in the form of rain, snow, sleet, hail, freezing rain, drizzle, graupel (soft, small pellets of ice etc.

Precipitation occurs when water vapor in the atmosphere condenses and cools, forming clouds. When these clouds become saturated, the water falls to the ground as precipitation. Precipitation is a vital component of the Earth's water cycle, and it plays a crucial role in shaping our climate, weather patterns, and ecosystems.

9.4.1 Types of Precipitation:

a. Rain
b. Snow
c. Sleet
d. Hail
e. Freezing rain

9.4.2 Causes of Precipitation:

a. Evaporation from oceans, lakes, and rivers
b. Condensation of water vapor in the atmosphere
c. Cooling of air masses, leading to cloud formation
d. Weather fronts and low-pressure systems

9.4.3 Importance of Precipitation:

a. Replenishes freshwater sources
b. Supports agriculture and food production
c. Maintains ecosystem balance
d. Influences weather patterns and climate

The total annual precipitation and its distribution vary from place to place. Effective precipitation is the rainwater that is not lost by runoff or evaporation and is available to plants. The natural vegetation of an area gives a good indication of effective precipitation, and a variety of vegetation patterns exist in different parts of the world depending on the amount of effective precipitation. For example, the average rainfall in the Northern Areas and Kashmir is much higher than that in the central parts of the country, and rainfall is negligible in Cholistan and the Thar deserts. There are considerable forest resources in the north, while there is very little life in Cholistan and the Thar deserts.

9.5 Soil

Soil is a natural resource that forms the uppermost layer of the Earth's crust, consisting of a mixture of organic matter, minerals, air, and water. It provides the foundation for plant growth and is essential for the survival of all life on Earth. Soil acts as a medium for plants to anchor their roots, access water and nutrients, and sustain life. Soil also plays an important role in regulating water, carbon, and nutrient cycles, influencing ecosystems and the environment.

9.5.1 Soil Structure

Soil structure refers to the arrangement of soil particles, such as sand, silt, and clay, into aggregates or peds, which provide pore spaces for air, water, and root growth. Soil structure is determined by the interaction of various factors, including:

i. Texture: The proportion of sand, silt, and clay particles.
ii. Particle size and shape: The size and shape of individual soil particles.
iii. Aggregation: The formation of soil particles into larger clusters or aggregates.
iv. Pore space: The spaces between soil particles and aggregates that allow for air, water, and root movement.

Soil structure affects many important soil properties, such as:

a. Water infiltration and retention
b. Aeration and oxygen availability
c. Root growth and penetration
d. Soil erosion and stability
e. Nutrient availability and cycling

There are several types of soil structure, including:

i. **Single-grained**: Individual particles are not aggregated.
ii. **Blocky**: Aggregates are block-like in shape.
iii. **Prismatic**: Aggregates are prism-like in shape.
iv. **Columnar**: Aggregates are column-like in shape.

Understanding soil structure is essential for managing soils sustainably, improving soil fertility, and optimizing plant growth. Soil structure plays a crucial role in plant growth, providing a suitable environment for roots to develop and absorb essential nutrients and water. Here are some key ways soil structure affects plant growth:

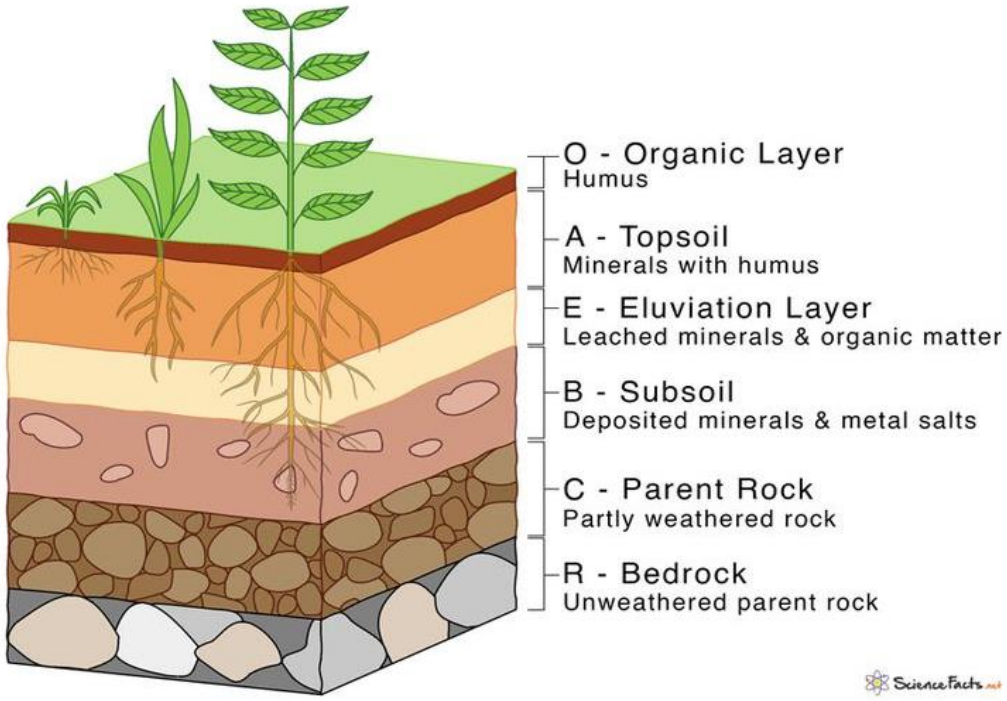


Fig 59: Soil Structure

9.5.1.1 Physical Properties

i. Aeration: Soil structure affects the availability of oxygen for roots. Well-structured soils with adequate pore space allow for good aeration, promoting healthy root growth.

ii. Water infiltration and retention: Soil structure influences the rate at which water enters the soil and is retained. A well-structured soil allows for efficient water infiltration and retention, reducing runoff and ensuring plants receive adequate water.

iii. Root penetration: Soil structure affects the ease with which roots can grow and penetrate the soil. A well-structured soil with a stable aggregate structure allows roots to grow deeper, accessing more nutrients and water.

9.5.1.2 Chemical Properties

i. Nutrient availability: Soil structure affects the availability of nutrients for plants. A well-structured soil with adequate organic matter and microbial activity promotes nutrient cycling, making essential nutrients available to plants.

ii. pH and nutrient interactions: Soil structure influences the pH and nutrient interactions in the soil. A well-structured soil with a balanced pH and nutrient levels promotes optimal plant growth.

9.5.1.3 Biological Properties

i. Microbial habitat: Soil structure provides a habitat for beneficial microorganisms, which play a crucial role in decomposing organic matter, fixing nitrogen, and solubilizing minerals.

ii. Soil biota: Soil structure affects the diversity and abundance of soil biota, including earthworms, insects, and microorganisms, which contribute to soil fertility and plant growth.

9.5.1.4 Impact on Plant Growth

i. Improved root growth: A well-structured soil promotes healthy root growth, allowing plants to absorb more nutrients and water.

ii. Increased water-use efficiency: Plants growing in well-structured soils tend to be more water-use efficient, as they can access water more easily.

iii. Enhanced nutrient uptake: A well-structured soil with adequate nutrient availability promotes optimal plant growth, as plants can access essential nutrients more easily.

iv. Better drought tolerance: Plants growing in well-structured soils tend to be more drought-tolerant, as they can access water more easily and have a more extensive root system.

In Short, it can be concluded that the soil structure plays a vital role in plant growth by providing a suitable environment for roots to develop, absorb nutrients and water, and interact with beneficial microorganisms.

9.5.2 Soil Sexture

Soil texture refers to the proportion of different-sized mineral particles, such as sand, silt, and clay, in a soil sample. Soil texture is a physical property of soil that affects its behavior, fertility, and overall quality. The three main components of soil texture are:

i. **Sand**: Large particles (0.05-2 mm) that feel gritty and allow for good drainage.

ii. Silt: Medium-sized particles (0.002-0.05 mm) that feel smooth and slippery.

iii. Clay: Small particles (<0.002 mm) that feel sticky and have a high surface area.

The proportion of these particles determines the soil's texture, which can be classified into 12 main categories:

i. Sand
ii. Loamy sand
iii. Sandy loam
iv. Loam
v. Silt loam
vi. Silt
vii. Clay loam

viii. Silty clay loam
ix. Sandy clay loam
x. Clay
xi. Silty clay
xii. Sandy clay
Soil texture affects many important soil properties, such as:
- Water-holding capacity
- Drainage
- Aeration
- Nutrient availability
- Root growth and penetration
- Erosion resistance
Understanding soil texture is essential for managing soils sustainably, selecting suitable crops, and applying appropriate conservation practices.
Soil texture plays a crucial role in plant growth, as it affects the soil's physical and chemical properties, which in turn influence plant development. Here are some ways soil texture impacts plant growth:

9.5.2.1 Physical Properties
a. Water-holding capacity: Soils with high clay content tend to retain more water, while sandy soils drain quickly. Plants require adequate water to grow.
b. Aeration: Well-draining soils with a mix of sand and silt provide good aeration, promoting healthy root growth.
c. Root penetration: Soils with a high sand content can be easily penetrated by roots, while clay soils can be more challenging.

9.5.2.2 Chemical Properties
a. Nutrient availability: Soil texture affects the availability of nutrients for plants. Clay soils tend to retain more nutrients, while sandy soils may require more frequent fertilization.
b. pH levels: Soil texture can influence pH levels, with clay soils often having higher pH levels than sandy soils.

9.5.3 Soil Fertility
Soil fertility refers to the ability of soil to provide essential nutrients, water, and oxygen to support plant growth and development. It encompasses the soil's capacity to supply nutrients, its physical structure, and its biological activity (Javed et al., 2022).

9.5.3.1 Role of Soil Fertility in Plant Growth
Soil fertility plays a critical role in plant growth, influencing:

i. Nutrient Availability: Soil fertility determines the availability of essential nutrients like nitrogen, phosphorus, potassium, and micronutrients, which are necessary for plant growth.
ii. Plant Nutrition: Soil fertility affects the uptake of nutrients by plants, influencing their growth, development, and productivity.
iii. Water-Holding Capacity: Soil fertility impacts the soil's water-holding capacity, affecting the availability of water for plants.
iv. Root Development: Soil fertility influences the development of roots, which are essential for plant growth and nutrient uptake.
v. Microbial Activity: Soil fertility supports the growth and activity of beneficial microorganisms, which play a crucial role in decomposing organic matter, fixing nitrogen, and solubilizing minerals.
vi. Soil Structure: Soil fertility affects the soil's physical structure, influencing its porosity, aeration, and water infiltration.

9.5.3.2 Factors Affecting Soil Fertility

i. Organic Matter: Addition of organic matter like compost, manure, or green manure enhances soil fertility.
ii. Crop Rotation: Rotating crops helps maintain soil fertility by breaking disease and pest cycles, improving soil structure, and increasing nutrient availability.
iii. Fertilizers: Application of balanced fertilizers provides essential nutrients for plant growth.
iv. Conservation Tillage: Reduced tillage or no-till farming helps preserve soil organic matter, reduces erosion, and promotes soil fertility.
v. Cover Cropping: Planting cover crops enhances soil fertility by adding organic matter, suppressing pests and diseases, and providing nutrients.
Overall, it can be concluded that maintaining soil fertility is essential for sustainable agriculture, as it ensures optimal plant growth, reduces environmental degradation, and promotes ecosystem services. Soil fertility plays a vital role in plant growth, influencing various physiological processes.
Nutrient Uptake and Utilization

9.6 Water

Given certain light and temperature conditions, water is the next most important limiting environmental factor in selecting a planting site and plant materials. Historically, agriculture started along the banks of rivers and lakes, and only later, when man developed a variety of irrigation systems, expanded into arid and semiarid areas. An adequate water supply must be ensured for any horticultural enterprise. The need for water cannot be overemphasized, as it performs many vital functions in plant life. Some of them are as follows.

- It is a necessary constituent of all living plant cells.
- It serves as a solvent for nutrients from soils and CO_2 from the air.

- It acts as a raw material in the process of photosynthesis.
- It is a medium of translocation from the site of uptake for raw material and the site of production of plant compounds to their sites of utilization.
- It is a reagent/substrate for a variety of chemical reactions and acts as a pH buffer.
- It maintains the turgidity of plant cells, which is required for growth and development, and for vital functions like stomatal opening.
- Because of its high specific heat, transpiration of water dissipates large quantities of heat and suppresses leaf temperature.



Fig 60: Plant growth in the pond

9.6.1 Properties of Water

Water covers up to 70 percent of the Earth's surface. Because of its unique properties, water is ubiquitous and functionally present in all living organisms in large quantities.

Most of the unusual properties of water are a result of its molecular structure. Water, consisting of two hydrogen atoms and one oxygen, is a covalently bonded

molecule. The bonding angle between hydrogens is 105°, and because of this asymmetry of hydrogen, water has a strong dipole moment, i.e. it is highly polarized, with a strong separation of positive and negative charges. Because of this polarization, it readily shares its hydrogen with the oxygen of other molecules of water and other oxygen-containing substances. Thus, water is both very cohesive and adhesive. Its strong dipolar nature results in electrostatic attraction for other dipoles and ions, and in hydrogen-bonding with oxygen-containing molecules. Water will adsorb to substances such as cellulose, but not to polyesters, which have few oxygen atoms available for hydrogen bonding. Many of the physical properties of water play a crucial role in plant water relations. Ice at 0°C has a density of about 0.999 g/cm^3 and at 4°C is 1.0 g/cm^3. Since the densest water sinks to the bottom of a body of water, the coldest water rises to the top, and water freezes from the top down rather than from the bottom up. The frozen water at the surface insulates the water below, preventing large bodies of water from freezing solid and killing aquatic life. Water has the highest specific heat of the common liquids. Water is issued as the standard for the calorie, the amount of heat required to raise 1g of water 1°C between 15.5° and 16.5°C. Hence, water has a specific heat of 1 call g per degree. This is important for the rates of heating and cooling of plant bodies as well as aqueous bodies. Large bodies of water, such as lakes and oceans, tend to moderate the temperatures of adjacent land. For the same reason, dry climates tend to have greater temperature extremes than humid climates. The rates of heating and cooling of plant tissue are also affected by the heat capacity of water.

The heat of vaporization, the amount of heat required to convert one gram of liquid to vapor, is much higher for water than for other liquids. This is due to the cohesiveness of water. Because of its high heat of vaporization, when water evaporates from living surfaces, much heat is lost and a cooling effect is produced. The heat of fusion, the heat required to change a solid to a liquid, is also higher for water (ice) than for other substances. An interesting application of this property of water is in frost protection. Orchards can be protected from frost injury by flooding. When the water freezes, the heat liberated during fusion (i.e., freezing) adds heat to the grove and protects the trees. Pure water is colourless, tasteless, and odourless. Due to molecular motion, water will tend to scatter short-wavelength light (blue) and transmit the visible long wavelengths (red), with the result that water appears blue. Other properties of interest include high viscosity (resistance to flow), high density(g/cm^3), and high surface tension (the tendency of the surface to contract and resemble an elastic membrane). To understand plant-water relations, both atmospheric and soil moisture content must be considered. Water utilization from the soil is strongly influenced by atmospheric humidity, i.e. water in vapor form. It is, therefore, essential to understand various

aspects of atmospheric moisture before discussing the soil-plant-water relationship.

9.6.2 Humidity

Absolute humidity is the weight of water vapor per unit volume of air, expressed as grams per cubic meter. For a given atmospheric pressure, the volume of air changes with changing temperature. Therefore, absolute humidity will vary with temperature without any change in absolute moisture content. **Specific humidity** is the weight of water vapor per unit weight of air, expressed as grams per kilogram. Since it is a ratio of weight to weight, temperature and pressure changes do not affect this measure of humidity. **Relative humidity** is the ratio of the amount of water vapour present in the air and the amount at saturation for a given temperature and pressure, expressed as a percentage. The water-holding capacity of air depends on temperature. The higher the temperature, the greater the water-holding capacity. Starting from 0°C air temperature and 100% relative humidity, when the temperature increases to 30°C, the relative humidity drops to 14%, with no change in moisture content. This shows that relative humidity as a measure of atmospheric moisture is meaningless if compared at different temperatures, and explains the daily variation in relative humidity from morning to evening. A very useful method of expressing atmospheric moisture is vapour pressure. **Water vapour pressure** is that part of the total atmospheric pressure which is due to water vapor, expressed in millimeters of mercury (mm Hg), or in millibars (1 mm Hg = 1.32 millibars). Since relative humidity is a measure of relative saturation, the actual vapor pressure is calculated by multiplying the saturation vapour pressure by the relative humidity. A parameter commonly used to describe atmospheric water relations is vapour pressure gradient. This measure is used to compare the vapour pressure at a relative humidity less than 100% with the saturation vapor pressure.

For the same relative humidity, a different vapour pressure gradient indicates the relationship of temperature with rate of evaporation. The relative humidity within the stomatal cavity is assumed to be 100%. For a given leaf surface temperature, one can work out the vapour pressure gradient, which will determine the rate of water loss through transpiration. It is important to remember that with a constant amount of water vapour present, vapour pressure does not change with temperature, but the vapour pressure gradient changes with temperature. There are several forms of atmospheric moisture or humidity, including rain, snow, vapour,

fog, sleet, hail, and dew. Rain forms when the condensation of atmospheric moisture takes place at temperatures above the freezing point. Snow forms when atmospheric moisture condenses at temperatures below the freezing point. When rain falls through a layer of air with temperatures below the freezing point, **sleet** is formed. If the air currents carry the frozen particles back up so that they accumulate a thicker covering of ice before falling again, hail is formed. Hailstorms cause considerable damage to crops. **Dew** forms at night when atmospheric moisture condenses on cold surfaces (relative humidity reaches 100%). **Fogs and mists** are low clouds that do not settle. In addition to providing high moisture in the air, winter fogs help in the accumulation of chilling hours for deciduous fruits. Atmospheric moisture can be measured by psychrometers, hygrometers, or rain gauges. The **psychrometer** is the simplest instrument to measure the vapor content of air. Typically, it consists of two similar thermometers. The bulb of one thermometer is covered with clean muslin cloth wetted with distilled water, and the bulb of the other is left dry. The two thermometers (wet-bulb and dry-bulb) are mounted side by side. If the relative humidity is below 100%, water evaporates from the wet bulb, and its temperature is lowered proportionately to the surface heat loss. The lower the humidity, the more rapid the evaporation. For a better estimate, the thermometers can be swung in the air until the temperature of the wet bulb no longer decreases. When the temperature of the wet bulb stops declining, the vapour pressures of the water in the wick and the water in the atmosphere are equal.

9.6.3 Soil Moisture. Water in soil is found in several forms. In a saturated soil (after irrigation or heavy rain), water moves through the pore spaces. The proportion of water that drains out/down is **free water or gravitational water**. Gravitational water is available to plants, but only for a short time. Most of the water retained by soil is capillary water, which is held by its own surface tension(cohesion) and by adhesion to the soil particles. It is the most important component of soil moisture available to plants. A small component of soil moisture, hygroscopic water, adheres tightly to soil particles and is not normally available to plants. Water is also present in soils in chemically bound forms, and is also unavailable for plant use. When all free water drains from the soil, it is said to be at field capacity. Field capacity differs with the type of soil. The field capacity of a heavy clay soil may be 30 percent, whereas it is only 3 percent in sand, on a dry-weight basis. After the depletion of all available capillary water,

the soil water reaches a level called the wilting point. Again, the percentage of water at this point depends on the type of soil. The difference between the wilting point and the field capacity is the available water.

9.6.4 Factors Influence the Movement of Water in Soil. Infiltration (movement of water into soil), percolation (movement of water through soil), and surface runoff are all influenced by the initial soil moisture content at the time of rain or irrigation. Soil structure, texture, and vegetation are other factors. The smaller pore size in clay soils and the larger pore sizes in loamy and sandy soils affect the movement of water accordingly. As water is taken up by plants and evaporates from the soil surface, water from lower parts of the soil moves upward. Upward and lateral movement is caused by capillary action, which is a surface tension phenomenon. The finer the soil spaces, the greater the distance water moves by capillary action. There are several ways of measuring and expressing soil water. The simplest way is as a percentage of the dry weight of soil. A more useful method of assessing soil moisture is to express the tension with which it is bound to the soil particles. Free water is held with very low tension; capillary water is bound tightly; and hygroscopic water is bound extremely tightly. Thus, free water has high potential energy (high potential), and bound water (under tension) has low potential energy (potential). The potential of soil water can be expressed in bars (one bar is equivalent to one atmosphere).
Available water in most soils is between -0.33 bars and -15 bars. A **tensiometer** is a device to measure the water tension/potential in soil. A soil tensiometer consists of a porous ceramic cup that is buried in the soil and connected with a tube to a vacuum gauge or mercury manometer situated above the soil surface. The cup and connecting tube are filled with water, which gradually comes to equilibrium with the soil moisture. At equilibrium, the water potential of the cup is the same as that of the soil, and can be directly read from the vacuum gauge or mercury manometer.

9.7 Precipitation

Precipitation is the process by which water in various forms falls from the atmosphere to the Earth's surface. It is a crucial component of the Earth's water cycle and is a primary source of fresh water for ecosystems, agriculture, and human consumption. Precipitation can occur in several forms, depending on the temperature, atmospheric conditions, and the state of the water:
Details are as follows:

i. **Rain**:
   The most common form of precipitation, rain, consists of liquid water

droplets that fall when the air temperature is above freezing. Rain is essential for maintaining freshwater supplies, replenishing rivers, lakes, and groundwater.

ii. **Snow**:
Snow occurs when the temperature is low enough that water vapor in the atmosphere freezes into ice crystals. Snowflakes can accumulate on the ground, and the water from melted snow is an important source of freshwater, especially in colder regions.

iii. **Sleet**:
Sleet occurs when raindrops freeze before reaching the ground, forming small ice pellets. Sleet can create hazardous driving conditions and has less significant water storage compared to rain and snow.

iv. **Hail**:
Hail consists of solid balls or lumps of ice that form when strong updrafts in thunderstorms carry raindrops into very cold areas of the atmosphere, causing them to freeze. Hail can vary in size and sometimes cause significant damage to crops, buildings, and vehicles.

v. **Drizzle**:
Drizzle refers to very light rain, with small water droplets that fall more slowly than regular rain. It usually occurs when the air is moist but not saturated enough to produce heavy rainfall.

vi. **Freezing Rain**:
Freezing rain occurs when liquid raindrops freeze on contact with surfaces like roads, trees, and power lines, creating ice coatings. It can be dangerous due to its tendency to cause ice accumulation, making surfaces slippery.

9.7.1 Precipitation Measurement:

Precipitation is typically measured using a **rain gauge**, an instrument that collects and measures the amount of liquid water that falls in a specific area over a given time period. Precipitation is usually expressed in millimeters (mm) or inches.

i. **Standard Rain Gauge**: A simple container used to collect rainwater, with a funnel that channels the water into a measuring tube.

ii. **Tipping Bucket Rain Gauge**: A more automated system that collects a specific amount of rain in a small bucket. Once the bucket tips, it triggers a counter, and the amount of rainfall is recorded.

iii. **Snow Gauge**: Specialized gauges are used to measure snowfall, often employing a combination of a standard rain gauge and a heated surface to convert snow depth into liquid equivalents.

9.7.2 Factors Influencing Precipitation:

Several factors influence the occurrence, intensity, and distribution of precipitation:

i. **Temperature**:
   The temperature of the air plays a crucial role in determining whether precipitation falls as rain, snow, sleet, or hail. For example, if the air temperature is below freezing, snow is more likely to form.

ii. **Humidity**:
   Precipitation occurs when the air is saturated with water vapor, and the moisture in the air condenses into clouds. High humidity levels increase the likelihood of precipitation.

iii. **Geographic Location**:
   Areas located near large bodies of water, such as oceans and lakes, tend to receive more precipitation due to the availability of moisture in the air. Coastal areas also experience more frequent rain due to prevailing winds.

iv. **Air Masses and Weather Fronts**:
   The interaction between different air masses (e.g., cold and warm air) can lead to the formation of clouds and precipitation. Weather fronts (the boundary between warm and cold air) often bring rain or storms when they collide.

v. **Topography**:
   The presence of mountains can affect precipitation patterns. When moist air is forced to rise over a mountain range, it cools and condenses, leading to rainfall on the windward side (the side facing the wind). The leeward side (the opposite side) may experience much drier conditions, a phenomenon known as the **rain shadow effect**.

vi. **Seasonal Changes**:
   Certain regions experience seasonal variations in precipitation, such as monsoon rains in tropical areas or winter snowfall in colder regions. Changes in temperature and wind patterns throughout the year can lead to distinct rainy and dry seasons.

9.7.3 Role of Precipitation in the Water Cycle:

Precipitation is a key process in the **water cycle** (also known as the hydrological cycle), which is the continuous movement of water on, above, and below the Earth's surface. The water cycle consists of the following stages:

i. **Evaporation**: Water from oceans, lakes, rivers, and plants (via transpiration) turns into water vapor and rises into the atmosphere.
ii. **Condensation**: As the water vapor cools, it condenses into tiny droplets, forming clouds.
iii. **Precipitation**: When the clouds become saturated with water, precipitation occurs as rain, snow, sleet, or hail.
iv. **Collection**: Water collects in rivers, lakes, oceans, and infiltrates the soil to replenish groundwater supplies.

Precipitation is crucial for replenishing freshwater sources, maintaining ecosystems, and supporting agricultural activities.

9.7.4 Global Distribution of Precipitation:

Precipitation is unevenly distributed around the world, with some regions receiving abundant rainfall and others being much drier. The distribution is influenced by factors like latitude, altitude, and proximity to large bodies of water.

i. **Tropical Regions**:
   Tropical areas near the equator, such as rainforests, receive high amounts of precipitation throughout the year due to the convergence of warm, moist air.
ii. **Temperate Regions**:
   These regions, including much of Europe and North America, experience moderate precipitation, often in the form of rain. These areas typically have four distinct seasons.
iii. **Deserts**:
   Deserts receive very little precipitation, often less than 250 mm (10 inches) per year. This is due to high pressure, low humidity, and the rain shadow effect caused by nearby mountain ranges.
iv. **Polar Regions**:
   Polar regions, such as the Arctic and Antarctic, experience very low precipitation, typically falling as snow. However, the total amount of precipitation is still much less than in tropical or temperate regions.

9.7.5 Impact of Precipitation on Agriculture and Ecosystems:

i. Agriculture: Precipitation is essential for growing crops, and the timing, amount, and intensity of rainfall directly influence crop yields. Droughts or excessive rainfall can negatively affect agricultural productivity.

ii. Ecosystems: Different ecosystems rely on varying amounts of precipitation. For example, rainforests require high precipitation, while deserts thrive with little to no rain.

iii. Water Supply: Precipitation is the primary source of water for rivers, lakes, and groundwater, which provide drinking water and support aquatic life.

Overall, it can be concluded that precipitation is a vital element of Earth's climate system and plays a significant role in the water cycle. It impacts weather patterns, agriculture, ecosystems, and human activity. The amount, timing, and form of precipitation can vary greatly across the planet, shaping local environments and influencing global weather systems. Understanding precipitation is essential for managing water resources and predicting weather conditions.

9.8 Self Assessment Questions

Fill in the blanks with appropriate words.

i. The narrow range of ……in which plants can grow makes temperature one of the most limiting factors in crop cultivation

ii. As the water vapor cools, it condenses into tiny droplets, forming…….

iii. Freezing rain occurs when liquid raindrops …… on contact with surfaces like roads, trees, and power lines, creating ice coatings.

iv. ……is the ratio of the amount of water vapour present in the air and the amount at saturation for a given temperature and pressure, expressed as a percentage.

v. When rain falls through a layer of air with temperatures below the freezing point ……. is formed.

vi. ..... helps maintain soil fertility by breaking disease and pest cycles, improving soil structure, and increasing nutrient availability.

vii. Well-draining soils with a mix of sand and silt provide good ……. promoting healthy root growth.

viii. ..... refers to the arrangement of soil particles, such as sand, silt, and clay, into aggregates or peds, which provide pore spaces for air, water, and root growth.

ix. Precipitation is essential for growing crops, and the timing, amount, and intensity of ……... directly influence crop yields.

x. Soils with high ……. content tends to retain more water, while sandy soils drain quickly.
xi. ……. plants will flower with any day length, provided the plant is otherwise ready to reproduce.
xii. Surface covers used as insulating agents to regulate soil temperature are called…….
xiii. …….is a form of energy that causes an increase in the temperature of matter when transferred into it.

Answers

i. temperature
ii. clouds
iii. freeze
iv. Relative humidity
v. sleet
vi. Crop rotation
vii. aeration
viii. Soil structure
ix. rainfall
x. clay
xi. Day-neutral
xii. mulches
xiii. Heat

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