



# Tropical Fruit Production

## LPLK10367U

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

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[Link to GitHub repository](#)



# **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.

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# 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	<ul style="list-style-type: none"><li>• No external censorship</li><li>• Several internal examiners</li></ul>
Re-exam	<ul style="list-style-type: none"><li>• As the ordinary exam.</li><li>• 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 %.</li></ul>

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# **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  $0^{\circ}$ - $23.5^{\circ}$ (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  $23.5^{\circ}$ - $40^{\circ}$ latitude: These regions receive the highest radiation in summer, have relatively thin cloud cover, and receive less moisture.
- Temperate zone from  $40^{\circ}$ - $60^{\circ}$ 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<sup>2</sup>/year. About 300 W/m<sup>2</sup>/year is lost as terrestrial re-radiation, leaving a surplus of 100 W/m<sup>2</sup> 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<sup>2</sup> 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<sup>+</sup> ions from water penetrating rock mineral structures and displacing ions like K<sup>+</sup>, Ca<sup>2+</sup>, Mg<sup>2+</sup>, and Al<sup>3+</sup>. 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:  $50 \mu\text{m} - 2 \text{ mm}$
- Silt size fraction:  $2 \mu\text{m} - 50 \mu\text{m}$
- Clay size fraction:  $< 2 \mu\text{m}$

**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:  $< 2 \mu\text{m}$

### 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  $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$ . 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 NH<sub>3</sub> volatilization. Internal processes within the soil involve mineralization, ammonification, nitrification, immobilization, and plant uptake. The forms of nitrogen include organic N, plant N, NH<sub>4</sub><sup>+</sup>, and NO<sub>3</sub><sup>-</sup>.

### 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<sub>2</sub><sup>+</sup>), Magnesium (Mg<sub>2</sub><sup>+</sup>), Potassium (K<sup>+</sup>), Sodium (Na<sup>+</sup>), and Ammonium (NH<sub>4</sub><sup>+</sup>) (see also Slides 5, 9, 11, 12, 13).

#### Acid Cations

These include Aluminium (Al<sub>3</sub><sup>+</sup>), Iron (Fe<sub>3</sub><sup>+</sup>), and Hydrogen (H<sup>+</sup>).

#### 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	Expansile	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,  $K^+ = 16 \text{ cmol/kg} (= 16 \text{ cmol(+)}/\text{kg})$ ,  $Ca^{++} = 4 \text{ cmol/kg} (= 8 \text{ cmol(+)}/\text{kg})$ ,  $Mg^{++} = 2 \text{ cmol/kg} (= 4 \text{ cmol(+)}/\text{kg})$ . Base saturation =  $100 \times (16+8+4) / 40 = 70\%$ .

**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 CO<sub>2</sub> 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

##### *Eleusine coracana* (L.) Gaertn.

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

## POACEAE Chloridoideae

### *Eragrostis téf* (Zucc.) Trotter

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

## 4.2 Eragrostis

*Eragrostis 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 ( $\alpha$ -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* Baner.

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, isafño, maswallo. An image illustrates the distribution of mashua (see slide 9). This map distinguishes between cultivated mashua (*Tropaeolum tuberosum* 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 ripened 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:  $\theta_H = (\Psi - \Psi_b(g))t_g$ .

- $\theta_H$  (Theta H) represents the hydrotime constant, measured in MPa days.
- $\Psi$  (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 hydrotome 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:  $6\text{CO}_2 + 6\text{H}_2\text{O} + \text{light} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2$ . 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 CO<sub>2</sub> 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 CO<sub>2</sub> 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 CO<sub>2</sub> Concentration

Plant growth and photosynthetic efficiency are influenced by CO<sub>2</sub> 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 ( $\Psi_w$ )

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

- Symbol: Greek letter psi ( $\Psi$ ).
- Units: Bar or Pascal (1 bar = 0.1 MPa).
- Pure water: Has a water potential ( $\Psi_w$ ) 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 ( $\Psi_p$ ) 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 ( $\Psi_w$ ) causes water uptake into the guard cells. As guard cells increase in volume and turgor pressure ( $\Psi_p$ ), 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 ( $\Psi_w$ ) 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<sup>-1</sup>); FI-0 (full irrigation-FI and 0 kg N ha<sup>-1</sup>); EDI-100 (extreme deficit irrigation-EDI and 100 kg N ha<sup>-1</sup>); EDI-0 (extreme deficit irrigation-EDI and 0 kg N ha<sup>-1</sup>). 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 controlled mainly by temperature and moisture, forming the scientific basis of traditional crop calendars. Farmers align sowing and harvesting with favourable climatic windows to optimise germination, growth, and yield. Phenological events follow the principle of thermal time — the accumulation of degree days above a base temperature. For example, cañahua germination begins at about  $-0.9^{\circ}\text{C}$  and requires  $476^{\circ}\text{C}$  hours, illustrating adaptation to cold, highland environments.

In regions like the Bolivian Altiplano, the crop calendar is fixed by short rainy seasons and low temperatures; early sowing between September and November allows crops to establish before drought. Climate shifts disturb this synchrony by altering temperature and rainfall patterns, shortening or lengthening growth cycles. In ahipa, later sowing reduced yield due to a shortened growth period, and comparisons between the 1990s and 2010s show reduced cycle durations, reflecting environmental change. Farmers increasingly replace long-cycle crops with shorter, marketable ones to manage risk.

Genetic diversity within native crops, such as frost-tolerant Solanum species, provides resilience, allowing flexible crop calendars under changing climates. Thus, the crop calendar represents an integration of phenological knowledge and climate adaptation, where thermal time and temperature thresholds govern planting decisions and responses to climate change.

## 2 Question 2 - Highland Crops

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

Introducing new highland crop varieties faces strong social barriers linked to market, cultural, and knowledge-related factors. Economically, farmers prefer short-cycle, high-value crops like cereals and vegetables because traditional species such as ahipa or mauka lack market demand, stable prices, and logistical access to urban centres. Culturally, native roots and tubers are often stigmatized as “poor man’s food” and rejected for their pungent or astringent flavours. Urban migration has further shifted diets toward processed staples, weakening the link between consumers and traditional crops. The loss of traditional agricultural knowledge, as younger generations leave rural areas, also limits the capacity to manage, process, and appreciate these species.

Agronomically, highland crops show remarkable adaptation to extreme conditions such as frost, drought, and poor soils. Species like cañahua and native Solanum potatoes thrive at high altitudes and under minimal input conditions. However, productivity remains limited by issues like seed shattering in cañahua, virus incidence in ulluco and mashua, and competition between roots and reproductive shoots in ahipa. Practices such as pruning, seed inoculation with rhizobia, and improved soil fertility management could substantially raise yields. Yet, these crops often receive fewer resources compared to commercial staples, reflecting the combined influence of social constraints and agronomic challenges on their wider adoption.

## 3 Question 3 - Intercropping

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

Intercropping is the cultivation of two or more crop species within the same plot, a practice common in traditional Andean farming systems. It involves combinations such as ahipa with tomato, onion, or maize; mauka with maize and beans; or mixed tuber systems of oca, ulluco, and mashua. These systems integrate food, fodder, and cash crops within a single field, optimising limited land resources.

The benefits of intercropping include enhanced soil fertility through biological nitrogen fixation by legumes like ahipa, which reduces the need for synthetic fertilizers. It improves pest and disease resilience, as mixed species can protect one another and reduce pathogen spread — for instance, mauka intercropped with maize shows greater frost tolerance and health due to antimicrobial compounds in its roots. Intercropping also increases yield stability and resource efficiency by producing multiple outputs (food and fodder) from the same area.

Moreover, intercropping sustains agrobiodiversity and maintains traditional polyculture systems that balance ecological, economic, and cultural resilience. This diversity strengthens environmental stability and supports long-term agricultural sustainability in highland systems.

## 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.**

Intercropping, though ecologically beneficial, faces several challenges in modern agricultural systems. Agronomically, competition between species can reduce yield efficiency. Fast-growing crops like mauka can overshadow companions, and systems prioritising multiple outputs—such as leaf and starch in achira—often compromise the main yield. High plant density in mixed systems may also limit root yield, as seen in ahipa.

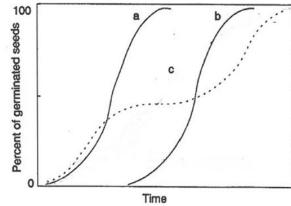
Labour intensity is another major limitation. Practices like reproductive pruning in ahipa can multiply yields but demand extensive manpower, making such systems economically unsustainable compared to low-labour monocrops. Market and industrial pressures further discourage intercropping, as these systems produce non-uniform, small-scale outputs that do not meet commercial processing standards or large-volume demands.

Intercropping is thus less suitable where uniformity, mechanisation, or rapid returns are required — for instance, industrial ahipa or achira production aiming for starch extraction, or in intensified zones where monocultures dominate for efficiency. Additionally, competitive crops like mauka are better placed along field borders rather than intercropped. Hence, while intercropping sustains biodiversity, its complexity and low profitability limit its adoption in modern, high-output agriculture.

## 5 Question 5 - Seed Germination

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

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 are cumulative germination-time curves. They differ in onset (time to first germination), rate (slope), and final fraction germinated. Curve a begins earlier and rises faster; b is delayed and slower but approaches a high final level; c shows a different shape with slower rise and a lower/asymptotic final fraction.
  - 2) Are they as expected for an ordinary germination test? Yes. Under ISTA-type conditions (controlled temperature/light; counts over time) cumulative germination typically follows a sigmoidal increase, with seed lots differing mainly in rate and time to a given percentile.
  - 3) How to estimate the germination curve mathematically? Fit the counts-over-time to the cumulative distribution function of the standard log-logistic model to obtain  $F(t)$ , the fraction germinated at time  $t$ .
  - 4) Necessary parameters in the model. The model requires at least:  $F(t)$  (cumulative fraction), and  $t_{50}$  (time to 50% germination). Differences in curve steepness are captured by the model's shape parameter (as reflected in the fitted curve).
  - 5) How to test whether seed lots a and b differ significantly? Fit the log-logistic model to each lot's time series and compare the fitted parameters—especially  $t_{50}$  (and shape)—between lots; statistical difference is inferred from non-overlap of fitted parameter estimates under the same ISTA test conditions.
  - 6) Why does seed lot c have another shape than a and b? It reflects different fitted parameters: a lower final fraction germinated and/or a different slope (shape) and  $t_{50}$ , indicating slower and incomplete germination under the same controlled test.
  - 7) If lots a and b are identical but a is from an ordinary germination test, what test could yield curve b? A seedling emergence test (following the standard emergence protocol) rather than a germination test—i.e., different test conditions (substrate/temperature regime) that alter the time course and fitted parameters.
1. **Describe the curves.**
    - (a) this curve
    - (b) this curve
    - (c) this curve
  2. **The germination curves represent developments as expected for an ordinary germination test for the three seed lots?**
  3. **How can you estimate the germination curve based on count over time using a mathematical model?**
  4. **Which parameters are necessary in the mathematical model?**
  5. **How can you test whether the curves for seed lots a and b are statistically significantly different?**
  6. **What could be the reason why the curve for seed lot c has another shape than seed lots a and b?**
  7. **If seed lots a and b are actually identical, but curve a is a result of an ordinary germination test, what kind of test could then result in curve b.**

## 6 Question 6 - Sugar Production

1. **What is sugar?**
2. Sugar refers to simple carbohydrates such as sucrose, glucose, and fructose that serve as major energy sources. In many root and tuber crops, sweetness results from the conversion of complex carbohydrates or fructooligosaccharides (FOS) into these simple sugars through enzymatic hydrolysis, often enhanced by sun exposure.
3. **Mention all the crops you know which are used for sugar production.**
4. Crops mentioned include yacon, oca, mashua, ahipa, achira, and sugarcane. These contain varying proportions of sucrose, glucose, and fructose. Yacon and oca are used for syrup or sweetener production, and sugarcane is used for molasses and syrup.
5. **Sugar cane can be used for several purposes. Mention these.**
6. Sugarcane is used to produce molasses (miel de caña), concentrated syrup, and sweeteners like chancaca. It can be processed for direct consumption, combined with other crops in traditional foods, or used as livestock feed when mixed with sweetpotato vines or foliage.
7. **Explain how sugar cane normally is established in the field.**
8. No information is available in the sources on sugarcane establishment methods.
9. **Is it necessary to establish a new sugar cane crop each year?**
10. No relevant information is provided in the sources regarding re-establishment frequency.
11. **Why and when do farmers in many places in the world ignite sugar cane fields?**
12. The sources provide no information on field burning practices for sugarcane
13. **After sugar canes have been processed in a factory, which types of waste products are produced and what can they be used for?**
14. The sources contain no information on industrial sugarcane by-products or their uses.

## 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.

Indicate the approximate onset and duration of the rainy season, give sowing and harvesting time for the two crops, and estimate a realistic yield for maize monocrop. Do you think the yields can improve with the intercropping, why?

Suggest crop establishment for the two crops. What could be the advantages of intercropping the two species?

Rainy season, sowing, and harvesting In semi-arid highlands with about 500 mm annual rainfall, the rainy season typically starts around September-November and lasts until March-April. Both maize and bean are sown at the onset of the rains (September-November). Beans mature earlier and are harvested around 60 days after sowing, while maize is harvested 110-150 days after sowing, typically between January and March.

Estimated yield for maize monocrop A realistic yield for a rainfed, unfertilized maize monocrop under these conditions is about  $1 \text{ t ha}^{-1}$ .

Yield improvement with intercropping Yields can improve because beans, as legumes, fix atmospheric nitrogen through symbiosis with Rhizobium bacteria, enriching soil fertility and benefiting maize. Intercropping also enhances water and nutrient use efficiency and reduces the risk of total crop failure under semi-arid conditions.

Crop establishment The field should be ploughed using oxen or simple tools to retain moisture. Maize is planted in rows at the start of the rains, with beans sown between maize rows to maximize space and soil cover.

Advantages of intercropping maize and bean

Nitrogen fixation by beans improves maize nutrition and system sustainability.

Efficient land use and higher total productivity from the same area.

Risk reduction against drought and crop failure.

Structural benefits, as maize provides support and partial shade for beans.

Maintenance of agrobiodiversity, characteristic of traditional milpa-type systems.

## 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?** Rainfall and temperature distribution In the highlands near Lake Titicaca, annual rainfall is about 800 mm, concentrated between September and April, corresponding to the short rainy and growing season. The dry season extends from May to November. Temperatures fluctuate strongly, with daytime maxima of 17-19°C and night minima near 0-3°C, occasionally dropping below freezing. The mean temperature during the cropping season is about 9-10°C, which suits quinoa's tolerance to cold conditions and low base temperature (around 3°C).

**When is quinoa sown and harvested?** Quinoa is typically sown from September to November, at the onset of the rains, to ensure good establishment. The crop matures with the decline of the rainy season and is harvested in April or May.

**Which other crops may the farmer grow?** Farmers near Lake Titicaca often combine quinoa with other traditional Andean crops and livestock. Common companion or rotation crops include potatoes (*Solanum spp.*), cañahua (*Chenopodium pallidicaule*), and other Andean root and tuber crops such as oca, mashua, and ulluco, all suited to 700-1000 mm rainfall and high altitudes. The farmer likely integrates llama husbandry into this agropastoral system to maintain soil fertility and livelihood diversity.

## 9 Question 9 - Intercropping

1) Monocropping vs. Intercropping Intercropping (polyculture) involves cultivating multiple species together, whereas monocropping focuses on one crop per field.

Advantages of intercropping: Enhances agrobiodiversity and resilience, improving adaptation to climatic stress. Promotes soil fertility through biological nitrogen fixation by legumes (e.g. ahipa). Reduces production risk, as crop diversity buffers against total failure.

Disadvantages of intercropping: Requires high labour input (e.g. pruning ahipa for yield). Causes competition between crops, possibly lowering individual yields. Has low marketability and scalability, unsuitable for mechanised or industrial systems.

Advantages of monocropping: Provides high yield potential for specific commercial crops. Offers quick economic returns and efficient management. Facilitates mechanisation and easier pest and nutrient control.

Disadvantages of monocropping: Causes loss of agrobiodiversity and increased vulnerability to pests. Leads to environmental unsustainability and soil depletion. Creates land-use conflicts, such as between quinoa fields and llama pastures.

2) Planning a trial to test intercropping effects Use a randomised block or split-plot design with treatments comparing:

Monocrop A (e.g. maize)

Monocrop B (e.g. bean)

Intercrop A+B (alternate rows or mixed plots)

Include several replicates, equal plant densities, and similar soil conditions. Record yield and yield components for each crop. Analyse data with ANOVA and compare means using Tukey's test. For multi-environment studies, use AMMI analysis to assess genotype  $\times$  environment interactions.

3) Land Equivalent Ratio (LER) LER measures how efficiently land is used under intercropping compared with monocropping:  $LER = (Y_{ab}/Y_a) + (Y_{ba}/Y_b)$  where  $Y_{ab}$  and  $Y_{ba}$  are intercrop yields of each species, and  $Y_a$  and  $Y_b$  are their monocrop yields. If  $LER > 1$ , intercropping uses land more efficiently than monocropping;  $LER = 1$  means equal efficiency;  $LER < 1$  indicates a disadvantage.

1. Discuss monocropping vs intercropping. Mention at least 3 advantages/ 3 disadvantages for each.

**Table 4.1:** A table with some examples of both advantages and disadvantages of monocropping.

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>1. Simplicity in management and mechanization.</li> <li>2. Easier to apply uniform pest and disease control.</li> <li>3. Specialization can lead to higher yields of a single crop.</li> </ul>	<ul style="list-style-type: none"> <li>1. Increased complexity in management.</li> <li>2. Potential for increased competition between crops.</li> <li>3. Risk of total crop failure due to pests or diseases.</li> </ul>

2. What is intercropping?
2. How would you plan a trial to test the effect of intercropping?
3. What is Land Equivalent Ratio?

**Table 4.2:** A table with some examples of both advantages and disadvantages of intercropping.

Advantages	Disadvantages
<ul style="list-style-type: none"> <li>1. Simplicity in management and mechanization.</li> <li>2. Easier to apply uniform pest and disease control.</li> <li>3. Specialization can lead to higher yields of a single crop.</li> </ul>	<ul style="list-style-type: none"> <li>1. Increased complexity in management.</li> <li>2. Potential for increased competition between crops.</li> <li>3. Risk of total crop failure due to pests or diseases.</li> </ul>

## 10 Question 10 - Fertility of Tropical Soils

1. Give an overview of the benefits of increasing the content of organic carbon in soil
2. Higher organic carbon improves soil structure, porosity, and water retention, which are vital in semi-arid tropical systems. It enhances nutrient-holding capacity and cation exchange, reducing nutrient losses. It also supports microbial activity, promoting biological soil health. Crops like mauka respond well to soils rich in organic matter ( $\geq 3\%$ ), showing better growth and productivity under such conditions.
3. What is the cation exchange capacity of a soil and how does it affect soil fertility?
4. CEC is the soil's ability to hold and exchange positively charged nutrients such as  $K^+$ ,  $Ca^{2+}$ , and  $Mg^{2+}$ . Soils with high CEC retain nutrients longer, preventing leaching and ensuring their availability for crops. Organic matter increases CEC, improving fertility and nutrient efficiency, particularly important for tropical soils that are often nutrient-poor.
5. Explain how the content of organic carbon of a soil can be increased.
6. Organic carbon can be raised by applying organic fertilizers (manure, compost, humus) and by integrating biomass-producing or nitrogen-fixing crops like achira and ahipa. Llama husbandry and traditional agropastoral practices recycle nutrients through manure. Incorporating crop residues and rotations further builds soil organic matter, enhancing fertility, sustainability, and crop resilience.

## 11 Question 11 - Legumes as Soil Nutrients Providers

**Importance of legumes for the fertility of tropical soils:**

1. **Explain how legumes can play an important role in tropical production systems.**
2. Legumes such as *Pachyrhizus ahipa* play a key role in tropical systems through biological nitrogen fixation, forming symbioses with *Rhizobium* or *Bradyrhizobium* that eliminate the need for nitrogen fertilizer. They improve soil fertility by returning nitrogen-rich residues to the soil (up to  $215 \text{ kg N ha}^{-1}$ ), lower input costs, and support sustainable, low-input farming. Their adaptability to smallholder systems and capacity to enhance biodiversity make them central to resilient tropical agriculture.
3. **What is the difference between a legume green manure and a legume cover crop?**
4. Both enrich the soil but differ in purpose and management. A green manure is grown primarily to be incorporated into the soil to increase organic matter and nitrogen. A cover crop protects the soil surface, suppresses weeds, and can also provide fodder before decomposition. In the case of *Pachyrhizus* species, above-ground biomass can serve either role—being incorporated as green manure or used as fodder while still recycling nutrients through manure.
5. **Are legumes always an advantage for the following crop in the crop rotation?**
6. Not always. Although legumes leave a positive nitrogen balance, continuous cultivation can cause pest and nematode buildup. For example, *Pachyrhizus erosus* performs poorly when grown for more than two consecutive seasons and requires 3–4 years of rotation to prevent pest accumulation. Thus, legumes must be integrated into diverse crop rotations to maintain their benefits.
7. **Explain how nitrogen fertilizer interacts with the ability of a legume to fix nitrogen.**
8. Applying nitrogen fertilizer reduces the need and often the efficiency of symbiotic fixation, as plants preferentially use available mineral N instead of fixing atmospheric  $\text{N}_2$ . In *ahipa*, inoculation with efficient rhizobia alone maximized yields, showing that external N input is unnecessary. High fixation rates (up to  $215 \text{ kg N ha}^{-1}$ ) confirm that these legumes can fully meet their nitrogen needs without fertilizer, lowering both cost and environmental impact.

## 12 Question 12 - Fertilizers and Manure

### Fertilizers in tropical crop production systems:

1. What are the advantages and disadvantages of using chemical fertilizers in tropical production systems?

2. Advantages:

- Provide high nutrient concentration, rapidly available to crops.
- Maximize yield, as seen in mauka where chemical fertilizers produced up to  $78.5 \text{ t ha}^{-1}$  roots.
- Allow precise control of nutrient inputs.

3. Disadvantages:

- Unsustainable: repeated use degrades soil structure and increases dependency.
- Do not improve water retention, porosity, or microbial life.
- Can mask management issues and lead to environmental pollution or economic inefficiency.

4. Compare these with organic fertilizers and explain advantages and disadvantages with these.

5. Advantages:

- Improve soil structure, porosity, and moisture retention.
- Enhance cation exchange capacity and biological activity.
- Recycle nutrients within the farming system; manure adds N, P, and K naturally.

6. Disadvantages:

- Lower yields than chemical fertilizers (about 59% of chemically fertilized yields).
- Limited availability, often prioritised for main crops like maize or potato.
- Slow nutrient release, requiring long-term application for noticeable effect.

7. Explain the importance of synchrony of supply and demand for nitrogen.

Nitrogen must be available when the crop needs it most to avoid loss or deficiency. In ahipa, synchrony is achieved through reproductive pruning, which redirects assimilates and nitrogen to roots. Applying manure before planting ensures N availability during early growth. Legumes naturally maintain synchrony through symbiotic fixation, supplying N as needed during development.

8. What is a nutrient deficiency symptom in plants and what can be learnt from them?

Deficiency symptoms, such as poor growth or low yields, indicate imbalances in soil fertility. They reveal which nutrients are limiting productivity. Chemical and nutritional analyses show that deficiencies in N, P, or K reduce root yield, while certain crops like mashua compensate dietary amino acid deficiencies. Observing these symptoms helps identify soil or crop management needs and informs crop selection for balanced nutrition.

## 13 Question 13 - The Importance of Agrobiodiversity

### 1. Mention four reasons why agro-biodiversity matters for crop breeding.

- (a) Provides genetic resources for stress tolerance, such as frost- and drought-resistant landraces of quinoa, cañahua, and native potatoes.
- (b) Enhances nutritional and functional diversity, supplying traits like high mineral content and unique compounds (e.g. FOS in yacon, glucosinolates in mashua).
- (c) Offers natural pest and disease resistance, seen in mauka, which produces antimicrobial proteins.
- (d) Supplies valuable agronomic and quality traits, such as improved starch quality or specific fruit characteristics useful for breeding and industrial purposes.

### 2. What are the challenges to work with it? Give at least 5 examples

- (a) Economic pressure from short-cycle, marketable crops leading to monoculture.
- (b) Loss of traditional knowledge as younger generations migrate away.
- (c) Cultural stigma labelling native crops as “poor people’s food,” reducing demand.
- (d) Agronomic limitations, such as seed shattering in cañahua or high labour needs in ahipa.
- (e) Biopiracy and legal barriers under the Nagoya Protocol limiting fair benefit sharing.
- (f) Lack of ex situ conservation and research for underutilised species like mauka.

### 3. How to conserve this agro-biodiversity?

- (a) In situ: Maintain diversity on-farm by supporting farmers as biodiversity custodians and monitoring landrace cultivation.
- (b) Ex situ: Collect and preserve germplasm in seed banks and research institutions.

Additionally, market revalorisation is crucial — promoting the nutritional value of native crops, developing value-added products (e.g. yacon syrup, mashua flour), linking producers with new markets, and training farmers in marketing and processing. These combined actions ensure both conservation and continued use of crop diversity.

## 14 Question 14 - Crop Phenotyping

1. **How can phenotyping approaches support crop production (in future)?**
2. Phenotyping enables precise measurement of plant traits to identify and improve genotypes best suited to future climate and management conditions. It supports breeding by identifying traits such as drought and frost tolerance, improves management efficiency through understanding growth responses to temperature and density, and allows modelling of thermal time and base temperature to optimise sowing and harvesting. It also enhances nutritional quality and resilience by linking phenotypic traits to productivity and adaptation.
3. **Can you give some examples for application in the tropics?**
  - Cañahua: Germination studies across temperatures (3-24°C) and sowing depths identify landraces with rapid emergence in cold soils.
  - Ahipa: Root growth phenotyping correlates yield with heat units and temperature, guiding site selection and planting time.
  - Capsicum and ARTCs: Chemical phenotyping identifies accessions rich in bioactive compounds (flavonoids, FOS, glucosinolates) for breeding and nutrition.
  - Participatory sensory phenotyping: Evaluates traits like colour, flavour, and texture to align crop improvement with consumer preference and local traditions.
4. **Do you see difficulties in its application in the tropics? How to overcome?**
5. Tropical systems face challenges such as environmental variability, logistical limitations, genetic heterogeneity, and low market value of traditional crops.
  - Use multivariate analyses to handle genotype × environment interactions.
  - Combine quantitative data with farmers' knowledge through participatory methods to overcome data gaps.
  - Apply standardized morphological descriptors and improve germplasm conservation.
  - Revalue crops economically by linking phenotyping outcomes to gastronomy and market innovation.

## 15 Question 15 - Small and Large Scale Farming

1. Mention at least two characteristics for each: small and large scale farming systems
2. Small-scale farming:
  - High agrobiodiversity on limited land, relying on mixed cropping systems like chiru and ananta.
  - Low input dependence, using traditional tools and manure, guided by local ecological knowledge.
3. Large-scale farming:
  - Monoculture of marketable crops, focusing on yield and commercial export (e.g. quinoa expansion in the Altiplano).
  - High mechanization and land use, often competing with traditional livestock systems such as llama husbandry.
4. Define “sustainable intensification” and explain why some people consider the term self-contradicting.
5. Sustainable intensification aims to increase food production while minimizing environmental impact and preserving ecosystem services. It focuses on closing yield gaps through efficient agronomic management rather than increasing input use.
6. However, some view it as self-contradictory because intensification historically causes biodiversity loss and resource degradation. Combining “sustainability” (biodiversity, low input) with “intensification” (high productivity, specialization) seems paradoxical when intensification itself threatens ecological balance.
7. Give 3 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 fertilizer need, and enrich soils.
  - (b) Integrated agropastoral systems: Balancing llama grazing and quinoa cultivation to maintain soil fertility and livelihood resilience.
  - (c) Improved agronomic management: Optimizing planting density and crop rotation to raise yields sustainably.
8. Detailed example:
9. Tuberous legumes like ahipa form symbioses with Rhizobium and Bradyrhizobium, fixing up to 215 kg N ha<sup>-1</sup>, removing the need for synthetic nitrogen. When residues are left on the field, they restore soil fertility for subsequent crops. This achieves higher productivity with minimal inputs, exemplifying sustainable intensification through natural nutrient cycling and low environmental impact.

## 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<sup>-1</sup> manure). Crops like mauka require soils with  $\geq 3\%$  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<sup>-1</sup>).
  - 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)	<ul style="list-style-type: none"> <li>• High, immediate yield response (e.g. mauka 78.5 t ha<sup>-1</sup> roots).</li> <li>• Concentrated nutrients easy to apply and control.</li> <li>• Precise nutrient management for specific crop needs.</li> </ul>	<ul style="list-style-type: none"> <li>• Does not improve soil structure or microbial health.</li> <li>• Enhance cation exchange capacity and microbial activity.</li> <li>• Recycle nutrients within the farming system.</li> </ul>
Organic Fertilizers (Manure)	<ul style="list-style-type: none"> <li>• Enhances physical (structure, porosity), chemical (CEC), and biological (microbial) properties.</li> <li>• Recycles farm nutrients and supports sustainability.</li> <li>• Provides N, P, and K naturally.</li> </ul>	<ul style="list-style-type: none"> <li>• Produces lower yields (<math>\approx 59\%</math> of chemical fertilizer).</li> <li>• Limited availability and labour-intensive handling.</li> <li>• Often reserved for main crops like potato and maize.</li> <li>• Slow nutrient release, requiring long-term application.</li> </ul>

Summary: Chemical fertilizers maximise short-term yield, while organic fertilizers sustain long-term soil fertility and resilience. Combining both judiciously allows higher efficiency and ecological stability in tropical production systems.

## 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  $\geq 3\%$  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.**
2. Green manure legumes are grown 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 amounts of fixed nitrogen, improving soil fertility and reducing fertilizer needs.
  - Disadvantages: Biomass cannot be used as fodder, reducing short-term income.
3. Cover crops protect soil from erosion 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 and recycles nutrients through manure.
  - Disadvantages: Risk of toxicity from rotenone if not properly managed; requires pruning and monitoring.
4. **What are the advantages and disadvantages of legumes in cropping system?**
5. Advantages:
  - Fix atmospheric nitrogen (up to 215 kg N ha<sup>-1</sup>), reducing fertilizer costs.
  - Improve soil fertility and sustainability through rotation or intercropping.
  - Provide diverse outputs: protein-rich seeds, roots, and fodder.
6. Disadvantages:
  - Labour-intensive management (e.g. reproductive pruning).
  - Toxic compounds (rotenone) in unpruned plants limit use.
  - Pest and nematode buildup requires long rotations (3-4 years).
7. **What are potential constraints in adaptation of legumes by small holder farmers?**
  - Labour demands: Manual pruning and management are time-consuming.
  - Market limitations: Weak demand and poor transport hinder profitability.
  - Competition: Cash crops replace legumes in limited land systems.
  - Knowledge and breeding gaps: Limited research and improved landraces.
  - Agronomic complexity: Perennial habit complicates short-cycle production.

## 19 Question 19 - Tropical Crop Physiology

1. **What are the four major environmental factors influencing crop evapotranspiration (ET)? How do they affect ET?**
  - (a) ET combines evaporation from soil and transpiration from plants, driven by the energy and water exchange between the surface and atmosphere.
  - (b) The four key environmental factors are:
    - Temperature: Governs atmospheric demand for water vapour through the vapour pressure deficit. High temperatures increase ET, while cold conditions reduce it and slow plant growth.
    - Water availability: ET depends on soil moisture; when rainfall is less than crop water requirement, transpiration and growth decline. Rapid germination helps crops exploit available soil water before dry periods.
    - Solar radiation: Provides the latent heat for water evaporation and drives physiological processes such as flowering and photosynthesis, influencing ET rates.
    - Air movement (wind): Removes humid air around leaves, maintaining the vapour gradient and enhancing ET. In calm conditions, ET is lower due to limited air exchange.
2. **Why is stomatal conductance important in controlling crop transpiration? How is it regulated under drought stress?**
  - (a) Stomatal conductance determines how open stomata are, controlling transpiration and CO<sub>2</sub> uptake. By adjusting stomatal aperture, crops regulate water loss while maintaining photosynthesis. Efficient water users like ahipa exhibit high water-use efficiency due to tight stomatal control.
  - (b) Under drought stress, regulation occurs through several adaptive responses:
    - Reduced leaf area: Some crops, like cassava, shed foliage to lower transpiring surface.
    - Early water use: Species such as cañahua germinate rapidly to use moisture before drought onset.
    - Intrinsic drought tolerance: Crops like mauka and cañahua maintain low transpiration or resilient stomatal function, allowing survival under low soil water conditions.
  - (c) Together, these mechanisms balance water conservation and productivity in tropical, high-altitude environments.

## 20 Question 20 - Rice

1. **What is the difference between upland and lowland rice production systems?**
  - Lowland (paddy) rice is cultivated in flooded or semi-flooded fields where water levels are actively managed using bunds or ridges. The soil remains saturated during most of the crop cycle, which suppresses weeds and supports anaerobic microbial activity. This system relies on controlled irrigation or heavy rainfall.
  - Upland rice grows under rainfed, non-flooded conditions in dryland fields. It depends entirely on rainfall, making it more vulnerable to drought and requiring well-drained soils.
2. **Provide examples of countries where each of these production systems can be found.**
  - Lowland (paddy) rice: Found in China (Sichuan and Chengdu provinces), where crops like yam bean or soybean are grown on the ridges between rice paddies.
  - Upland rice: Common in Central American dryland systems where crops are cultivated under rainfed conditions similar to those described for yam bean fields.

## 21 Question 21 - Legumes as Nutrient Providers

1. **How can legumes play an important role in tropical production systems? Detail the mechanism.**
  - Legumes improve tropical soil fertility through Biological Nitrogen Fixation (BNF). Symbiotic Rhizobium or Bradyrhizobium bacteria in root nodules convert atmospheric N<sub>2</sub> into ammonia, which the plant uses for growth. This process supplies the entire N requirement of crops like *Pachyrhizus ahipa* without external fertilizers. When residues are left in the field, a substantial portion of the fixed N (up to 215 kg N ha<sup>-1</sup>) enriches the soil, benefiting subsequent crops. Legumes also reduce input costs, enhance sustainability, and can be intercropped for diversified yields and resilience.
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?**
  - (a) Legumes are generally beneficial due to their N contribution but may not always be advantageous if pests or nematodes accumulate. For example, *Pachyrhizus erosus* performs poorly after continuous cultivation and requires 3-4 years before replanting.
  - (b) To assess advantage:
    - Measure soil N balance or fixed N amount.
    - Observe yield response of the following crop.
    - Evaluate nodule efficiency (e.g. by rhizobial inoculation). A clear yield or fertility improvement confirms advantage.
3. **How do nitrogen fertilizers interact with the ability of a legume to fix nitrogen?**
  - External nitrogen fertilization makes BNF redundant or suppressed, as the legume's symbiosis down-regulates when mineral N is available. Efficient fixers like *P. ahipa* meet their own N needs biologically, so added fertilizer is unnecessary and economically wasteful.

## 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 high protein and nutrient value. Among true cereals (Poaceae), maize (*Zea mays*) and wheat (*Triticum aestivum*) are also regionally significant 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 direct yield data are not given, minor cereals like cañahua and quinoa generally produce lower yields than major cereals under optimal conditions but perform more reliably in extreme environments. Their capacity to germinate and mature quickly under drought, cold, or heat stress makes them superior for food security in marginal tropical and high-altitude areas.

### 3. As a consequence, how are they commonly grown in the tropics (what type of cropping system)?

- Minor cereals are usually grown in low-input, diversified systems, such as:
  - Agropastoral systems, where quinoa and other grains are integrated with llama husbandry.
  - Rotations with potatoes or legumes, taking advantage of residual fertility.
- However, in commercial areas, these crops are increasingly cultivated as monocultures, replacing mixed traditional fields and creating land-use competition.

### 4. What are the 2 main factors determining the choice of cropping system?

- (a) Environmental adaptation and resilience - selection of crops suited to cold, drought, and poor soils.
- (b) Socio-economic viability and labour demand - preference for short-cycle, less labour-intensive, and marketable crops over traditional, labour-heavy systems.

# Chapter 5

## Abbreviations and Explanations

Topic	Abb.	Description
Leaching	n.a.	<i>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</i>