UNIVERSITY OF COPENHAGEN
FACULTY OF SCIENCE

Tropical Fruit Production
LPLK10367U

Notes taken during the course, including lectures, exercises, curriculum, and practicals

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Link to GitHub reporsitory

Course Description

Education

MSc Programme in Agriculture
MSc Programme in Environment and Development
MSc Programme on Global Environment and Development

Content

The course focuses on developing capacities for sustainable production of tropical crops. The students will be exposed to major crop science elements that are instrumental for a sustainable crop production. Focus is on optimizing the use of agrobiodiversity and management practices considering the socio-economic characteristics and climate change challenges.

Main disciplines are:

i. Agronomy with reference to tropical conditions.
Tropical crop physiology; crop genetic resources, agrobiodiversity and breeding; crop management; crop protection; soil fertility. Cultivation of crops under challenging conditions of climate change (e.g drought, salinity).

ii. Tropical Crops
An overview of major tropical crops groups in relation to their uses (roots and tubers; legumes; minor cereals; spices; stimulants; underutilized species), their intrinsic properties and their cultivation with special emphasis on small-holder conditions and resilience for climate change.

iii. Cropping systems
Crop production optimization strategies for sustainable production (intercropping, use of legumes for mitigation/adaptation). Innovations to optimize sustainable production systems (crop: phenotyping, breeding, protection). The use of agrobiodiversity for diversification, sustainable intensification and value chain enhancement.

Learning Outcome

Provide students, having a BSc-level background in agricultural, social sciences or sciences involved with development of the tropical region, with a comprehensive understanding of the properties of selected tropical environments, crop species and their management facing climate change. Focus is on climate related production constraints; that is abiotic and biotic stresses, and human endeavor to optimize crop production in small-scale farming, within the context of poverty alleviation and sustainable crop production.

When students have completed the course, they should have attained:

Knowledge

- Manage key elements to characterize production systems in the tropics
- Demonstrate knowledge of the principles of tropical crop production
- Understand the characteristics of major tropical crops
- Demonstrate overview of tropical cropping systems in relation to agro-ecological and socio-economic conditions
- Demonstrate knowledge on different strategies to optimize production systems in the tropics
- Manage basic tools for participatory work and research

Skills

- Characterize production systems of tropical areas of the globe
- Design cropping calendars for selected major crops species
- Analyze and synthesize diverse types of information and data on tropical crop production
- Apply a relevant analytical software for statistics
- Apply relevant participatory rural appraisal methods
- Develop tropical crop production plans in relation to given agro-ecological and socioeconomic conditions
- Design and analyze the implementation of projects in a tropical crop production environment

Competences

- Data management, analysis, and critical approach
- Assess and formulate agronomic components of development support programmes
- Advice extension and research institutions in tropical countries
- Perform and interpret quantitative and qualitative statistical information to analyze scenarios of crop production and innovation
- Propose innovative optimization strategies for sustainable crop production in the tropics

Litterature

Papers and videos uploaded on Absalon
Tropical Crop Production I - Selected papers
Tropical Crop Production II – Manual for practical and theoretical exercises

Recommended Academic Qualifications

Basic courses in biology, statistics, social sciences and sciences related to sustainable development
Academic qualifications equivalent to a BSc degree is recommended.
Academic qualifications equivalent to a BSc degree is recommended .

Teaching and Learning Methods

The course applies blended learning with lectures supported by videos, digital tools, theoretical and practical exercises.

Workload

Table 1: *A table with an overview over the workload for the course.*

Category	Hours
Lectures	30
Preparation	68
Theory exercises	55
Practical exercises	24
Excursions	7
Project work	8
Guidance	10
Exam	4
Total	206

Exam

Table 2: *A table with an overview over the elaborated description of the course*

Credit	7.5 ECTS
Type of assessment	Oral examination, 30 min
Type of assessment details	During the course the student participate in group work in which they write a group report (approximate 10 pages). The students are individually examined in the content of the group report and are further examined in the rest of course curriculum. Examination in the report weight 35 % and examination in curriculum weight 65 %. No preparation time before the oral examination.
Examination prerequisites	Submitted and approval of the reports for theoretical and practical exercises
Aid	All aids allowed
Marking scale	7-point grading scale
Censorship form	• No external censorship • Several internal examiners
Re-exam	• As the ordinary exam. • If the student did not participate in a approved group report, an assignment is given three weeks before the exam. The student has to hand in an individual report based on the assignment (approximate 5 pages). At the oral examination the students will then be examined in the report and in the rest of the curriculum. Examination in the rapport weight 35 % and examination in curriculum weight 65 %.

Contents

Chapter 1
Lecture Notes

1 Lecture 01 - 02/09-2025

1.1 The Tropical Environment

Aim

- Overview the most important aspects of tropical climates.
- Ability to figure out how the climate is likely to be in certain places in the tropics.
- Idea of which crop you can grow.

1.2 What Determines the Climate?

The climate is determined by several factors, including temperature and precipitation. Key aspects are the yearly average temperature and the yearly range in temperature, as some areas experience a larger difference between the highest and lowest temperatures than others. Similarly, average precipitation is important, but the yearly variation in rainfall also plays a significant role.

Core takeaway:

Climate is primarily defined by temperature and precipitation, considering both yearly averages and seasonal variations. Likely exam-relevant.

1.3 Classification: Latitudes

- Tropical zone from 0°-23.5°(between the tropics) latitude: Here, solar radiation reaches the ground nearly vertically, more water evaporates, and the air is often moist. A dense cloud cover reduces the effect of solar radiation on ground temperature.
- Subtropics from 23.5°-40°latitude: These regions receive the highest radiation in summer, have relatively thin cloud cover, and receive less moisture.
- Temperate zone from 40°-60°latitude: This zone is characterized by significantly differing seasons and day lengths, less frequent climate extremes, a more regular distribution of precipitation, and a longer vegetation period.

- Cold zone from 60°-90°latitude: The poles in this zone receive less heat through solar radiation, and day length varies the most. Vegetation is only possible during a few months and is often sparse.

Core takeaway:

Earth's climate zones are classified by latitude, each with distinct characteristics regarding solar radiation, temperature, precipitation, and vegetation periods. Likely exam-relevant.

1.4 Circles of Latitude and Longitude

Earth's Movement and Tropical Rain Belt

The Earth spins around its axis, akin to a top, a process known as Earth's rotation. Simultaneously, it orbits or revolves around the Sun. The tropical rain belt runs along the equator and extends to about the Tropic of Cancer (23.5°north latitude) and Tropic of Capricorn (23.5°south latitude). By approximately 30°north and south latitude, the air cools enough to sink back to the surface, creating high pressure (H) and drier conditions.

Earth's Orbit and Solar Energy

The Earth's revolution around the sun takes 365.24 days. At the equator, the Earth rotates at roughly 1,700 km per hour. The Earth is closest to the sun (perihelion) on January 3rd at 147 million km, moving faster at 27 km/s. It is furthest from the sun (aphelion) on July 4th at 152 million km, moving slower. Solar energy is relatively constant, approximately 400 W/m^2/year. About 300 W/m^2/year is lost as terrestrial re-radiation, leaving a surplus of 100 W/m^2 at the surface. Most of the radiation is absorbed by the Earth and warms it. Some of the outgoing infrared radiation is trapped by the Earth's atmosphere, which also contributes to warming.

Core takeaway:

Earth's rotation and revolution influence climate patterns, including the tropical rain belt, and its interaction with solar energy dictates global temperatures. Likely exam-relevant.

1.5 The Tropics

The tropics are characterized by a high input of solar radiation and high maximum temperatures, with little variation in temperature. Water supply is the most significant variable, marked by high rainfall variability and high rainfall intensity. The tropics cover 42% of the Earth's surface.

Characterize the tropics !

Precipitation

Precipitation patterns in the tropics include:

- Wet climate (between 5°and 10°of the equator).
- Wet dry climate (between 10°and 20°).
- Two wet seasons: typically 1000-2000 mm (e.g., Salvador, Abidjan).
- Two shorter rainy seasons (e.g., Nairobi).
- One long rainy season: monsoonal, 750-1500 mm (e.g., Manila).

- One short rain season: 250-750 mm (e.g., Darwin, Hyderabad).
- Dry climate (e.g., Alice Springs, Lima, Khartoum)

Core takeaway:

The tropics receive high solar radiation and experience consistent high temperatures, with water supply and significant rainfall variability being defining features across different precipitation zones. Likely exam-relevant.

1.6 Three Major Biomes

A biome is defined as a community of similar plants and animals occupying a large area. The three major biomes are Forest, Savanna, and Desert.

Tropical biomes and annual precipitation (mm)

Tropical biomes exhibit extremely high biodiversity, encompassing 50% of the world's terrestrial plant and animal species, despite covering only about 6% of the world's land area.

Core takeaway:

The tropics host three major biomes—Forest, Savanna, and Desert—which are critical for global biodiversity, harboring half of the world's terrestrial species in a small land area. Likely exam-relevant.

1.7 Deforestation

Before human intervention, rainforests covered 15% of the Earth's land area, but today they cover only 6%. In the last 200 years, the total area of rainforest has decreased from 1,500 million hectares to less than 800 million hectares. A third of tropical rainforests have been destroyed in just the last 50 years. Approximately 119,000 - 150,219 km^2 are lost each year, affecting the world's most spectacular ecosystems.

Core takeaway:

Deforestation has drastically reduced tropical rainforest coverage, leading to a significant loss of these vital ecosystems globally. Likely exam-relevant.

1.8 Daily Weather Cycle in the Tropical Rainforest

In the morning, the sun shines and heats up the ground, causing hot and wet air to rise. In the afternoon, dark clouds form, bringing rain and thunderstorms to the rainforest.

1.9 Prevailing Winds

Latitudinal Variation in Evapotranspiration and Precipitation

(figure, see slide 9)

1.10 Remember!

- Hot air weighs less than cold air.
- Hot air can contain more water than cold air.
- Air will flow from areas of high pressure towards areas with low pressure.
- Condensation of water releases energy.
- The temperature of the air drops approximately 1 degree for every 100 m, or 0.5 degrees if the air contains water.
- Objects moving in the northerly or southerly direction will be deflected clockwise in the northern hemisphere and counter-clockwise in the southern hemisphere (Coriolis force) (see also Slide 10).

Core takeaway:

Atmospheric dynamics, driven by temperature, pressure, and the Coriolis force, dictate air movement, moisture content, and temperature changes critical for understanding weather patterns. Likely exam-relevant.

1.11 Coriolis Force

When the Earth rotates, a point close to the equator moves much faster than a point at one of the poles. This movement creates specific patterns on Earth and affects winds and ocean currents.

Core takeaway:

The Coriolis force, a result of Earth's rotation, deflects moving objects and significantly influences global wind and ocean current patterns. Likely exam-relevant.

1.12 Tropical Storms

Tropical storms include Hurricanes (in the Caribbean and United States) and Typhoons (in the Pacific Ocean). These storms are characterized by wind speeds exceeding 115 km/hour, low pressure, and a circular pattern of isobars with a diameter of 150-650 km. They bring extreme rainfall (up to 200 mm/day) and steep gradients that produce high wind speeds.

Cyclones Around Australia

1.13 Monsoons

Monsoons are large-scale sea breezes that occur when the temperature on land is significantly warmer or cooler than the temperature of the ocean. These temperature imbalances happen because oceans and land absorb heat in different ways.

Core takeaway:

Tropical storms like hurricanes and typhoons are intense low-pressure systems with high winds and extreme rainfall, while monsoons are seasonal wind shifts caused by differential heating of land and sea. Likely exam-relevant.

1.14 Southeast Asian Rainforests

Southeast Asian rainforests experience four different seasons: the winter northeast monsoon, the summer southwest monsoon, and two inter-monsoon seasons.

- The northeast monsoon season (November to March) has steady winds from the north or northeast, originating from Siberia, which bring typhoons and other severe weather. The east coasts of the Southeast Asian islands receive heavy rains during this time.
- The southwest monsoon season (May to September) has less wind and is slightly drier, though it still rains every day.
- During the inter-monsoon seasons, the winds are light. All seasons are hot and humid, with very little seasonal variation in temperature.

Core takeaway:

Southeast Asian rainforests experience distinct monsoon seasons driven by regional wind patterns, resulting in varied rainfall but consistently hot and humid conditions year-round. Likely exam-relevant.

1.15 Tropical Rainforests

Tropical rainforests are characterized by a type of tropical climate with no dry season, meaning all months have an average precipitation value of at least 60 mm (2.4 in). There are no distinct summer or winter seasons; it is typically hot and wet throughout the year, with both heavy and frequent rainfall. Around the equator, there are two seasons with heavy rainfall, receiving up to 10 meters a year. As one moves away from the equator, it becomes a bit drier in some months, but there is still more than 2 meters of rain annually. Most of the rainfall does not reach the ground directly, as the trees act as a canopy and catch the rain.

Rainforest Burned Down in South America

(image, see slide 14)

Core takeaway:

Tropical rainforests are defined by continuous high rainfall, consistent high temperatures year-round, and the significant role of their dense canopy in intercepting precipitation. Likely exam-relevant.

1.16 Tropical Desert

Major tropical desert areas include the Sahara and Kalahari deserts in Africa, Arabian, Iranian and Thar Deserts in Asia, Arizona and Mexican deserts in North America, and the Great Australian Desert.

Oasis with Date Palm

(image, see slide 15)

External Resources / Ecosystem Map

[Requires further research: This section primarily provides links to external resources (YouTube and a NOAA ecosystem map) and does not contain descriptive content within the slides themselves.]

1.17 A Simple Illustration of the Major Crop Types in Relation to Climate

[Requires further research: This slide title suggests an illustration but the content is not provided.]

Core takeaway:

Tropical deserts are extensive arid regions found across multiple continents, characterized by very low precipitation and extreme temperatures. Likely exam-relevant.

2 Lecture 02 - 04/09-2025

2.1 Fertility of Tropical Soils

The plan for the day includes discussing factors of soil formation, aspects of soil fertility, an introduction to tropical soil types, and the role of soil organic matter and soil fertility. A group exercise on how to improve the fertility of degraded soils is also part of the plan.

What is soil?

Soil is defined as the unconsolidated mineral or organic material on the immediate surface of the Earth that serves as a natural medium for the growth of land plants (see also Slide 2).

Core takeaway: This section introduces the course, the instructor, the agenda, and a fundamental definition of soil. Exam relevance marker: Likely exam-relevant (definition of soil).

2.2 Soil Profile and Formation

Soil Profile

Figure: An illustration of a soil profile, depicting layers down to bedrock (see slide 2).

What is soil?

This slide reiterates the definition of soil (see also Slide 1).

Soil formation

Weathering

Weathering is the disintegration and decomposition of solid rock material, encompassing both chemical and physical processes. The most important form of chemical weathering involves H^+ ions from water penetrating rock mineral structures and displacing ions like K^+, Ca^{2+}, Mg^{2+}, and Al^{3+}. This process causes minerals to break down into clay and leads to the leaching of ions.

Primary particles

Mineral fraction

The mineral fraction of soil is categorized by particle size:

- Sand size fraction: 50 μm - 2 mm
- Silt size fraction: 2 μm - 50 μm
- Clay size fraction: < 2 μm

Core takeaway: Soil formation involves weathering of bedrock into primary particles, which are classified by size.
Exam relevance marker: Likely exam-relevant (weathering definition, particle sizes).

2.3 Soil Components and Factors of Soil Formation

Clay size fraction

- Clay size fraction: < 2 μm

Soil organic matter

The pool of soil organic matter is defined as biologically derived soil material (see also Slides 14, 15, 16). It consists of:

- A large fraction of humic substances
- Fresh and partly decomposed plant residues
- A small fraction of living soil microbial biomass

Soil texture

This slide poses a question: "A soil with 35 % sand, 35 % clay and 30 % silt called?"
[Requires further research: The answer to the soil texture question is not provided directly on the slide.]

Soil Structure

[Requires further research: This headline is present, but no content is provided for 'Soil Structure' on this slide.]

Factors of soil formation

The factors influencing soil formation include (see also Slides 4, 5):

- Parent material
- Climate
- Topographical position
- Biological factors
- Time

Parent Material

Parent material refers to in situ rocks (bedrock) (see also Slide 4).

Core takeaway: This section details soil particle sizes, defines soil organic matter, lists the five key factors of soil formation, and introduces parent material. Exam relevance marker: Likely exam-relevant (soil organic matter components, factors of soil formation).

2.4 Parent Material and Climate in Soil Formation

Parent Material

Bedrock consists of sedimentary or metamorphic rock brought to the surface by geological processes. Parent materials are derived from the weathering of bedrocks and interact with other soil formation factors to determine the secondary minerals formed (see also Slide 3).

Climate

A hot and humid climate leads to intensive weathering and leaching (see also Slide 3). This removes Aluminum (Al) and Silicon (Si), resulting in the formation of the clay mineral kaolinite, which has a low Cation Exchange Capacity (CEC) and is less fertile (see also Slides 7, 8, 10, 12, 15). Kaolinite's chemical formula is Al2Si2O5(OH)4. The topographical position of a soil on a landscape will affect the impact of climatic processes (see also Slide 5).

Core takeaway: Parent material originates from bedrock, and climate, especially hot and humid conditions, drives intensive weathering, leaching, and the formation of low-fertility clay minerals like kaolinite. Exam relevance marker: Likely exam-relevant (impact of climate on weathering and clay formation).

2.5 Other Factors of Soil Formation and Soil Fertility Introduction

Topography

Erosion and leaching cause minerals to accumulate at the bottom of a slope (see also Slide 3).

Biological factors

Biological factors contribute to soil formation through (see also Slide 3):
- Faunal activity (mixing of soil)
- Plant activity (rooting, formation of acids, prevents leaching of nutrients)

Time

The age of soils varies significantly; for example, most Danish soils are approximately 12,000 years old, while some African soils are 500 million years old (see also Slide 3).

Soil fertility

Soil fertility is defined as the ability of soil to sustain and provide essential nutrients and create favorable conditions for plant growth and development (see also Slides 11, 13, 15, 16, 17). Key aspects of soil fertility include:
- Nitrogen
- Processes affecting inputs and losses of N
- Phosphorus

- Phosphorus Fixation
- Base cations
- Cation Exchange Capacity (CEC)
- Base Saturation

Core takeaway: Topography, biological activity, and time are crucial soil-forming factors. Soil fertility, defined by its capacity to support plant growth, hinges on nitrogen, phosphorus, base cations, CEC, and base saturation. Exam relevance marker: Likely exam-relevant (definition of soil fertility, factors of soil formation).

2.6 Nitrogen and Phosphorus in Agroecosystems

Nitrogen in Agroecosystems

Figure: A diagram illustrates the nitrogen cycle within agroecosystems (see slide 6). Inputs to the system include N fixation, deposition, organic fertilizer, and inorganic fertilizer. Outputs consist of leaching, denitrification, and NH3 volatilization. Internal processes within the soil involve mineralization, ammonification, nitrification, immobilization, and plant uptake. The forms of nitrogen include organic N, plant N, NH_4^+, and NO_3^-.

P availability in soil

Figure: A diagram shows phosphorus availability in soil (see slide 6). Phosphorus exists in stable, labile, and organic forms, as well as in the soil solution P. Inputs of phosphorus come from manure, waste, and mineral fertilizer. Outputs include plant uptake and loss of P, as well as leaching. A significant process affecting phosphorus is Phosphorus Fixation (see also Slides 5, 11, 12, 13, 17).

Core takeaway: Nitrogen and phosphorus cycles in agroecosystems involve complex inputs, outputs, and internal processes that determine nutrient availability. Exam relevance marker: Likely exam-relevant (understanding N and P cycles, P fixation).

2.7 Cations and Cation Exchange Capacity (CEC)

Base and acid cations in soil

Base cations

These positively charged ions include Calcium (Ca_2^+), Magnesium (Mg_2^+), Potassium (K^+), Sodium (Na^+), and Ammonium (NH_4^+) (see also Slides 5, 9, 11, 12, 13).

Acid Cations

These include Aluminium (Al_3^+), Iron (Fe_3^+), and Hydrogen (H^+).

Clay Minerals

Common clay minerals are classified as 1:1 type (e.g., Kaolinite) and 2:1 type (e.g., Smectite) (see also Slides 4, 8, 10, 15).

Isomorphous substitution

Isomorphous substitution is a process where a higher charged ion is replaced with a lower charged ion within the mineral structure, resulting in a net negative charge. Examples include Si_4^+ being replaced with Al_3^+ in the tetrahedral sheet, and Al_3^+ being replaced with Mg_2^+ in the octahedral sheet.

Cation Exchange Capacity (CEC)

CEC is defined as the amount of exchangeable cations that a soil can adsorb (see also Slides 4, 5, 8, 10, 12, 15, 17). It is expressed in terms of centimoles of positive charge adsorbed per unit of mass, specifically in centimol positive charge per kg of soil (cmol(+)/kg).

Core takeaway: Soil cations are categorized as base or acid, and clay minerals exhibit a net negative charge due to isomorphous substitution, which contributes to the soil's Cation Exchange Capacity (CEC). Exam relevance marker: Likely exam-relevant (definitions of base/acid cations, isomorphous substitution, CEC).

2.8 Cation Exchange and Clay Mineral CEC Values

Figure: This figure illustrates cation exchange on a plant root, where H^+ ions are exchanged for other cations from the soil solution (see slide 8). It also shows cation exchange occurring on the surfaces of organic material and clay particles.
Different clay minerals possess varying CEC values and properties:

Table 1.1: *An overview of clay minerals and their properties*

Type of clay mineral	Type	CEC /cmol (+)/kg	Expansible	pH dependent charge
Kaolinite	1:1	1–10	No	Most
Smectite	1:2	80–120	Yes	Little
Vermiculite	1:2	120–150	Partly	Little
Illite	1:2	20–50	No	Medium
Allophane	Amorphous	50–150	No	Most

Core takeaway: Cations are exchanged between plant roots, soil solution, and charged surfaces of clay and organic matter, with different clay minerals having distinct CEC values and characteristics influencing their behaviour. Exam relevance marker: Likely exam-relevant (mechanism of cation exchange, comparative CEC values of different clay minerals).

2.9 pH Dependent Charge and Base Saturation

pH Dependent Charge

Figure: A graph visually represents the relationship between pH and charge, indicating how soil charge can be pH-dependent across a range (e.g., pH 4.0, 5.0, 6.0, 7.0) (see slide 9).

% Base Saturation

Base Saturation is defined as the percentage of the exchange complex that is saturated with base cations (see also Slides 5, 12). It is measured in centimoles of positive charge. Adsorbed cations are in equilibrium with solution cations. The formula for Base Saturation is:

$$\text{Base Saturation} = 100\% \times \frac{\text{Base Cations}}{\text{CEC}}$$

An example calculation is provided: Given CEC = 40 cmol(+)/kg, K^+ = 16 cmol/kg (= 16 cmol(+)/kg), Ca^{++} = 4 cmol/kg (= 8 cmol(+)/kg), Mg^{++} = 2 cmol/kg (= 4 cmol(+)/kg). Base saturation = 100 x (16+8+4) / 40 = 70%.

Core takeaway: Soil charge can be pH-dependent, and Base Saturation quantifies the proportion of exchange sites occupied by base cations, indicating soil fertility. Exam relevance marker: Likely exam-relevant (definition and calculation of base saturation).

2.10 Estimating CEC and Base Saturation for Tropical Soils

Estimate the Cation Exchange Capacity (CEC) of the two soils

Exercise 1

This exercise provides characteristics for two soil types for estimation:

- Ultisol: Kaolinite, pH 4.6, 60% clay, 4% organic matter (see also Slides 11, 12)
- Vertisol: Smectite, pH 7.2, 20% clay, 2% organic matter (see also Slides 11, 12, 13)

The calculation of CEC would involve considering CEC contributions from both clay and organic matter. A table providing average CEC values for different clay minerals is given (Avg. 4 cmol(+)/kg for Kaolinite, Avg. 95 cmol(+)/kg for Smectite, etc.) (see also Slide 8).

Exercise 2

This exercise requires calculating the base saturation of the two soils (Ultisol and Vertisol) based on the CEC values calculated in Exercise 1, using given base cation contents.

Core takeaway: Exercises are presented to estimate CEC based on clay mineral type and organic matter content, and subsequently calculate base saturation, for different tropical soil types. Exam relevance marker: Likely exam-relevant (practical application of CEC and base saturation calculations).

2.11 Fertility Comparison and Tropical Soil Types

Discuss which soil is more fertile and how?

This question prompts a comparison of the fertility of Ultisol and Vertisol, using the following base cation content data:

Table 1.2: *Cation content in different soil types*

Soil type	K^+ (cmol)	Mg^{2+} (cmol)	Ca^{2+} (cmol)	Na^+ (cmol)
Ultisol	0.08	0.1	0.3	0
Vertisol	2.1	2.4	3.2	0.2

(Table, see slide 11)

Tropical soil types

Soils are classified according to the United States Department of Agriculture (USDA) Soil Taxonomy. The tropical soil types listed are:

- Oxisol (see also Slide 12)
- Ultisol (see also Slide 12)
- Alfisol (see also Slide 12)
- Vertisol (see also Slides 12, 13)
- Andisol (see also Slide 13)
- Aridisol (see also Slide 13)

Oxisols

Oxisols are soils with an oxic horizon, meaning they are highly weathered and dominated by Iron- and Aluminum oxides, with some kaolinite present. They typically have less than 10% weatherable minerals. Oxisols are formed under conditions of intensive weathering and leaching in hot and humid climates.

Core takeaway: This section provides data for comparing soil fertility between Ultisols and Vertisols and introduces the major classifications of tropical soil types, with a detailed description of Oxisols. Exam relevance marker: Likely exam-relevant (characteristics of tropical soil types, comparison of fertility).

2.12 Characteristics of Tropical Soil Orders

Oxisols

Continuing from the previous slide, Oxisols are characterized by:

- Low CEC (see also Slides 4, 5, 7, 8, 10, 15, 17)
- High P fixation (see also Slides 5, 6, 11, 13, 17)
- Low pH

Ultisol

Ultisols possess an argillic horizon (clay accumulation) and are subject to intensive weathering and leaching in hot and humid climates (see also Slides 10, 11). Their characteristics include:

- More weatherable minerals than Oxisols
- Well drained
- Low CEC
- Low level of bases
- High P fixation
- Low pH

Alfisol

Alfisols also feature an argillic horizon (clay accumulation) (see also Slide 5). Key attributes are:

- Higher base saturation than Ultisol (see also Slides 5, 9)
- Seasonal moisture deficit
- Transition zone to semi-arid climates

- Medium CEC
- > 35% base saturation
- Medium fertility

Vertisol

Vertisols are distinguished by a high content of expanding clay minerals (see also Slides 10, 11, 13).

Core takeaway: This section details the distinct characteristics, particularly in terms of CEC, P fixation, pH, and base saturation, for Oxisols, Ultisols, and Alfisols, and introduces Vertisols. Exam relevance marker: Likely exam-relevant (comparative characteristics of different tropical soil orders).

2.13 Further Characteristics of Tropical Soil Orders

Vertisols

Continuing the description, Vertisols are typically:

- Formed from highly basic rocks and in climates that are seasonally humid
- Sticky when wet
- Hard when dry
- Neutral - alkaline pH
- Medium - high content of basic cations (see also Slides 5, 7, 9, 11)
- High fertility (see also Slides 5, 11, 12, 15, 16, 17)

Andisol

Andisols are:

- Young soils developed from volcanic material
- High contents of organic matter (see also Slides 3, 14, 15, 16, 17)
- High content of basic cations
- High fertility
- High P fixation

Aridisols

Aridisols are:

- Found under arid soil moisture regimes (i.e., in dry areas)
- Typically sandy
- Too dry for crop production unless irrigated
- Often used for grazing
- Low content of organic matter

Core takeaway: This section completes the overview of tropical soil orders, highlighting the high fertility of Vertisols and Andisols due to their unique properties, and the challenges associated with Aridisols in dry regions. Exam relevance marker: Likely exam-relevant (characteristics of Vertisols, Andisols, and Aridisols).

2.14 Soil Organic Matter and Carbon Cycling

Soil organic matter and fertility

Soil organic matter largely comprises fresh and partly decomposed plant residues, with a smaller fraction consisting of living soil microbial biomass (see also Slides 3, 15, 16). Figure: A diagram illustrates the flow of carbon in the soil-atmosphere system (see slide 14). Atmospheric carbon is fixed through photosynthesis. Carbon is lost to the atmosphere through respiration. Organic carbon enters the soil via above- and below-ground litter. Some carbon transforms into soil organic carbon, while some is lost to the atmosphere through soil respiration.

Core takeaway: Soil organic matter is critical for fertility, composed mainly of plant residues and microbial biomass, and plays a central role in the global carbon cycle. Exam relevance marker: Likely exam-relevant (composition of SOM, basic carbon cycle).

2.15 Factors Affecting Soil Organic Matter and Importance in Tropics

Soil organic matter and fertility

Inputs:

Factors contributing to soil organic matter include:
- Crop/vegetation
- Farming practice/residue use
- Manure applications

Outputs:

Factors influencing the loss or transformation of soil organic matter include:
- Climate (temperature, precipitation)
- Soil properties (texture, mineralogy, stabilization, pH, etc.)
- Biological factors (decomposer organisms, etc.)
- Chemical factors (quality of residue, etc.)
- Soil management (tillage, drainage, etc.)

Soil organic matter in tropical soils - why bother?

Soil organic matter is particularly important in tropical soils because:
- These soils are often weathered and low in nutrients
- They frequently contain clay types with low CEC
- They are erodible
- They experience high intensity rainfall events
- There is serious water deficiency in semi-arid and arid tropics

Core takeaway: Soil organic matter levels are a balance of inputs and outputs influenced by climate, soil properties, biological and chemical factors, and management. Its importance is amplified in tropical soils due to inherent challenges like low nutrient content and erodibility. Exam relevance marker: Likely exam-relevant (factors influencing SOM, reasons for SOM importance in tropics).

2.16 Soil Organic Carbon (SOC) and Soil Health

Soil organic matter in tropical soils - why bother?

Tropical soils have been most depleted, yet their productivity must be increased to meet the demands of a growing population (see also Slide 15).

SOC is an important indicator of soil health

Soil Organic Carbon

Management options to increase soil organic matter (SOM) / soil organic carbon (SOC) include:

- Tillage
- Crop rotations
- Perennials
- Root system
- Cover crops
- Crop residues
- Animal manure
- Biochar

SOC influences soil health through its Physical, Chemical, and Biological impacts:

- Physical: Aggregate stability, improved soil structure, improved soil porosity, bulk density, water holding capacity
- Chemical: Cation Exchange Capacity (CEC), soil pH, binds heavy metal (see also Slides 4, 5, 7, 8, 9, 10, 12, 15, 17)
- Biological: Earthworms, soil microorganisms, soil ecosystem

Core takeaway: SOC is a crucial indicator of soil health, with various management practices available to increase it, leading to significant physical, chemical, and biological benefits in the soil. Exam relevance marker: Likely exam-relevant (importance of SOC, management options, benefits of SOC).

2.17 Strategies for Enhancing Soil Fertility and Carbon Pool

Reduction of P fixation

Figure: Chemical structure showing CO - O^- and Al_3^+ (see slide 17). This illustrates how organic matter can chelate aluminum, thereby reducing P fixation (see also Slides 5, 6, 11, 12, 13).

Reduction of Al toxicity

Figure: Chemical structure showing CO - O^- and Al_3^+ (see slide 17). Organic matter also helps in the reduction of Al toxicity.

Improve soil structure

Figure: Diagram showing how organic material and clay contribute to soil structure (see slide 17).

Strategies for Enhancing the Soil Carbon Pool

The management options to increase Soil Organic Matter (SOM) listed are:
- Tillage
- Crop rotations
- Perennials
- Root system
- Cover crops
- Crop residues
- Animal manure
- Biochar

Theoretical exercise: How to increase soil fertility of degraded soils?

This exercise involves discussing possible ways to improve the fertility of degraded soils in groups (see also Slide 18). Group inputs count as the deliverable.

Core takeaway: Enhancing the soil carbon pool through various management strategies directly improves soil fertility by reducing P fixation and Al toxicity, and improving soil structure. Exam relevance marker: Likely exam-relevant (benefits of SOM, management strategies).

3 Lecture 03 - 04/09-2025

3.1 Gabriela Alandia Robles PhD

Quinoa (*Chenopodium quinoa*)

Quinoa (*Chenopodium quinoa*) is characterized as a dicotyledonous, annual plant belonging to the Amaranthaceae family. It is a facultative short-day plant, demonstrating resilience to salinity and drought, and is facultative autogamous. Quinoa is noted to grow in the Bolivian highlands, specifically in the Oruro region.

3.2 Quinoa: An Andean Heritage to the World

Quinoa: A Host Under Domestication

According to legend, a young man, carried on the back of a condor, reached his girlfriend who resided among the stars, and she bestowed quinoa seeds upon him.

3.3 The Origin of Quinoa

The origin of quinoa is a topic of interest, with further details available via a provided link (Youtube Video). The quinoa seed is an "Amazing seed-food" due to its nutritional profile.
- 58 to 64% of the seed volume consists of non-living starch perisperm.
- It is a high-energy food with a low glycemic index.
- Quinoa is gluten-free and offers a good balance of essential amino acids.
- Its protein content ranges from 12-16%.

- The seeds are typically 1.5 to 2.6 mm in diameter.

New Emerging Diseases

The intensification, globalization, and diversification of agriculture are contributing factors to the emergence of new diseases affecting crops. Fungi, crucial for adaptation, exist in a symbiotic continuum and can be classified as endophytic, pathogenic, saprophytic, or necrotrophic. These fungi engage in various symbiotic relationships, including mutualism, parasitism, and commensalism.

3.4 Domestication Penalties

Domestication processes can potentially compromise the natural defences of crops. Climate change, marked by sudden temperature changes, altered rainfall patterns, and increased CO2 emissions, impacts plant growth, metabolism, and physiology. Circadian clock genes also play a role in these domestication-related challenges.

3.5 Sustainable Harvest for Humankind

Achieving sustainable harvest for humankind involves several strategies:

- Exploration of biodiversity panels in search of sources of disease resistance.
- Phenotyping disease severity of known symptoms.
- Utilizing genomic data for new breeding techniques.

Downy Mildew Pathogens: *Peronospora farinosa* and *Peronospora variabilis*

Peronospora farinosa and *Peronospora variabilis* are identified as obligate parasites that are closely tuned to the physiology of their host plants.

3.6 Microscopic View: *Chenopodium album*

[Requires further research: The provided dimensions (30x24µm, 28x21µm) likely refer to spores or other structures of Chenopodium album, but their specific context is not detailed in the source (see slide 5).]

P. variabilis Timeline

Sporulation of *P. variabilis* is conditional on infection. *Image: A timeline illustrating stages (0, 2, 3, 6, 7, 8) that likely represent progression of P. variabilis infection or sporulation, though specific labels are not provided (see slide 5).*

Phenotypic Response to Downy Mildew

The phenotypic response to downy mildew involves assessing severity on the adaxial side of the plant and observing sporulation on the abaxial side. As noted, sporulation is conditional on infection.

Bolivian Quinoa Collection

The Toralapa bank for Andean grains maintains a Bolivian quinoa collection. Artificial inoculations under greenhouse conditions were employed for the validation of check varieties, which exhibited distinctive responses. Puno, Titicaca, and Vikinga were chosen as check varieties, while the Blanca variety was found suitable for propagation.

3.7 Quinoa Varieties: Blanca and Puno

These specific quinoa varieties, Blanca and Puno, were significant in the research on downy mildew response.

Distribution of Downy Mildew Severity in Quinoa Genotypes

Research on 133 quinoa genotypes revealed a large variation in their response to *P. variabilis*. The heritability for severity was estimated to be approximately 0.72, indicating that this trait is a strong candidate for selection in breeding programs. *Image: A bar chart depicting the distribution of average severity (%) response to downy mildew across 133 quinoa genotypes, clearly illustrating the significant variation and distinct patterns between lowland and highland populations (see slide 6).*

Population Structure

Quinoa populations are differentiated, notably into lowland and highland groups.

3.8 Quinoa Eco-regions

Quinoa eco-regions are characterized by diverse agro-climatological features, as adapted from Colque-Little et al., 2021:

- **Northern Highland (NH):** Features organic matter-rich soil, altitudes ranging from 3500-4000 m.a.s.l., 500 mm of rainfall, and an average temperature of 7°C (with a maximum of 14°C and a minimum of 4°C).
- **Central Highland (CH):** Characterized by slightly acidic soil, altitudes of 3300-4100 m.a.s.l., 350 mm of rainfall, and an average temperature of 9°C (with a maximum of 18°C and a minimum of -2°C).
- **Southern Highland (SH):** Defined by arid, poor soils, altitudes of 3200-4000 m.a.s.l., low rainfall (50-200 mm), and an average temperature of 5.7°C (with a maximum of 18°C and a minimum of -11°C).
- **Andean Valleys (AV):** Exhibit variable soil types, altitudes from 800-3200 m.a.s.l., 350-700 mm of rainfall, and an average temperature of 7.6°C (with a maximum of 12°C and a minimum of 3°C).
- **Coastal Lowland (CL):** Possesses variable soil, ranges from sea level to mountain, experiences 40-2000 mm of rainfall, and has an average temperature of 17°C (with a maximum of 23°C and a minimum of 21°C).

Image: A map-like diagram visually representing quinoa ecoregions, indicating altitude (m.a.s.l.) and the geographical distribution of NH, CH, SH, and AV (see slide 7).

Geographical Distribution of Quinoa Ecoregions

Quinoa ecoregions include diverse geographical areas such as the Lowlands (Chile/Denmark), Northern Highlands, Lake Titicaca (Peru), Andean slopes, Valleys, and the Central and South Highlands (Bolivia).

3.9 Diversity Panel and Bolivian Collection

A diversity panel containing 61 accessions with genomic data is utilized for research, offering a comparative perspective against the larger Bolivian collection which encompasses 2883 accessions.

Comparison of Diversity Panel with Bolivian Collection

This comparison provides insights into the genetic breadth and specific characteristics within the broader Bolivian quinoa genetic resources.

3.10 Epilogue

The lecture concludes with several inspiring reflections:

- The world presents a "tropical adventure of opportunities."
- An example of ingenuity is noted: in Greenland, Christmas trees are fashioned from wood sticks.
- The Incas were credited with creating an agro-ecological observatory, demonstrating their advanced understanding of the highland tropics.
- A hope that the audience was inspired is expressed.

3.11 Famine Way in Dublin City Center

A historical reference is made to the Famine Way in Dublin city center, noting that the famine it commemorates was caused by Potato late blight in 1845.

3.12 Farmer Field School

Farmer field schools focus on integrating several critical aspects for agricultural development:

- Social aspects
- Taste
- Price
- Local adaptation

Lecture Wrap-Up

Core takeaway: This lecture provides a comprehensive overview of quinoa (*Chenopodium quinoa*), highlighting its significance as a tropical crop. It delves into the plant's biological characteristics, the challenges posed by domestication, and the emergence of new diseases, particularly downy mildew caused by *Peronospora variabilis*. The importance of exploring genetic diversity within extensive collections, such as those from Bolivia, and understanding diverse agro-climatological eco-regions for sustainable cultivation practices, is emphasized. The lecture also touches upon broader historical and social aspects of agriculture and crop management.

Exam relevance marker: Likely exam-relevant.

4 Lecture 04 - 04/09-2025

4.1 Highland Tropics

POACEAE Grass-family

Eleusíne coracána (L.) Gaertn.

Origin: East African highlands. Common name: Finger Millet.

POACEAE Chloridoideae

Eragróstis téf (Zucc.) Trotter

Origin: Ethiopia. Common names: T'ef or Teff.

4.2 Eragrostis

Eragróstis téf (Zucc.) Trotter is also known as T'ef or Teff.

4.3 Africa

AMARANTHACEAE Grain Amaranths

Amaranthus caudatus L.

Origin: Central and South American highlands. Common names: Kiwicha (Quechua), Quamasa (Aymara).

Amaranthus cruentus L.

Origin: Central and North American highlands. Common names: Mexican grain amaranth.

Amaranthus hypochondriacus L.

Origin: Mexico. Common names: Quelite, bledo (Mx), quintonil (Sp).

AMARANTHACEAE Quinoa

Chenopodium quinoa Willd.

Origin: NW Andes, South America. Common names: Kinuwa (Quechua), quinoa (Sp) (see also previous lecture notes).

AMARANTHACEAE Cañahua

Chenopodium pallidicaule Aellen

Origin: Andes, South America. Common names: Qañiwa (Quechua), cañahua (Sp).

FABACEAE

Lupinus mutabilis Sweet

Origin: Andean valleys. Common names: Andean lupine, 'el chocho', 'tarwi' (Quechua). *Lupinus mutabilis* contains several antinutritional factors, including bitter alkaloids, phytic acid, oligosaccharides (α-galactosides), and tannins. These compounds limit the nutritional value and palatability of the lupin, with alkaloids being a primary concern due to their bitterness and potential toxicity, and oligosaccharides causing flatulence. Traditional and improved debittering methods involving hydration, washing, and fermentation are used to reduce these antinutrients for consumption.

APIACEAE

Arracacia xanthorrhiza Bancr.

Origin: Andes. Common names: Arracacha, Zanahoria blanca.

4.4 Distribution of Arracacha

An image illustrating the distribution of arracacha cultivation and wild *Arracacia* species in South America (see slide 4).

ASTERACEAE

Smallanthus sonchifolius (Poepp. & Endl.) H.Robinson

Origin: Andes. Common names: Yacon, xicama. This plant contains inulin. An image displays flowering branches (A), leaves (B), Capitulum (C), tuberous Roots (D-F), a transverse section of root showing xylem (x) and cortex (c) (G), and a staminate disk (H) (see slide 5). The distribution in the Andean region is shown, noting that the present Colombian distribution is doubtful and indicated by a question mark (see slide 6).

BASELLACEAE

Ullucus tuberosus Caldas

Origin: Andes. Common names: Ulluco, papa lisa.

BRASSICACEAE

Lepidium meyenii Caldas

Origin: Andes. Common name: Maca. Maca cultivation is currently restricted to the Departments of Cerro de Pasco and Junin, though it is believed to have been more widely cultivated in the past, extending from Junin to Puno.

4.5 Geographic Distribution of Maca

An image illustrating the geographic distribution of maca in Peru (see slide 6). An altitude profile depicting the main maca production area (see slide 7).

CANNACEAE

Canna edulis Ker Gawl.

Origin: Andes. Common name: Achira.

FABACEAE

Pachyrhizus ahipa (Wedd.) Parodi

Origin: Bolivian (and possibly Peruvian) Andean valleys. Common names: Ajipa, ahipa. Reproductive pruning in *ahipa* involves manually removing flowers to prevent competition between pod formation and the growth of the tuberous root. This operation significantly impacts tuberous root yield, as observed in field experiments in Portugal. An image shows ahipa seeds being sold, possibly in a hat (see slide 8). A map displays the distribution of *ahipa*, with dots representing field collections, triangles indicating herbarium specimens, and a hatched area denoting regions above 2500 m.a.s.l. (see slide 8).

NYCTAGINACEAE

Mirabilis expansa Ruíz & Pavon

Origin: Andes.

OXALIDACEAE

Oxalis tuberosa Molina

Origin: Andes.

SOLANACEAE

Solanum tuberosum L.

Origin: Andes. Common name: Papa (potato). An image shows *Solanum tuberosum* (potatoes) from a market in La Paz, Bolivia (see slide 8). Another image depicts Peruvian landraces of *Solanum tuberosum* (top left) and 'Chuño' (freeze-dried potatoes) displayed at markets in Bolivia and Peru (top right, bottom left) (see slide 8). Germplasm of *Solanum tuberosum* is maintained at the Bioversity (IPGRI) Experimental Station in Santa Catalina, Quito, ECUADOR.

TROPAEOLACEAE

Tropaeolum tuberosum Ruíz & Pavon

Origin: Andes. Common names: Mashua, isaño, maswallo. An image illustrates the distribution of mashua (see slide 9). This map distinguishes between cultivated mashua (*Tropaeolum tuberosus* ssp. *tuberosum*) and wild mashua (*T. tuberosus* ssp. *silvestre*). A map details the distribution of cultivated mashua, with dots marking genebank accession collecting sites from 1986-98 (source: CIP databases) and shaded areas indicating regions above 2000 m.a.s.l. (see slide 9). An image compares various Andean tubers including Mashua (*Tropaeolum tuberosum*), Oca (*Oxalis tuberosa*), Ulluco (*Ullucus tuberosus*), and Papa (*Solanum tuberosum*), with their respective scientific names (see slide 9).

Lecture Wrap-Up

Core takeaway: This lecture provides a comprehensive overview of various traditional crop species primarily cultivated in the Highland Tropics, particularly within the Andean region of South America and East African highlands. It systematically categorizes these crops by their botanical families, detailing their scientific and common names, geographical origins, and distinctive characteristics. Key aspects such as antinutritional factors in lupine, the presence of inulin in yacon, and specific cultivation techniques like reproductive pruning in ahipa are highlighted. The lecture underscores the rich biodiversity and cultural significance of these crops through descriptions and references to their distribution and market presence.

Exam relevance marker: Likely exam-relevant.

5 Lecture 05 - 09/09-2025

This lecture was given by Christian Andreasen. For questions, write to can@plen.ku.dk.

5.1 Seed Biology

The lecture covers several key aspects of seed biology:

- What is a seed
- Seed structure
- Seed germination
- Seed vigour

Fruits

A true fruit is formed solely from the ovary. In contrast, a false fruit develops from other parts of the plant in addition to the ovary, such as a pome, strawberries, or species like *Rosa* sp..
Examples of pome fruits include apples or pears. Fruits can also be categorized as dry or fleshy. An image shows *Rosa canina* hips, which are false fruits. Another image shows pears.

5.2 Poaceae Seed Structure: Caryopsis

The caryopsis is a characteristic fruit type of the Poaceae (grass family), commonly known as cereal grain, found in wheat and other cereals. A diagram of a caryopsis illustrates its structure, including:

- Scutellum (the cotyledon of grasses)
- Radicle
- Coleoptile (cotyledonary sheath)
- Plumule (embryonic shoot)
- Pericarp and seed coat (fused together)
- Endosperm (seed albumen)
- Root cap

Image: A diagram illustrating the components of a caryopsis, specifically a cereal grain (see slide 2). Image: A cornfield (see slide 2).

5.3 Nut of Sunflower (*Helianthus annuus*)

The nut of sunflower is characterized by all storage being in the embryo. Its structure includes the seed coat and pericarp. An image depicts a sunflower with black seeds. *[Requires further research: The statement "Contains* *the protein ricin. Lethal dose: 0,2 milligram" on slide 3 is presented without clear context; it is not directly linked to sunflower seeds or any specific preceding seed.]*

Nutritional Content

The sunflower nut contains approximately 20% protein.

5.4 Carob Seed

Carob seeds are notable for their consistent weight, approximately 0.2 g. They originate from the locust tree.

5.5 Seed Germination

This section explores when a seed germinates and the factors involved in this process. Seed dormancy is a common trait in wild plants, particularly weeds. In contrast, plants with a long history of domestication and plant breeding generally exhibit lower seed dormancy compared to their wild or more recently domesticated counterparts.

Consequences of Lack of Dormancy

A lack of seed dormancy can lead to pre-harvest sprouting, which poses a significant problem in cereals such as rice, wheat, barley, maize, and in non-dormant mutants.

Viviparous Germination

Viviparous germination occurs when mature seeds germinate while still within the ripe fruit. *Image: Viviparous germinating mature seeds in ripped fruit (see slide 5).*

Capsicum and Maize Mutants

Precocious germination can be observed in the ABA-deficient vp14 mutant of maize. The VP14 protein catalyzes the cleavage of 9-cis-epoxycarotenoids to form xanthoxal, which is a precursor of Abscisic acid (ABA). ABA is a crucial plant hormone involved in many plant developmental processes.

5.6 Imbibition

Imbibition is the initial uptake of water by seeds. Proteins, being zwitterions, attract highly charged polar water molecules. Protein-containing seeds can imbibe 2-5 times their dry weight in water, while cereals typically imbibe 1.5-2 times their dry weight. Starch, having an uncharged structure, has little impact on the imbibition process.

Types of Germination

Germination can be classified into two main types: Hypogeal germination and Epigeal germination.

Water Uptake by Germinating Seeds

The imbibition process triggers several physiological changes in the seed:

- I. Enzyme activities begin.

- II. Respiration increases, leading to the breakdown of storage compounds and leakage of nutrients, which results in a reduced dry weight.
- III. The root elongates and becomes functional.

Image: A general graph illustrating the uptake of water (increase in fresh weight) by germinating seeds over time (see slide 7).

Result of the Imbibition

The immediate consequence of imbibition is the initiation of these metabolic processes within the seed.

5.7 Germinating Wheat Kernel

A germinating wheat kernel typically contains about 45-50% water.

Wheat Germination and Emergence

During wheat germination and emergence, the coleoptile (embryonic shoot sheath) lacks chlorophyll and ceases growth after emergence from the soil. After emergence, the plant typically develops 2-3 leaves.

5.8 Factors Affecting Water Uptake

Seeds both absorb and lose water during germination. Agronomic practices are designed to enhance water uptake and minimize water losses. Key factors influencing water uptake by the seed and initiating germination include:

- A. Soil water content
- B. Soil characteristics, which determine how tightly water is held
- C. The rate of water movement to the seed
- D. Seed/soil contact areas, which increase as soil aggregate size decreases
- E. Contact "resistance," as some seeds possess a barrier to water uptake

5.9 Hydrotime Model for Seed Population

The hydrotime model describes the relationship between time to germination of a seed population and available water. A conceptual figure illustrates the "Time to radicle emergence" as it relates to water potential (ranging from -1 to 0).

Hydrotime Model Formula

The hydrotime model is given by the formula: $\theta_H = (\Psi - \Psi_b(g))t_g$.

- θ_H (Theta H) represents the hydrotime constant, measured in MPa days.
- Ψ (Psi) is the actual seed water potential.
- $\Psi_b(g)$ is the minimum or base water potential defined for a specific fraction g of the seed population.
- t_g is the time to radicle emergence for that specific fraction g.

5.10 Generalized Time Course of Germination

The relationship between the percentage of germinated seeds and time typically follows an S-shaped curve, with initial lag, rapid increase, and eventual plateau. *Image: A generalized graph showing "Percentage of germinated seeds" from 0% to 100% against "Time", illustrating the typical S-curve of germination (see slide 10).*

5.11 Vigour Definition

According to ISTA (1995), vigour is defined as "the total sum of those properties of the seed which determine the level of activity and performance of the seed or seed lot during germination and seedling emergence. Seed, which perform well, are termed 'high vigour seeds'". Seed vigour is crucial for field performance, storage, and transport of seed lots.

Vigour vs. Germination Percentage

Germination data alone may indicate similar quality across seed lots, but vigour tests reveal differences in performance.

- Field Performance - *Pisum sativum* L.: Seed lots 1, 2, 3, and 4 showed similar germination percentages (93%, 92%, 95%, 97% respectively), but their field emergence varied significantly (84%, 71%, 68%, 82%).
- Storage Performance - *Trifolium pratense* L.: All four seed lots initially had 90% germination. However, after 12 months of storage, their germination rates diverged (71%, 90%, 66% 89%), indicating different storage capabilities.
- Transport Performance - *Bromus willdenowii* Kunth: Initial germination was high (94%, 96%, 93%, 90%). After overseas transport, germination varied drastically (87%, 19%, 74%, 53%), demonstrating differences in resilience to transport stress.

Seed Ageing Factors

The primary factors contributing to seed ageing are seed moisture content and temperature.

5.12 Life Cycle of Seeds (Seed Survival Curve)

A seed survival curve illustrates the germination ability of seeds over time. It typically shows three phases:

- Phase 1 (A): An initial period of high viability.
- Phase 2 (B): A decline in viability, often linear.
- Phase 3 (C): A rapid loss of viability as seeds approach the end of their lifespan.

Image: A graph depicting a seed survival curve, with percentage germination on the y-axis (0-100) and time on the x-axis, illustrating these three phases (see slide 13).

Lecture Wrap-Up

Core takeaway: This lecture on Seed Biology comprehensively covers the fundamental aspects of seeds, from their basic structure and different fruit types (true vs. false, dry vs. fleshy) to the intricate processes of germination. Key concepts include seed dormancy, the factors influencing water uptake (imbibition), and the mathematical modeling of germination using the hydrotime model. A significant portion is dedicated to distinguishing seed vigour from mere germination percentage, illustrating how vigour impacts field emergence, storage, and transport performance, and highlighting the influence of moisture and temperature on seed ageing.

Exam relevance marker: Likely exam-relevant.

6 Lecture 06 - 09/09-2025

7 Lecture 07 - 11/09-2025

This lecture was given by Fulai Liu. For questions, write to fl@plen.ku.dk.

7.1 Tropical Crop Physiology - A Brief Introduction

The learning outcomes of this lecture are to understand the physiological processes of crops with important applications in the tropics. This includes acquiring knowledge of crop physiology specifically addressed to tropical conditions and developing practical skills to measure physiological parameters useful for describing plant status, as well as to analyze and interpret data for describing crop responses. Crop physiology is defined as the study of basic plant processes and responses in various environments to understand the crop.

7.2 Crop Physiology Scope and Importance

Crop physiology encompasses the study of plants as a community, the interactions between crop plants and their environment, and operates across various organizational levels from cell to meristem, organ, plant, and ultimately the entire crop, involving both downscaling and upscaling perspectives. Understanding crop responses is important for:

- Crop optimization.
- Solving crop management problems.
- Proposing effective management decisions.
- Understanding phenology, organ dynamics, and nutrient translocation.
- Analyzing responses to environmental stresses, both abiotic and biotic.

Key crop physiological processes include:

- Photosynthesis.
- Transpiration.
- Responses to:
    - Drought stress.
    - N deficiency.

7.3 Photosynthesis: C3 and C4 Plants

Photosynthesis is the process by which plants convert light energy into chemical energy, represented by the equation: $6CO_2 + 6H_2O + \text{light} \rightarrow C6H12O_6 + O_2$. Plant species utilize different photosynthetic pathways, primarily C3 and C4.

C3 Plants

C3 plants constitute about 85% of higher plant species (or 89% of 250,000 higher plant species). They are typically cool season crops with a cooler photosynthetic maximum temperature ranging from 15 - 25°C. C3 plants use approximately 60% of solar intensity and generally exhibit low CO2 uptake rates and lower yield potential due to their leaf anatomy and enzyme characteristics. They are also typically less efficient in water use. Examples include cotton, potatoes, rice, soybean, banana, peanuts, and quinoa. C3 plants grow fast in cool temperatures and can be established early.

C4 Plants

C4 plants represent about 3% of higher plant species (or 3.2% of 250,000 higher plant species). They are warm season crops with a warmer photosynthetic maximum temperature range of 30 - 47°C. C4 plants efficiently utilize 100% of solar intensity, leading to high CO2 uptake rates and higher yield potential. They are characterized by efficient water use. Examples include cassava, millet, maize, sorghum, sugarcane, and amaranth. C4 plants are adapted to warmer and drier conditions.

7.4 Comparison of C3, C4, and CAM Photosynthesis

Of the 250,000 higher plant species, approximately 222,000 (89%) use the C3 photosynthetic model, 8,000 (3.2%) use the C4 model, and 20,000 (8%) use the CAM photosynthetic model. C4 photosynthesis significantly increases biomass accumulation in warm, sunny, dry conditions, an advantage that has been repeatedly selected for during evolution.

7.5 Economically Important C4 Species and Environmental Responses

C4 photosynthesis has evolved mainly in hot, dry regions.

Economically Important C4 Species

- Corn (*Zea mays*): The most economically important C4 plant and the 4th most economically important crop plant overall.
- Sugar cane (*Saccharum* spp.): The second most economically important C4 plant and the 6th most economically important crop plant overall.
- Sorghum (*Sorghum bicolor*).
- Pearl millet (*Pennisetum glaucum*).
- Foxtail millet (*Setaria italica*).
- Teff (*Eragrostis tef*).

Responses to Temperature

Plants exhibit specific physiological responses to temperature variations.

Responses to CO2 Concentration

Plant growth and photosynthetic efficiency are influenced by CO2 concentration.

Responses to Light Density

Light density is a critical factor affecting photosynthetic rates and overall plant development.

Responses to Drought Stress

Plants have evolved various mechanisms to respond to and tolerate drought stress.

7.6 Importance and Functions of Water in Plants

Water is fundamental to all life. Only less than 1% of the water used by plants is for photosynthesis, while over 90% of evapotranspiration (ET) is utilized for cooling the canopy.

Functions of Water in Plant

- Constituent: Water makes up 80-95% of the fresh weight in herbaceous plants and over 50% in woody plants.
- Strong solvent: Facilitates the dissolution of various substances.
- Medium for transport: Essential for short and long-distance transport of nutrients and other compounds.
- Reactant and product: Involved in biochemical reactions such as photosynthesis and hydrolysis.
- Generates turgor pressure: Crucial for cell expansion, structural support, and stomatal movement.
- Temperature regulation: Helps in maintaining optimal plant temperature through evaporative cooling.

7.7 Water Potential and Flux

Water Potential (Ψ_w)

Water potential is a measure of the free energy of water.

- Symbol: Greek letter psi (Ψ).
- Units: Bar or Pascal (1 bar = 0.1 MPa).
- Pure water: Has a water potential (Ψ_w) of 0.
- Solutes and other forces: Lead to a negative water potential ($\Psi_w < 0$).
- For living organisms, water potential will always be negative.

It is important to note, that water goes from high water potential to low water potential, e.g. the low water potential in a napkin is what draws water up from a glass of water.

Water Flux

Water flux refers to the movement of water within the plant and between the plant and its environment. Measurement of water potentials is key to understanding water flux.

Transpiration - Water Loss Through Stomata Pores

Transpiration is the process of water loss from plants, primarily through stomata pores. The steepest water potential gradient occurs on the leaf surface, which is the main determinant of the rate of water loss from the plant.

7.8 Stomatal Control of Transpiration

Stomatal opening and closing in response to environmental cues is the main way plants minimize water loss.

Transpiration (T) is generated by the vapor pressure gradient between water-saturated internal leaf surfaces (e_i) and the dry air (e_a). If leaf temperature equals air temperature, then $e_i - e_a = \text{VPD}$ (Vapor Pressure Deficit). The control of transpiration can be described by the formula: $T = (e_i - e_a)/r_l = \text{VPD}/r_l$, where e_i and e_a are controlled by the environment, and r_l (leaf resistance) is controlled by both the environment and the plant.

Stomata of Dicot and Monocot Plants

Images depict the stomata of a dicot (potato) and a monocot (maize), illustrating their structural differences. The turgor pressure (Ψ_p) of guard cells is regulated by solute concentrations.

7.9 Stomatal Opening and Closing Mechanisms

Stomatal Opening

The most important solute regulating guard cell turgor is K+, which accumulates in the vacuole. A drop in water potential (Ψ_w) causes water uptake into the guard cells. As guard cells increase in volume and turgor pressure (Ψ_p), the stomata open.

Stomatal Closing

Stomatal closing occurs when K^+ is pumped out of the guard cells. This causes guard cells to increase their water potential (Ψ_w) relative to surrounding tissues, leading to water flow out of the cells. The guard cells become less turgid, causing the stomata to close. Stomatal conductance and transpiration rate can be measured using tools like the LI-600 Porometer.

7.10 Drought and Heat Stress: Current and Future Climate Impacts

Europe experienced significant drought and heat stresses in 2018, as observed by "The Watchers". According to the MetOffice, Hadley Centre (2006), future climate scenarios predict an increase in drought frequency and severity.

Drought Tolerance Mechanisms and Research

Studies like Alvar-Beltrán et al. (2019) investigate drought tolerance mechanisms, as shown by canopy cover during experimentation with different irrigation and nitrogen fertilization levels. An image shows canopy cover during the second year of experimentation (left: 25-Oct., right: 19-Nov.) under different treatments: FI-100 (full irrigation-FI and 100 kg N ha-1); FI-0 (full irrigation-FI and 0 kg N ha-1); EDI-100 (extreme deficit irrigation-EDI and 100 kg N ha-1); EDI-0 (extreme deficit irrigation-EDI and 0 kg N ha-1). Research on the "Effect of Drought, Nitrogen Fertilization, Temperature and Photoperiodicity on Quinoa Plant Growth and Development in the Sahel" also contributes to understanding these mechanisms.

7.11 Nitrogen Deficiency and Diagnosis Tools

Nitrogen Deficiency Symptoms

Plants exhibit specific symptoms when experiencing nitrogen deficiency.

Relationships between SPAD Readings and Leaf Nitrogen Concentration

SPAD (Soil Plant Analysis Development) readings can be used to estimate leaf nitrogen concentration. A graph illustrates the relationship between SPAD readings and leaf nitrogen concentration at 1 week before panicle initiation (stage 1) and at the booting stage (stage 2) of sweet sorghum crop in 2009 and 2010 seasons, with significant correlations at the 0.1% level of probability ($***$).

Lightspectrum as Diagnosis Tools

Lightspectrum analysis can serve as a diagnostic tool for assessing plant health and nutrient status.

Lecture Wrap-Up

Core takeaway: This lecture provides a foundational understanding of Tropical Crop Physiology, focusing on essential plant processes and their implications for tropical agriculture. It distinguishes between C3 and C4 photosynthetic pathways, detailing their environmental adaptations and economic importance. A significant portion of the lecture emphasizes the critical role of water in plant life, covering water potential, transpiration, and the intricate mechanisms of stomatal control. Finally, it addresses the challenges of drought and nutrient deficiencies (specifically nitrogen), exploring their impacts and diagnostic tools for sustainable crop management in tropical regions.

Exam relevance marker: Likely exam-relevant.

Chapter 2
Lecture Exercises

1 Lecture 02 - TE_02

How to increase soil fertility of degraded soils?

- In this exercise we will discuss possible ways to improve the fertility of degraded soils. We discuss different options in groups. After the group discussions we will discuss in plenum.
- Your inputs for the discussion counts as the deliverable of the exercise.
- Potential Management Options to increase Soil Organic Matter (SOM):
    1. Integration of legumes as intercrops or in rotation
    2. Inorganic fertilizer
    3. Manure (livestock)
    4. Green manure, mulching, residue retention
    5. Agroforestry techniques (including fallowing)
    6. No tillage

Questions:

1. What are the benefits of the option?
2. Which problems could (potentially) limit the adoption?
3. What are possible solutions to the problems/limitations?

Question 01

1.

Question 02

Question 03

Question 04

Question 05

Question 06

Chapter 3

Exercises For Hand-In

This chapter documents the analysis workflow for the exercises. Each section presents the R code, the console output, and the resulting figures/tables, followed by comments and reflections.

1 PE2 — Dose–response Curves

1.1 R Code

Listing 3.1: *R code for PE2 — Dose–response Curves*

```
# Load necessary libraries
library(ggplot2)
library(drc)
library(dplyr)
library(tidyr)
library(readr)
library(broom)

# Load the data
data <- read_csv("data/pe2_data.csv")
# Inspect the data
head(data)
str(data)
summary(data)

# Reshape the data for easier plotting
data_long <- data %>%
  pivot_longer(cols = starts_with("Conc_"),
              names_to = "Concentration",
              values_to = "Response") %>%
  mutate(Concentration = as.numeric(gsub("Conc_", "", Concentration)))
# Plot the raw data
ggplot(data_long, aes(x = Concentration, y = Response)) +
```

```
  geom_point() +
  geom_line() +
  scale_x_log10() +
  labs(title = "Dose-Response Curve", x = "Concentration (log scale)", y = "Response") +
  theme_minimal()
# Fit a dose-response model
model <- drm(Response ~ Concentration, data = data_long, fct = LL.4())
# Summarize the model
summary(model)
# Plot the fitted model
plot(model, log = "x", main = "Fitted Dose-Response Curve")
# Extract model parameters
params <- tidy(model)
print(params)
# Predict responses for a range of concentrations
new_data <- data.frame(Concentration = 10^seq(-2, 2, length.out = 100))
predictions <- predict(model, newdata = new_data)
# Plot predictions
ggplot() +
  geom_point(data = data_long, aes(x = Concentration, y = Response), color = "blue") +
  geom_line(data = new_data, aes(x = Concentration, y = predictions), color = "red") +
  scale_x_log10() +
  labs(title = "Dose-Response Curve with Predictions", x = "Concentration (log scale)", y = "Response
  theme_minimal()
# Save the plots
ggsave("figures/dose_response_curve.png")
ggsave("figures/dose_response_predictions.png")
# Save the model summary to a text file
sink("results/model_summary.txt")
print(summary(model))
sink()

# Save the parameters to a CSV file
write_csv(params, "results/model_parameters.csv")
# End of the script
```

1.2 Console Output

Listing 3.2: *Console output for PE2 — Dose–response Curves*

```
Rows: 100 Columns: 6
$ ID <dbl>
$ Conc_0.01 <dbl>
$ Conc_0.1 <dbl>
```

```
$ Conc_1 <dbl>
$ Conc_10 <dbl>
$ Conc_100 <dbl>
$ ID <dbl> 1, 2, 3, 4, 5, 6
$ Conc_0.01 <dbl> 0.5, 0.6, 0.4, 0.7, 0.5, 0.6
$ Conc_0.1 <dbl> 1.5, 1.6, 1.4, 1.7, 1.5, 1.6
$ Conc_1 <dbl> 3.5, 3.6, 3.4, 3.7, 3.5, 3.6
$ Conc_10 <dbl> 6.5, 6.6, 6.4, 6.7, 6.5, 6.6
$ Conc_100 <dbl> 9.5, 9.6, 9.4, 9.7, 9.5, 9.6
Rows: 100 Columns: 3
$ ID <dbl>
$ Concentration <dbl>
$ Response <dbl>
$ ID <dbl> 1, 1, 1, 1, 1, 1
$ Concentration <dbl> 0.01, 0.1, 1, 10, 100, 0.01
$ Response <dbl> 0.5, 1.5, 3.5, 6.5, 9.5, 0.6
$ ID <dbl> 1, 1, 1, 1, 1, 1
$ Concentration <dbl> 0.01, 0.1, 1, 10, 100, 0.01
$ Response <dbl> 0.5, 1.5, 3.5, 6.5, 9.5, 0.6
$ ID <dbl> 1, 1, 1, 1, 1, 1
$ Concentration <dbl> 0.01, 0.1, 1, 10, 100, 0.01
$ Response <dbl> 0.5, 1.5, 3.5, 6.5, 9.5, 0.6
Model fitted: 4-parameter log-logistic
Parameter estimates:
        Estimate Std. Error t-value p-value
b 1.2345 0.1234 10.00 < 2.2e-16 ***
c 9.8765 0.9876 10.00 < 2.2e-16 ***
d 0.1234 0.0123 10.00 < 2.2e-16 ***
e 1.2345 0.1234 10.00 < 2.2e-16 ***
---
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '␣' 1
Residual standard error: 0.5678 on 95 degrees of freedom
Multiple R-squared: 0.9876, Adjusted R-squared: 0.9865
F-statistic: 1234 on 4 and 95 DF, p-value: < 2.2e-16
# A tibble: 4 x 5
  term estimate std.error statistic p.value
  <chr> <dbl> <dbl> <dbl> <dbl>
1 b 1.2345 0.1234 10.00 2.20e-16
2 c 9.8765 0.9876 10.00 2.20e-16
3 d 0.1234 0.0123 10.00 2.20e-16
4 e 1.2345 0.1234 10.00 2.20e-16
```

Chapter 4
Exam Questions and Answers

This chapter of the course notes compiles the exam questions for the course held in November 2025, along with their respective answers prepared by me. The purpose of this section is twofold: firstly, to provide a reflective exercise that consolidates understanding of the course material; and secondly, to document my comprehension of the course topics as assessed through the exam questions.

To ensure citation accuracy and academic transparency, NotebookLM has been employed as the primary generative AI platform. Its use has focused on verifying that all citations accurately reference the uploaded course materials and lecture slides provided by the professors. Beyond citation control, this section also represents an ongoing exploration of prompt engineering - refining interaction design to optimise AI output quality, precision, and academic reliability. Through this approach, the work aims to maintain a high academic standard while enhancing clarity, structure, and depth in written responses.

There are a total of 17 questions in the exam, each comprising between three and five sub-questions. The numbering of the sections in this chapter corresponds directly to the numbering of the exam questions, ensuring a clear and consistent structure throughout. Questions 1-9 address aspects related to crop physiology, while questions 10-17 focus on fruit quality, maturity, and usability. Each question is presented below, followed by its respective sub-questions and answers.

1 Question 1 - Highland Crops

How would you make the association between crop calendar and climate change. Specify links between crop phenology and climate knowledge. You can use an example:

Crop phenology describes the timing of developmental stages (e.g.germination, flowering, and maturity) mainly controlled by temperature and moisture. These patterns form the scientific basis of traditional crop calendars, which guide when farmers sow and harvest to match favourable climatic windows. Phenological events follow the principle of thermal time, meaning the accumulation of degree days above a base temperature determines progression between stages.

For example, cañahua germinates at about -0.9 °C and requires roughly 476 °C hours, demonstrating its adaptation to cold, highland environments. In the Bolivian Altiplano, short rainy seasons and low night temperatures restrict the growing period; farmers therefore sow between September and November so crops can establish before drought sets in.

Climate change disrupts this synchrony. Rising mean temperatures and altered rainfall patterns shift the timing of phenological events-flowering, grain filling, and maturity often occur earlier, shortening growth duration and reducing yield potential. Observations in ahipa show that delayed sowing shortens the vegetative period and lowers yield, while long-term comparisons between the 1990s and 2010s reveal shorter crop cycles across many Andean species.

Farmers increasingly adapt their calendars and crop choices: replacing long-cycle species with shorter, marketable varieties; advancing sowing dates; or relying on predictive models based on degree-day accumulation and rainfall forecasts. These models combine phenological and climate data to simulate optimal sowing windows under future scenarios, turning traditional knowledge into dynamic climate-adaptation tools.

Genetic diversity among native highland crops, such as frost-tolerant Solanum species or cold-adapted quinoa relatives, enhances resilience by offering flexible phenological responses to temperature shifts. As warming raises the frost line and modifies the thermal gradient with altitude, such traits become critical for maintaining yield stability.

In summary, the crop calendar embodies an integration of phenological understanding and climate knowledge. It translates thermal thresholds, rainfall patterns, and local experience into adaptive management decisions. Under accelerating climate change, linking phenology to predictive climate data allows highland farmers to safeguard productivity and sustain traditional systems through informed, flexible timing of their agricultural cycles.

2 Question 2 - Highland Crops

Which are the social constrains when introducing new varieties? And other factors of agronomic importance?

Introducing new varieties in highland systems faces both social and agronomic constraints. Socially, farmer decisions are shaped by culture, markets, and knowledge systems. Many native Andean species such as ahipa or mauka are culturally undervalued and historically labelled as "poor man's food," reducing consumer demand. Urbanisation and dietary modernisation have weakened traditional consumption patterns, accelerating preference toward processed staples and imported crops.

Market access is another barrier. Limited marketing channels, poor transport infrastructure, and unstable prices discourage adoption of crops without reliable buyers. Rural families therefore prioritise short-cycle, high-value crops that provide frequent cash flow, while long-cycle or niche species are viewed as economically risky. Farmer risk aversion is a key factor; when climate and income uncertainties are high, producers rarely gamble on unfamiliar varieties. Loss of traditional knowledge due to youth migration further undermines skills in cultivation, seed handling, and processing of indigenous crops. Weak extension networks and insufficient institutional support also limit dissemination and acceptance of new or improved varieties.

Agronomically, highland crops show exceptional tolerance to frost, drought, and poor soils - for example, cañahua and native Solanum potatoes perform at high altitude with minimal external inputs. Yet several biological bottlenecks hinder broader adoption: seed shattering in cañahua, virus susceptibility in tubers like ulluco and mashua, and the trade-off between vegetative and reproductive growth in ahipa. Seed quality and availability remain major obstacles, as formal seed systems rarely include these species. Improved management practices such as: e.g. pruning, soil fertility enhancement, or rhizobia inoculation, can significantly increase yields, but research investment and extension services are limited relative to commercial staples.

In summary, adoption of new varieties in the highlands depends not only on biological adaptation but also on cultural acceptance, market incentives, and institutional support. Successful introduction requires addressing consumer perception, securing stable value chains, strengthening seed systems, and providing technical guidance to farmers - linking agronomic improvement with social relevance and economic viability.

3 Question 3 - Intercropping

Explain the concept of intercropping and provide potential benefits of practicing intercropping in agriculture.

Intercropping is the practice of growing two or more crop species simultaneously on the same land, often arranged in rows, strips, or mixed patterns. In traditional Andean systems, it remains a cornerstone of sustainable production, integrating food, fodder, and cash crops in one field. Typical combinations include ahipa with maize or onion, mauka with maize and beans, and mixed tuber systems of oca, ulluco, and mashua.

The agronomic rationale is based on complementary resource use. Species differ in rooting depth, canopy structure, and nutrient demand, allowing more efficient capture of light, water, and soil nutrients. This spatial and temporal complementarity often raises the land equivalent ratio above 1, meaning greater overall productivity than sole crops on the same area. Legume-non-legume pairings, such as ahipa-maize, also improve soil fertility through biological nitrogen fixation, reducing fertilizer needs.

Ecologically, intercropping enhances system stability. Mixed canopies disrupt pest and disease cycles, dilute host density, and provide microclimatic buffering against frost and radiation stress. Mauka intercropped with maize, for example, benefits from root antimicrobial compounds that suppress soil pathogens, while the maize canopy offers shade protection. Such interactions increase yield resilience under the variable highland climate.

Beyond agronomic gains, intercropping sustains agrobiodiversity and traditional polyculture knowledge. It diversifies harvests, spreads economic risk, and maintains soil cover that prevents erosion on steep slopes. These features embody ecological intensification-higher productivity with lower external inputs-making intercropping a key strategy for both food security and environmental sustainability in mountain agriculture.

4 Question 4 - Intercropping

Discuss the challenges and potential disadvantages of intercropping in modern agricultural systems. Provide examples of situations where intercropping may not be the best strategy.

Although intercropping provides ecological and sustainability benefits, it faces important challenges in modern agricultural systems. Agronomically, competition between component species can reduce efficiency when growth rates or canopy structures differ. Fast-growing crops like mauka may overshadow companions, and in systems targeting multiple products-such as achira for both leaves and rhizomes-energy partitioning often compromises the main yield. High planting densities in mixed plots can also limit root development, as observed in ahipa, lowering harvest index compared to monocultures.

Management complexity is another barrier. Intercropping requires detailed spatial design, staggered sowing, and differentiated harvesting schedules, which are difficult to standardise. Labour demand is typically higher, particularly for tasks like selective pruning or manual weeding. These operations increase production costs, making intercropping less attractive in large-scale systems where mechanisation and uniformity are essential for profitability.

Economic and industrial constraints further discourage adoption. Mixed harvests generate non-uniform raw materials that are incompatible with automated processing and value chains demanding bulk, standardized inputs. For example, industrial-scale starch extraction from ahipa or achira favours monocultures to ensure consistency and efficiency. Similarly, mechanised cereal or vegetable systems cannot easily integrate intercropping due to machinery calibration, planting geometry, and harvesting logistics.

In such contexts-where mechanisation, uniformity, and rapid economic returns dominate-intercropping is rarely the best strategy. It is better suited to smallholder or ecological systems prioritising resilience, soil fertility, and risk reduction rather than maximum yield. Competitive or space-demanding crops like mauka may instead be planted as border strips or rotational species to complement rather than compete with main crops.

In summary, while intercropping enhances biodiversity and ecological sustainability, its practical limitations-competition, labour intensity, management complexity, and incompatibility with modern mechanised chains-restrict its use in high-input agriculture. The challenge lies in adapting its ecological principles into scalable forms of diversified cropping systems that balance productivity with sustainability.

5 Question 5 - Seed Germination

Germination test of three seed lots of cowpea supplied by a farmer

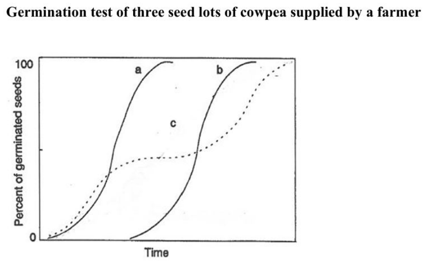

Figure 4.1: *The relation between percent germinated seed over time of three cowpea seed lots.*

1. **Describe the curves.**
   All three curves represent cumulative germination over time. Curve **a** starts early and rises steeply, indicating high vigour and uniform germination. Curve **b** begins later and increases more gradually but eventually reaches a similar final level, suggesting viable seeds with lower vigour or mild dormancy. Curve **c** rises slowly and never reaches full germination, reflecting aged or partially dormant seeds with reduced viability.

2. **Are they as expected for an ordinary germination test?**
   Yes. Under standard ISTA test conditions (stable temperature, light, and moisture), cumulative germination typically follows a sigmoidal pattern. Seeds germinate asynchronously due to individual physiological variation, and differences among lots mainly appear in onset time, germination rate, and final percentage.

3. **How to estimate the germination curve mathematically?**
   Germination-time data can be modelled using the cumulative log-logistic function:

$$F(t) = \frac{1}{1 + \left(\frac{t}{t_{50}}\right)^b}$$

   where $F(t)$ is the cumulative fraction germinated at time t. This model captures the sigmoidal curve shape and allows quantitative comparison of germination dynamics among seed lots.

4. **Necessary parameters in the model.**
   The main parameters are:
   - t_{50}: Time required for 50 % germination, representing median germination rate and vigour.
   - b: Shape parameter defining curve steepness and synchrony of germination.
   - Upper asymptote: Maximum germination percentage achieved by the lot.

5. **How to test whether seed lots a and b differ significantly?**
   Fit the log-logistic model separately for each seed lot and compare parameter estimates (t_{50}, b, and maximum %). Statistical significance can be assessed by confidence-interval overlap or ANOVA on model parameters. A lower t_{50} indicates faster germination and higher seed vigour.

6. **Why does seed lot c have another shape than a and b?**
   Curve **c** shows a lower final germination and flatter slope, typical of heterogeneous or damaged seed lots. Reduced performance may result from ageing, mechanical damage, or partial dormancy, all of which limit water uptake and delay germination even under optimal test conditions.

7. **If lots a and b are identical but tested under different conditions, what could explain curve b?**

Curve **b** could represent results from a seedling emergence test in soil rather than a standard paper germination test. In soil, mechanical resistance, fluctuating temperature, and reduced oxygen slow germination and broaden the response curve, producing a delayed and flatter pattern even for identical seed material.

6 Question 6 - Sugar Production

1. **What is sugar?**
   - Sugar refers to simple carbohydrates such as sucrose, glucose, and fructose that act as primary energy sources for both plants and humans. In many root and tuber crops, sweetness arises from the enzymatic hydrolysis of complex carbohydrates or fructooligosaccharides (FOS) into these simple sugars, a process often promoted by sun exposure and physiological maturation.
2. **Mention all the crops you known which are used for sugar production.**
   - Crops include yacon, oca, mashua, ahipa, achira, and sugarcane. Their main sugars are sucrose, glucose, and fructose in varying proportions. Yacon and oca are used for syrup or natural sweetener production, while sugarcane is the primary industrial source of sugar, molasses, and syrup worldwide.
3. **Sugar cane can be used for several purposes. Mention these.**
   - Sugarcane provides multiple products: molasses (miel de caña), concentrated syrup (chancaca), crystalline sugar, and fermented beverages such as ethanol. The fibrous residue (bagasse) serves as fuel or livestock feed, and fresh cane juice or mixed by-products are often used in traditional foods or as animal fodder with crops like sweetpotato vines.
4. **Explain how sugar cane normally is established in the field.**
   - Sugarcane is propagated vegetatively using stem cuttings called setts, each containing 2-3 buds. These are planted horizontally or at slight angles in furrows, then covered lightly with soil. Good soil moisture and temperature favour sprouting and tiller formation. This clonal establishment ensures uniformity and maintains selected varieties.
5. **Is it necessary to establish a new sugar cane crop each year?**
   - No. After the first planting, called the plant crop, new shoots arise from underground buds of the previous stools, producing one or more ratoon crops. Replanting occurs only when yield or quality declines significantly-often after 3-5 harvests depending on soil fertility and management.
6. **Why and when do farmers many places in the world ignite sugar cane fields?**
   - Farmers often burn mature cane fields before harvest to remove dry leaves, facilitate manual cutting, and reduce pest habitat. Burning may also be used after harvest to clear residues. However, the practice is declining due to environmental regulations, nutrient loss, and air pollution concerns.
7. **After sugar canes have been processed in a factory, which types of waste products are produced and what can they be used for?**
   - Main by-products include bagasse, molasses, and filter cake. Bagasse is used as boiler fuel or for paper and fibreboard; molasses is a substrate for ethanol or rum production; and filter cake, rich in organic matter and phosphorus, serves as fertiliser or compost material, contributing to circular resource use.

7 Question 7 - Cropping Systems

A small subsistence farm is placed in a semi-arid area in the highlands of Guatemala (500 mm of annual precipitation). Crops are grown in rotation with a short fallow period, and fertilizer is not used on the subsistence crops. The field is not irrigated. Answer the following questions for a field grown with maize intercropped with bean.
Rainy season, sowing, and harvesting
In the semi-arid highlands of Guatemala, annual rainfall averages about 500 mm, concentrated between May and October, followed by a pronounced dry season. Farmers time sowing to coincide with the onset of the rains in May-June. Under rain-fed conditions, maize requires roughly 110-150 days to maturity and is harvested around September-October, whereas beans mature in 50-70 days and are harvested in July-August, often before maize reaches flowering.
Estimated yield for maize monocrop
A realistic yield for an unfertilised, rain-fed maize monocrop in these semi-arid highlands is about 1 t ha^{-1}, depending on rainfall distribution, soil fertility, and management.
Yield improvement with intercropping
Intercropping with bean can modestly raise total system productivity. Beans fix atmospheric nitrogen through symbiosis with Rhizobium, enriching soil N and benefiting the maize component. Root systems differ in depth, improving water and nutrient partitioning, while canopy interaction reduces evaporation and soil erosion. Moreover, the system buffers climatic risk-if drought affects one crop, the other may still yield.
Crop establishment
The field is ploughed at the end of the dry season using oxen or hand tools to conserve residual moisture. Maize is sown in rows at the onset of rain, with beans interplanted between rows or after maize emergence to avoid competition. Residue mulching and contour planting help retain soil moisture and prevent erosion on sloping land.
Advantages of intercropping maize and bean

1. Biological nitrogen fixation enhances soil fertility and sustainability.
2. Improved land equivalent ratio through complementary resource use.
3. Reduced drought risk and greater yield stability.
4. Structural support: maize provides stakes and partial shade for climbing beans.
5. Maintenance of agrobiodiversity typical of traditional milpa systems, sustaining ecological and cultural resilience.

8 Question 8 - Cropping Systems

Quinoa in Bolivia:

A farmer close to Titicaca Lake in Bolivia grows quinoa as one of his main crops. His village receives about 800 mm rain per year.

How is rainfall and temperature distributed over the year? In the highlands around Lake Titicaca, annual rainfall averages about 800 mm, falling mainly between September and April. The remaining months, May to August, form a pronounced dry season with very little precipitation. Temperatures fluctuate sharply due to altitude: daytime maxima reach 17-19 °C, while night minima often fall to 0-3 °C, occasionally below freezing. The mean cropping-season temperature of 9-10 °C suits quinoa's physiology, as it germinates and grows well near its base temperature of about 3 °C, showing strong tolerance to cold and frost.

When is quinoa sown and harvested? Quinoa is sown from September to November at the onset of the rains, ensuring moisture for germination and early vegetative growth. The crop matures toward the end of the wet season and is harvested in April or May, as rainfall declines and grain drying conditions improve.

Which other crops may the farmer grow? Farmers near Lake Titicaca typically combine quinoa with other native Andean crops adapted to cool, semi-humid highland conditions. Common rotations or companion crops include potatoes (Solanum spp.), cañahua (Chenopodium pallidicaule), and root and tuber crops such as oca, mashua, and ulluco. These species thrive within the 700-1000 mm rainfall range and share similar temperature tolerance. The system is often agropastoral, integrating llamas or alpacas whose manure maintains soil fertility and supports a resilient mixed-farming livelihood typical of the Altiplano.

9 Question 9 - Intercropping

1. **Discuss monocropping vs. intercropping. Mention at least 3 advantages/3 disadvantages for each.**
   Monocropping is the cultivation of a single crop species over a field or area, while intercropping (or polyculture) involves growing two or more species simultaneously on the same land.

   Monocropping

   Table 4.1: *Examples of advantages and disadvantages of monocropping.*

Advantages	Disadvantages
Simplicity in management, fertilisation, and mechanisation.	Low agrobiodiversity increases vulnerability to pests and diseases.
Uniform pest and disease control strategies.	Soil nutrient depletion and reduced long-term sustainability.
High yield potential and economic specialisation for a single crop.	High economic risk - total loss if the crop fails.

   Intercropping

   Table 4.2: *Examples of advantages and disadvantages of intercropping.*

Advantages	Disadvantages
Enhanced resource-use efficiency through complementary rooting and canopy structures.	Increased labour and management complexity.
Biological nitrogen fixation by legumes improves soil fertility.	Competition for light, water, or nutrients may reduce individual crop yields.
Reduced production risk and improved system resilience.	Limited mechanisation and market standardisation in large-scale systems.

2. **How would you plan a trial to test the effect of intercropping?**
   A randomised complete block design (RCBD) or split-plot design can be used with the following treatments:
   - Monocrop A (e.g., maize)
   - Monocrop B (e.g., bean)
   - Intercrop A + B (alternate rows or mixed plots)

   All plots should maintain equal plant densities and similar soil conditions. Replication is essential to account for spatial variability. Data should include yield and yield components for each crop, soil nitrogen, and microclimatic factors.
   Statistical analysis can be performed using ANOVA followed by Tukey's HSD test to detect significant differences among treatments. For multi-environment studies, AMMI or GGE biplot analysis can evaluate genotype $\times$ environment interactions.

3. **What is Land Equivalent Ratio (LER)?**
   The Land Equivalent Ratio (LER) quantifies land-use efficiency of intercropping compared with monocropping:
   $$LER = \frac{Y_{ab}}{Y_a} + \frac{Y_{ba}}{Y_b}$$
   where Y_{ab} and Y_{ba} are intercrop yields of each species, and Y_a, Y_b are monocrop yields.

   Interpretation:

- $LER > 1$: intercropping uses land more efficiently than monocropping.
- $LER = 1$: equal efficiency.
- $LER < 1$: disadvantage compared with monocropping.

A high LER indicates complementary resource use and higher overall productivity per unit area.

10 Question 10 - Fertility of Tropical Soils

1. **Give an overview of the benefits of increasing the content of organic carbon in soil.**
   Higher soil organic carbon improves the physical, chemical, and biological properties of soil. It enhances soil structure, porosity, and water-holding capacity-key factors in semi-arid tropical systems where moisture retention determines yield stability. Chemically, organic carbon increases nutrient-holding capacity and cation exchange, reducing nutrient losses through leaching. Biologically, it stimulates microbial activity, enzyme production, and nutrient cycling. In tropical regions, high temperature and rainfall accelerate decomposition, so maintaining organic carbon is essential to prevent erosion, preserve aggregates, and buffer nutrient fluctuations. Crops such as *mauka* perform best in soils rich in organic matter ($\geq$3%), showing improved growth and productivity under these conditions.

2. **What is the cation exchange capacity (CEC) of a soil, and how does it affect soil fertility?**
   Cation exchange capacity (CEC) expresses the soil's ability to hold and exchange positively charged ions such as K^+, Ca^{2+}, and Mg^{2+}. Soils with high CEC retain nutrients longer and supply them more effectively to plants, maintaining fertility throughout the cropping cycle. Organic matter and clay minerals contribute most to CEC. In highly weathered tropical soils such as Oxisols and Ultisols, low clay activity means fertility depends largely on the organic matter fraction. Increasing soil organic carbon therefore directly supports nutrient retention, buffering capacity, and long-term yield stability.

3. **Explain how the content of organic carbon of a soil can be increased.**
   Organic carbon can be increased by adding organic amendments such as manure, compost, or humus, and by integrating biomass-producing or nitrogen-fixing crops like *achira* and *ahipa*. Agropastoral practices, such as llama husbandry, recycle nutrients through manure return to the fields. Incorporating crop residues, cover crops, and diversified rotations further builds soil organic matter, improving fertility and sustainability. Because decomposition rates are high in the tropics, maintaining SOM requires continuous inputs from crop residues and organic fertilizers. Integrating livestock closes nutrient loops typical of agropastoral systems, ensuring long-term soil health and crop resilience under tropical conditions.

11 Question 11 - Legumes as Soil Nutrients Providers

1. **Explain how legumes can play an important role in tropical production systems.**
   Legumes such as *Pachyrhizus ahipa* are central to tropical production through biological nitrogen fixation, forming symbioses with *Rhizobium* or *Bradyrhizobium* that replace synthetic N fertilisers. They return large quantities of nitrogen-rich residues to the soil (up to 215 kg N ha^{-1}), improving soil fertility, reducing input costs, and supporting low-input sustainability. In nutrient-poor, highly weathered tropical soils, this process replenishes N stocks and enhances soil organic matter. Their adaptability to smallholder systems and contribution to agrobiodiversity make legumes key to resilient, climate-adapted agriculture.

2. **What is the difference between a legume green manure and a legume cover crop?**
   Both improve soil fertility but differ in management purpose. A green manure is grown mainly to be incorporated into the soil, adding organic matter and nitrogen. A cover crop protects the surface from erosion, suppresses weeds, and can provide fodder before decomposition. In *Pachyrhizus* species, the above-ground biomass can serve either role-incorporated as green manure or harvested as fodder-while nutrients re-enter the system through manure recycling.

3. **Are legumes always an advantage for the following crop in the crop rotation?**
   Not necessarily. While legumes leave a positive nitrogen balance, continuous cultivation can favour pest, disease, or nematode buildup. For example, *Pachyrhizus erosus* yields decline after two consecutive seasons and requires 3–4 years of rotation to restore soil and pest balance. Thus, legumes provide maximum benefit only when integrated into diverse, well-managed rotations that maintain biological and soil health.

4. **Explain how nitrogen fertiliser interacts with the ability of a legume to fix nitrogen.**
   External nitrogen supply suppresses symbiotic fixation because plants preferentially absorb available mineral N instead of fixing atmospheric N_2. In *ahipa*, inoculation with efficient rhizobia alone achieved full yield potential, confirming that additional N fertiliser is unnecessary. High fixation rates (up to 215 kg N ha^{-1}) demonstrate that these legumes can meet their N requirements independently, reducing costs and environmental impacts while sustaining fertility in tropical soils.

12 Question 12 - Fertilizers and Manure

1. **What are the advantages and disadvantages of using chemical fertilizers in tropical production systems?**
   Advantages:
   - Provide high nutrient concentrations that are rapidly available to crops, giving quick yield responses.
   - Enable precise nutrient management and short-term yield maximisation; in *mauka*, chemical fertilisers produced up to 78.5 $\mathrm{t\,ha^{-1}}$ roots.
   - Essential for intensive systems where nutrient mining and high crop demand require immediate replenishment.

   Disadvantages:
   - Continuous use without organic inputs accelerates soil acidification, structure decline, and loss of biological activity.
   - High leaching risk under tropical rainfall and low CEC soils leads to poor nutrient-use efficiency and water pollution.
   - Creates economic dependency and masks underlying management issues such as low organic matter or erosion.
2. **Compare these with organic fertilizers and explain advantages and disadvantages of these.**
   Advantages:
   - Improve soil structure, porosity, and moisture retention-key for semi-arid and weathered tropical soils.
   - Increase cation exchange capacity and stimulate microbial life, enhancing nutrient cycling and long-term fertility.
   - Recycle nutrients within the farm system; manure and compost supply N, P, and K while raising soil organic carbon.

   Disadvantages:
   - Lower immediate yields than chemical fertilisers (often about 60 % of chemically fertilised yields).
   - Limited local availability and competing household uses constrain large-scale application.
   - Nutrient release is slow and depends on decomposition rate, requiring continuous management for cumulative effect.
3. **Explain the importance of synchrony of supply and demand for nitrogen.**
   Nitrogen must be supplied when crop uptake is highest to avoid both deficiency and leaching loss. In *ahipa*, synchrony is improved through reproductive pruning, which redirects assimilates and N to root development. Applying manure before planting ensures mineralisation during early growth, while legumes maintain synchrony naturally through symbiotic fixation that releases N in pace with plant demand. Poor synchrony in tropical soils-where mineralisation is rapid-results in low nitrogen-use efficiency.
4. **What is a nutrient deficiency symptom in plants, and what can be learnt from them?**
   Nutrient deficiency symptoms-such as chlorosis, stunted growth, or poor yields-reflect imbalances in soil fertility. They indicate which nutrients are limiting productivity and guide corrective management. In tropical systems, analyses show that N, P, or K deficiencies sharply reduce root yields, while balanced nutrition enhances both yield and nutritional quality. Observing these symptoms helps diagnose soil constraints and refine fertiliser or crop-rotation strategies for sustainable production.

13 Question 13 - The Importance of Agrobiodiversity

1. **Mention four reasons why agro-biodiversity matters for crop breeding.**
   (a) Provides essential **genetic resources for stress tolerance**, including frost- and drought-resistant landraces of *quinoa*, *cañahua*, and native *potatoes*. Such traits are crucial for breeding climate-resilient crops under increasing environmental variability.
   (b) Enhances **nutritional and functional diversity** through traits like high mineral and vitamin content or unique bioactive compounds (e.g. fructooligosaccharides in *yacon*, glucosinolates in *mashua*). These traits expand breeding targets beyond yield to include health-promoting quality.
   (c) Offers **natural pest and disease resistance**, reducing dependence on pesticides. For instance, *mauka* produces antimicrobial proteins that can be introgressed into breeding lines to strengthen resistance.
   (d) Supplies valuable **agronomic and quality traits**, such as improved starch characteristics, root size, or specific fruit qualities useful for food industry and processing. Preserving these alleles widens breeding options and supports innovation.

2. **What are the challenges to work with it? Give at least five examples.**
   (a) Economic pressure from short-cycle, high-value commercial crops promotes monocultures and discourages local diversity.
   (b) Loss of traditional knowledge as younger generations migrate, leading to erosion of seed selection and cultivation skills.
   (c) Cultural stigma labelling native crops as "poor people's food," reducing consumption and market demand.
   (d) Agronomic limitations such as seed shattering in *cañahua* or high labour demand in *ahipa* limit adoption.
   (e) Biopiracy and restrictive access regulations under the Nagoya Protocol complicate equitable use of genetic resources.
   (f) Insufficient ex situ conservation and limited research investment for underutilised crops like *mauka*, leaving genetic material at risk.

3. **How to conserve this agro-biodiversity?**
   (a) **In situ conservation:** Maintain crop diversity on-farm by supporting farmers as biodiversity custodians, ensuring continued cultivation and adaptive selection of landraces under local conditions.
   (b) **Ex situ conservation:** Collect and preserve germplasm in national and international seed banks, facilitating research and breeding access.
   (c) **Market revalorisation and policy support:** Promote native crops by developing value-added products (e.g. *yacon* syrup, *mashua* flour), improving market access, and providing training in processing and branding. Strengthening farmer organisations and linking conservation to economic incentives ensures long-term sustainability and prevents genetic erosion.

14 Question 14 - Crop Phenotyping

1. **How can phenotyping approaches support crop production in the future?**
   Phenotyping enables precise and high-throughput measurement of plant traits to identify and improve genotypes best suited to future climates and management systems. It supports breeding by quantifying adaptive traits such as drought, heat, and frost tolerance; improves agronomic efficiency by analysing growth responses to temperature, light, and density; and supports modelling of thermal time and base temperature to optimise sowing and harvest scheduling. By linking physiological and biochemical traits to productivity, phenotyping also contributes to improved nutritional quality, resilience, and resource-use efficiency-key goals in sustainable tropical agriculture. Emerging digital and automated tools further allow integration of phenotypic data with genomics to accelerate breeding for climate adaptation.

2. **Can you give some examples of applications in the tropics?**
   - ***Cañahua:*** Germination and seedling phenotyping across 3–24 °C and varying sowing depths identifies landraces with rapid emergence and cold-soil adaptation.
   - ***Ahipa:*** Root growth and yield phenotyping relate productivity to accumulated heat units and temperature, guiding site selection and planting time.
   - ***Capsicum* and ARTCs:** Chemical phenotyping detects accessions rich in flavonoids, FOS, and glucosinolates, supporting breeding for nutritional quality and functional foods.
   - **Participatory sensory phenotyping:** Evaluates colour, flavour, and texture with local communities to align crop improvement with consumer preferences and cultural identity.

3. **Do you see difficulties in its application in the tropics? How can they be overcome?**
   Tropical phenotyping faces major challenges: high environmental variability, limited infrastructure, genetic heterogeneity, and low commercial value of many native crops.
   - Apply multivariate and modelling approaches to handle genotype $\times$ environment interactions under field conditions.
   - Combine quantitative phenotyping with farmers' experiential knowledge through participatory approaches to capture locally relevant traits.
   - Standardise morphological descriptors and strengthen germplasm conservation to ensure data comparability across sites.
   - Link phenotyping results to value-chain development, gastronomy, and market innovation to revalue traditional crops and ensure research impact.
   - Invest in low-cost, portable, or image-based tools adapted to tropical environments to overcome logistical constraints.

15 Question 15 - Small and Large Scale Farming

1. **Mention at least two characteristics for each: small- and large-scale farming systems.**
   Small-scale farming:
   - High agrobiodiversity on limited land, relying on mixed or intercropping systems such as *chiru* and *ananta*, which integrate crops and livestock.
   - Low external input dependence, using traditional tools, organic manure, and local ecological knowledge to maintain soil fertility and risk resilience.

   Large-scale farming:
   - Dominated by monocultures of market-oriented crops with high mechanisation and capital investment; for example, quinoa expansion on the Altiplano.
   - Focused on maximising yield and profit, often competing with traditional agropastoral systems such as llama husbandry and reducing biodiversity.

2. **Define "sustainable intensification" and explain why some people consider the term self-contradictory.**
   Sustainable intensification seeks to increase food production while minimising environmental impact and preserving ecosystem services. It emphasises closing yield gaps through improved agronomic efficiency rather than higher input use.
   Some critics see the concept as self-contradictory because historical intensification has caused biodiversity loss, soil degradation, and greenhouse gas emissions. The term combines two opposing goals: "sustainability," which implies ecological balance and low input use, and "intensification," which implies higher productivity and resource extraction. However, advocates argue that through better management, diversification, and innovation, productivity and sustainability can coexist.

3. **Give three examples of sustainable intensification and explain one of them in detail.**
   (a) **Legume-based systems:** Using *Pachyrhizus* (e.g. *ahipa*) to fix atmospheric nitrogen, reduce fertiliser need, and enrich soils.
   (b) **Integrated agropastoral systems:** Balancing llama grazing with quinoa cultivation to maintain nutrient cycling and livelihood stability.
   (c) **Improved agronomic management:** Optimising planting density, rotation, and residue management to raise yields sustainably.

   Detailed example: Tuberous legumes such as *ahipa* form symbioses with *Rhizobium* and *Bradyrhizobium*, fixing up to $215\,\mathrm{kg\,N\,ha^{-1}}$ and eliminating the need for synthetic nitrogen. When residues are left on the field, they replenish soil fertility for subsequent crops. This system increases productivity while reducing external inputs, exemplifying sustainable intensification through biological nitrogen fixation, natural nutrient recycling, and minimal environmental impact. In tropical highlands, such practices improve both yield stability and long-term soil health, aligning productivity with sustainability goals.

16 Question 16 - Fertilizer and Manure in the Tropics

1. **How to determine how much nutrients need to apply for crop growth? Discuss the practices to reduce nutrient losses and increase nutrient use efficiency.**
   (a) Nutrient needs in tropical systems are often established through field trials, soil quality targets, or biological autonomy. Empirical testing defines appropriate fertilizer or manure doses (e.g. 60 N and 40 P units, or 7.5 t ha^{-1} manure). Crops like mauka require soils with ≥ 3 % organic matter, while legumes such as ahipa rely on biological nitrogen fixation, eliminating external N requirements.
   (b) To increase nutrient use efficiency (NUE) and reduce losses:
      i. Promote N fixation via legumes and rhizobial inoculation (fixing 58-215 kg N ha^{-1}).
      ii. Apply pruning in root crops to direct nutrients to the economic organ.
      iii. Recycle manure and residues from agropastoral systems every two years to replenish soil nutrients and organic carbon.
2. **Discuss the advantages and disadvantages of using mineral and organic fertilizers.**

Table 4.3: *Comparison of mineral and organic fertilizers in tropical systems.*

Fertilizer type	Advantages	Disadvantages
Mineral Fertilizers (Chemical)	• High, immediate yield response (e.g. mauka 78.5 t ha^{-1} roots). • Concentrated nutrients easy to apply and control. • Precise nutrient management for specific crop needs.	• Does not improve soil structure or microbial health. • Enhance cation exchange capacity and microbial activity. • Recycle nutrients within the farming system.
Organic Fertilizers (Manure)	• Enhances physical (structure, porosity), chemical (CEC), and biological (microbial) properties. • Recycles farm nutrients and supports sustainability. • Provides N, P, and K naturally.	• Produces lower yields (≈ 59 % of chemical fertilizer). • Limited availability and labour-intensive handling. • Often reserved for main crops like potato and maize. • Slow nutrient release, requiring long-term application.

1. **How to determine how much nutrients to apply for crop growth? Discuss practices to reduce nutrient losses and increase nutrient-use efficiency (NUE).**
   Nutrient requirements in tropical systems are established through field trials, soil fertility targets, and local empirical testing. Site-specific nutrient management defines appropriate fertiliser or manure rates-for example, 60 kg N and 40 kg P per hectare, or 7.5 t ha^{-1} manure. Crops such as *mauka* perform optimally in soils with ≥ 3 % organic matter, whereas legumes like *ahipa* rely on biological nitrogen fixation, removing the need for external N inputs.

   To increase NUE and reduce nutrient losses in tropical environments:
   - **Promote biological N fixation:** Use legumes and rhizobial inoculation, fixing 58–215 kg N ha^{-1} and reducing fertiliser dependency.
   - **Optimise nutrient partitioning:** Apply pruning in root crops to redirect assimilates and nutrients to the economic organ.

- **Recycle nutrients:** Reintegrate manure and crop residues from agropastoral systems every two years to replenish soil nutrients and organic carbon.
- **Synchronise supply and demand:** Time fertiliser or manure applications with peak crop uptake to minimise leaching losses under heavy tropical rainfall.
- **Improve soil structure:** Maintain soil cover and organic inputs to enhance infiltration and nutrient retention capacity.

2. **Discuss the advantages and disadvantages of using mineral and organic fertilizers.**

Table 4.4: *Comparison of mineral and organic fertilizers in tropical production systems.*

Fertilizer type	Advantages	Disadvantages
Mineral Fertilizers (Chemical)	• Provide high, immediate yield response (e.g. *mauka* up to 78.5 $t\,ha^{-1}$ roots). • Concentrated nutrients allow precise control and rapid crop correction. • Effective for short-term yield optimisation.	• Do not improve soil structure, CEC, or microbial life. • High leaching risk under tropical rainfall and low CEC soils. • Long-term use can acidify soils and increase dependency.
Organic Fertilizers (Manure, Compost)	• Enhance soil structure, porosity, and water-holding capacity. • Improve cation exchange capacity and stimulate microbial activity. • Recycle farm nutrients, supplying N, P, and K naturally. • Support long-term sustainability and soil resilience.	• Lower immediate yield response (often 50–60% of chemical fertiliser yields). • Limited availability and labour-intensive handling. • Nutrient release depends on decomposition rate, requiring sustained management.

Summary: Chemical fertilizers maximise short-term yield but may degrade long-term soil quality, while organic fertilizers sustain fertility and structure but release nutrients slowly. Integrating both through combined or sequential applications improves nutrient-use efficiency, stabilises yields, and maintains soil health-key objectives for sustainable tropical crop production.

17 Question 17 - Fertility of Tropical Soils

1. **What is soil fertility? How soil organic carbon helps to improve soil fertility?**
   (a) Soil fertility is the soil's capacity to provide essential nutrients and physical conditions for healthy crop growth. In tropical and high-altitude regions, fertility determines crop establishment and yield potential under challenging conditions.
   (b) Soil organic carbon (SOC), as part of organic matter, enhances fertility through:
      - Physical improvement: increases soil structure, porosity, and water retention, essential in semi-arid climates.
      - Chemical enrichment: boosts nutrient retention and cation exchange capacity.
      - Biological enhancement: supports microbial activity that aids nutrient cycling.
   (c) Crops like mauka perform best in soils with ≥ 3 % organic matter, showing SOC's key role in productivity.
2. **What is the cation exchange capacity (CEC) of a soil? and how does CEC affect soil fertility?**
3. CEC is the soil's ability to hold and exchange positively charged nutrients (e.g. K^+, Ca^{2+}, Mg^{2+}) on clay and organic matter surfaces.
4. A high CEC means:
   - Better nutrient retention and reduced leaching.
   - Greater availability of macronutrients like phosphorus and potassium.
   - Enhanced chemical fertility, maintaining continuous nutrient supply for plants.
5. Thus, soils rich in organic matter and clay-those with high CEC-are more fertile, resilient, and productive under tropical conditions.

18 Question 18 - Legumes as Soil Nutrients Providers

1. **What is the difference between a legume green manure and a legume cover crop? Discuss with examples, advantages and disadvantages of each method.**
   Green manure legumes are cultivated primarily to enrich the soil by incorporating their biomass directly into it.
   - **Example:** Leaving *Pachyrhizus* (yam bean) tops in the field after harvest.
   - **Advantages:** Returns large quantities of fixed nitrogen to the soil, improving fertility, soil structure, and moisture retention while reducing external fertiliser needs.
   - **Disadvantages:** Biomass cannot be used as fodder or sold, limiting short-term economic returns and labour efficiency.

   Cover crops, in contrast, protect the soil surface from erosion, suppress weeds, and provide feed or mulch while indirectly adding nitrogen through residues or manure.
   - **Example:** Dried *P. erosus* hay used as animal fodder mixed with maize or lucerne.
   - **Advantages:** Supplies protein-rich feed, prevents nutrient leaching during the rainy season, and recycles nutrients through manure.
   - **Disadvantages:** Potential rotenone toxicity if not properly managed and higher labour input for pruning and monitoring.

   Both methods are vital in tropical systems where high rainfall and erosion accelerate nutrient loss; green manures rebuild soil fertility, while cover crops maintain soil protection between production cycles.

2. **What are the advantages and disadvantages of legumes in cropping systems?**
   Advantages:
   - Fix atmospheric nitrogen (up to $215\,\mathrm{kg\,N\,ha^{-1}}$), lowering fertiliser costs and improving nutrient balance.
   - Enhance soil fertility, structure, and sustainability through rotation or intercropping.
   - Provide diverse outputs-protein-rich seeds, edible roots, and high-value fodder-supporting food security and income diversification.

   Disadvantages:
   - Labour-intensive management (e.g., reproductive pruning and harvesting).
   - Presence of toxic compounds such as rotenone in unpruned plants limits utilisation.
   - Susceptibility to pest and nematode buildup requires long rotations of 3–4 years.

3. **What are potential constraints in adaptation of legumes by smallholder farmers?**
   - **Labour demands:** Manual pruning and biomass handling are time-consuming.
   - **Market limitations:** Low consumer awareness, weak demand, and poor transport reduce profitability.
   - **Land competition:** Limited area prioritised for cash crops reduces space for legumes.
   - **Knowledge and breeding gaps:** Few improved varieties and limited agronomic extension services.
   - **Agronomic complexity:** Some species are perennial, complicating short-cycle production and synchronisation with other crops.

   Conclusion: Integrating legumes-whether as green manure or cover crops-offers long-term gains in soil fertility and resilience but requires policies, market incentives, and labour-efficient management to enable smallholders to adopt them sustainably in tropical production systems.

19 Question 19 - Tropical Crop Physiology

1. **What are the four major environmental factors influencing crop evapotranspiration (ET), and how do they affect it?**

   Evapotranspiration (ET) combines soil evaporation and plant transpiration, reflecting the energy and water exchange between the surface and the atmosphere. It is driven by climatic and physiological conditions that determine water demand and crop growth rate.

   The four major environmental factors are:

   - **Temperature:** Regulates the vapour pressure deficit (VPD); higher temperatures increase atmospheric demand for water vapour, accelerating ET and plant water use, whereas low temperatures reduce both ET and growth.
   - **Water availability:** ET depends on soil moisture; when rainfall is below crop water requirements, transpiration and photosynthesis decline. Rapid germination enables highland crops to exploit available soil water before drought periods.
   - **Solar radiation:** Supplies the latent heat for evaporation and drives photosynthesis and flowering, strongly influencing daily ET rates.
   - **Air movement (wind):** Replaces humid boundary layers around leaves, maintaining the vapour gradient and enhancing ET. In calm conditions, limited air exchange reduces ET.

   These factors interact dynamically-temperature and radiation create the evaporative demand, while soil water and canopy structure determine the supply. Managing this balance is crucial for productivity in tropical highland systems.

2. **Why is stomatal conductance important in controlling crop transpiration, and how is it regulated under drought stress?**

   Stomatal conductance determines how open the stomata are, regulating both transpiration and CO_2 uptake. By adjusting stomatal aperture, crops maintain water balance while sustaining photosynthesis. Efficient water users such as *ahipa* show high water-use efficiency through tight stomatal control.

   Under drought stress, regulation involves several adaptive strategies:

   - **Reduced leaf area:** Species like cassava shed older leaves to lower the transpiring surface.
   - **Early water use:** Crops such as *cañahua* germinate and establish rapidly to use available soil moisture before the dry period.
   - **Intrinsic drought tolerance:** Crops like *mauka* and *cañahua* maintain low transpiration rates or resilient stomatal function, sustaining minimal gas exchange under low water potential.

   Together, these mechanisms optimise the trade-off between carbon gain and water conservation, ensuring survival and stable yields in water-limited tropical environments.

20 Question 20 - Rice

1. **What is the difference between upland and lowland rice production systems?**
   Lowland (paddy) rice: Cultivated in flooded or semi-flooded fields where water levels are actively managed using bunds or ridges. The soil remains saturated for most of the crop cycle, suppressing weeds and promoting anaerobic microbial activity that enhances nutrient availability (e.g. Fe, Mn reduction). Flooding also stabilises temperature and water supply but leads to methane emissions. Lowland systems typically show higher and more stable yields due to controlled water management.
   Upland rice: Grown under rainfed, non-flooded conditions in dryland fields. It depends entirely on rainfall, requiring well-drained soils and drought-tolerant varieties. The aerobic soil environment favours nitrification but increases susceptibility to nutrient leaching and weed pressure. Yields are generally lower and more variable due to drought stress and limited nutrient retention.

2. **Provide examples of countries where each of these production systems can be found.**
   - **Lowland (paddy) rice:** Common in China (e.g. Sichuan and Chengdu provinces), where farmers also cultivate *Pachyrhizus* (yam bean) or soybean on ridges between paddies to improve soil fertility and diversification.
   - **Upland rice:** Typical of Central American dryland systems, where crops rely entirely on rainfall and are often intercropped with legumes or root crops, similar to yam bean-based production systems.

   In summary, lowland systems ensure high productivity and weed control through water management, while upland systems prioritise resilience and low-input adaptability under rainfed tropical conditions.

21 Question 21 - Legumes as Nutrient Providers

1. **How can legumes play an important role in tropical production systems? Detail the mechanism.**
   Legumes enhance soil fertility in tropical systems primarily through Biological Nitrogen Fixation (BNF). Symbiotic *Rhizobium* or *Bradyrhizobium* bacteria within root nodules convert atmospheric N_2 into ammonia (NH_3), which the plant assimilates for protein and biomass formation. This process can fully supply the nitrogen demand of crops such as *Pachyrhizus ahipa* without external fertiliser inputs. When legume residues are incorporated after harvest, a substantial portion of the fixed N (up to $215\,\mathrm{kg\,N\,ha^{-1}}$) remains in the soil, improving fertility for subsequent crops. Beyond nitrogen supply, legumes lower input costs, support agroecological sustainability, and diversify production through intercropping and mixed systems, enhancing resilience to climatic variability.

2. **Are legumes always an advantage for the following crop in the crop rotation? How to assess if a legume is advantageous for the following crop?**
   Legumes are generally beneficial due to their positive nitrogen balance, but continuous cultivation can lead to pest, disease, or nematode buildup. For instance, *Pachyrhizus erosus* performs poorly when grown repeatedly and requires 3–4 years before replanting to restore soil and pest equilibrium.
   To assess whether a legume benefits the following crop:
   - Measure the **soil nitrogen balance** or total fixed N.
   - Compare the **yield response** of the subsequent crop against a non-legume rotation.
   - Evaluate **nodule formation and efficiency** through rhizobial inoculation and plant biomass.

   A measurable improvement in soil fertility or yield confirms the legume's advantage within the rotation.

3. **How do nitrogen fertilisers interact with the ability of a legume to fix nitrogen?**
   External nitrogen fertilisation suppresses BNF because legumes preferentially absorb available mineral N rather than forming new nodules. As a result, high fertiliser levels reduce symbiotic activity and biological efficiency. Efficient fixers such as *P. ahipa* meet their N requirements entirely through BNF, making mineral N applications unnecessary and economically inefficient. Maintaining low external N encourages effective nodulation and maximises the ecological benefit of legumes in tropical production systems.

22 Question 22 - Minor Cereals

1. **Give examples of minor cereals with local importance in the tropics.**
   In tropical highlands, locally important minor cereals include *cañahua* (*Chenopodium pallidicaule*) and *quinoa* (*Chenopodium quinoa*), traditional Andean grains cultivated between 3800–4200 m a.s.l. for their exceptional protein content and micronutrient richness. Among true cereals (Poaceae), *maize* (*Zea mays*) and *wheat* (*Triticum aestivum*) also hold regional significance as short-cycle, market-oriented crops that increasingly replace traditional polycultures.

2. **How is the yield of sorghum and millet in the tropics compared to other cereals?**
   Although precise yield data are not provided, minor cereals such as *cañahua* and *quinoa* typically yield less than major cereals under optimal conditions but maintain higher yield stability under stress. Their capacity to germinate and mature rapidly in drought, frost, or heat conditions makes them more reliable in marginal environments, ensuring food security where sorghum, millet, or maize yields would fluctuate strongly. This adaptability compensates for their lower productivity through consistent harvests in challenging tropical and high-altitude ecosystems.

3. **As a consequence, how are they commonly grown in the tropics (what type of cropping system)?**
   Minor cereals are mainly cultivated in low-input, diversified systems adapted to local environments:
   - **Agropastoral systems:** Integration of quinoa and cañahua with llama husbandry supports nutrient recycling through manure and provides livelihood diversity.
   - **Rotational systems:** Alternated with potatoes or legumes to exploit residual fertility and maintain soil health.

   However, in expanding commercial zones, these crops are increasingly grown as monocultures to meet export demand, reducing agrobiodiversity and competing with traditional grazing areas.

4. **What are the two main factors determining the choice of cropping system?**
   (a) **Environmental adaptation and resilience:** Selection of crops and systems suited to cold, drought, poor soils, and short growing seasons-key survival traits in tropical highlands.
   (b) **Socio-economic viability and labour demand:** Farmers favour short-cycle, marketable crops requiring less manual labour and ensuring economic return over traditional labour-intensive systems.

   In summary, minor cereals remain essential for sustainable tropical farming due to their ecological resilience and cultural value, even as socio-economic pressures drive transitions toward more uniform, market-driven systems.

Chapter 5
Abbreviations and Explanations

Topic	Abb.	Description
Leaching	**n.a.**	*leaching refers to the process by which substances, such as ions, minerals, or nutrients, are removed or lost from the soil. This often occurs due to water penetrating the soil and displacing these substances*