UNIVERSITY OF COPENHAGEN
FACULTY OF SCIENCE

Tropical Fruit Production LPLK10367U

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

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Last compiled: 11-09-2025
Link to GitHub reporsitory

Course Description

Education

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

Content

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

Main disciplines are:

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

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

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

Learning Outcome

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

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

Knowledge

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

Skills

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

Competences

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

Litterature

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

Recommended Academic Qualifications

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

Teaching and Learning Methods

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

Workload

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

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

Exam

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

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

Contents

Chapter 1
Lecture Notes

1 Lecture 01 - 02/09-2025

1.1 The Tropical Environment

1.1.1 Aim

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

1.2 What Determines the Climate?

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

Core takeaway:

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

1.3 Classification: Latitudes

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

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

Core takeaway:

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

1.4 Circles of Latitude and Longitude

1.4.1 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.

1.4.2 Earth's Orbit and Solar Energy

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

Core takeaway:

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

1.5 The Tropics

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

1.5.1 Characterize the tropics !

1.5.2 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.

1.6.1 Tropical biomes and annual precipitation (mm)

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

Core takeaway:

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

1.7 Deforestation

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

Core takeaway:

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

1.8 Daily Weather Cycle in the Tropical Rainforest

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

1.9 Prevailing Winds

1.9.1 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.

1.12.1 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.

1.15.1 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.

1.16.1 Oasis with Date Palm

(image, see slide 15)

1.16.2 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.

2.1.1 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

2.2.1 Soil Profile

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

2.2.2 What is soil?

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

2.2.3 Soil formation

2.2.3.1 Weathering

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

2.2.4 Primary particles

2.2.4.1 Mineral fraction

The mineral fraction of soil is categorized by particle size:

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

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

2.3 Soil Components and Factors of Soil Formation

2.3.1 Clay size fraction

- Clay size fraction: < 2 μm

2.3.2 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

2.3.3 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.]

2.3.4 Soil Structure

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

2.3.5 Factors of soil formation

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

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

2.3.6 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

2.4.1 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).

2.4.2 Climate

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

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

2.5 Other Factors of Soil Formation and Soil Fertility Introduction

2.5.1 Topography

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

2.5.2 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)

2.5.3 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).

2.5.4 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

2.6.1 Nitrogen in Agroecosystems

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

2.6.2 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)

2.7.1 Base and acid cations in soil

2.7.1.1 Base cations

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

2.7.1.2 Acid Cations

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

2.7.2 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).

2.7.2.1 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.

2.7.3 Cation Exchange Capacity (CEC)

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

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

2.8 Cation Exchange and Clay Mineral CEC Values

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

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

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

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

2.9 pH Dependent Charge and Base Saturation

2.9.1 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).

2.9.2 % Base Saturation

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

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

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

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

2.10 Estimating CEC and Base Saturation for Tropical Soils

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

2.10.2 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).

2.10.3 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

2.11.1 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)

2.11.2 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)

2.11.3 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

2.12.1 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

2.12.2 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

2.12.3 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

2.12.4 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

2.13.1 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)

2.13.2 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

2.13.3 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

2.14.1 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

2.15.1 Soil organic matter and fertility

2.15.1.1 Inputs:

Factors contributing to soil organic matter include:

- Crop/vegetation
- Farming practice/residue use
- Manure applications

2.15.1.2 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.)

2.15.2 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

2.16.1 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).

2.16.2 SOC is an important indicator of soil health

2.16.2.1 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

2.17.1 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).

2.17.2 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.

2.17.3 Improve soil structure

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

2.17.4 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

2.17.5 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

3.1.1 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

3.2.1 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.

3.3.1 New Emerging Diseases

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

3.4 Domestication Penalties

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

3.5 Sustainable Harvest for Humankind

Achieving sustainable harvest for humankind involves several strategies:

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

3.5.1 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).]

3.6.1 *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).*

3.6.2 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.

3.6.3 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.

3.7.1 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).*

3.7.2 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).

3.8.1 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.

3.9.1 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

4.1.1 POACEAE Grass-family

4.1.1.1 *Eleusíne coracána* (L.) Gaertn.

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

4.1.2 POACEAE Chloridoideae

4.1.2.1 *Eragróstis téf* (Zucc.) Trotter

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

4.2 Eragrostis

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

4.3 Africa

4.3.1 AMARANTHACEAE Grain Amaranths

4.3.1.1 *Amaranthus caudatus* L.

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

4.3.1.2 *Amaranthus cruentus* L.

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

4.3.1.3 *Amaranthus hypochondriacus* L.

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

4.3.2 AMARANTHACEAE Quinoa

4.3.2.1 *Chenopodium quinoa* Willd.

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

4.3.3 AMARANTHACEAE Cañahua

4.3.3.1 *Chenopodium pallidicaule* Aellen

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

4.3.4 FABACEAE

4.3.4.1 *Lupinus mutabilis* Sweet

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

4.3.5 APIACEAE

4.3.5.1 *Arracacia xanthorrhiza* Bancr.

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

4.4 Distribution of Arracacha

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

4.4.1 ASTERACEAE

4.4.1.1 *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).

4.4.2 BASELLACEAE

4.4.2.1 *Ullucus tuberosus* Caldas

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

4.4.3 BRASSICACEAE

4.4.3.1 *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).

4.5.1 CANNACEAE

4.5.1.1 *Canna edulis* Ker Gawl.

Origin: Andes. Common name: Achira.

4.5.2 FABACEAE

4.5.2.1 *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).

4.5.3 NYCTAGINACEAE

4.5.3.1 *Mirabilis expansa* Ruíz & Pavon

Origin: Andes.

4.5.4 OXALIDACEAE

4.5.4.1 *Oxalis tuberosa* Molina

Origin: Andes.

4.5.5 SOLANACEAE

4.5.5.1 *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.

4.5.6 TROPAEOLACEAE

4.5.6.1 *Tropaeolum tuberosum* Ruíz & Pavon

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

Lecture Wrap-Up

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

Exam relevance marker: Likely exam-relevant.

5 Lecture 05 - 09/09-2025

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

5.1 Seed Biology

The lecture covers several key aspects of seed biology:

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

5.1.1 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.]*

5.3.1 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.

5.5.1 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.

5.5.2 Viviparous Germination

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

5.5.3 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.

5.6.1 Types of Germination

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

5.6.2 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).

5.6.3 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.

5.7.1 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).

5.9.1 Hydrotime Model Formula

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

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

5.10 Generalized Time Course of Germination

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

5.11 Vigour Definition

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

5.11.1 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.

5.11.2 Seed Ageing Factors

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

5.12 Life Cycle of Seeds (Seed Survival Curve)

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

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

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

Lecture Wrap-Up

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

Exam relevance marker: Likely exam-relevant.

6 Lecture 06 - 09/09-2025

7 Lecture 07 - 11/09-2025

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

7.1 Tropical Crop Physiology - A Brief Introduction

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

7.2 Crop Physiology Scope and Importance

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

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

Key crop physiological processes include:

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

7.3 Photosynthesis: C3 and C4 Plants

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

7.3.1 C3 Plants

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

7.3.2 C4 Plants

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

7.4 Comparison of C3, C4, and CAM Photosynthesis

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

7.5 Economically Important C4 Species and Environmental Responses

C4 photosynthesis has evolved mainly in hot, dry regions.

7.5.1 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*).

7.5.2 Responses to Temperature

Plants exhibit specific physiological responses to temperature variations.

7.5.3 Responses to CO2 Concentration

Plant growth and photosynthetic efficiency are influenced by CO2 concentration.

7.5.4 Responses to Light Density

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

7.5.5 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.

7.6.1 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

7.7.1 Water Potential (Ψ_w)

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

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

7.7.2 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.

7.7.3 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.

7.8.1 Stomata of Dicot and Monocot Plants

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

7.9 Stomatal Opening and Closing Mechanisms

7.9.1 Stomatal Opening

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

7.9.2 Stomatal Closing

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

7.10 Drought and Heat Stress: Current and Future Climate Impacts

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

7.10.1 Drought Tolerance Mechanisms and Research

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

7.11 Nitrogen Deficiency and Diagnosis Tools

7.11.1 Nitrogen Deficiency Symptoms

Plants exhibit specific symptoms when experiencing nitrogen deficiency.

7.11.2 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 ($***$).

7.11.3 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
Abbreviations and Explanations

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

Appendices

1 Appendix 1 - Practical Exercise 01

PE1: Tropical Crop products
Group n. 01 Group members: - Lucas Daniel Paz Zuleta, TZS159
Photo of your culinary preparation 
List the tropical products used: White rice, Pequi, Okra, Black beans, lentils, Cassava, salad (mix; rocula, spinach), Assorted Cherry tomatoes, Pineapple, Lentils, Olive oil, Palm hearts, and Jílo.

Discuss the potential macro nutrients composition of your dish (Use chatgpt):

Potential Macronutrient Composition of the Dish

- **Carbohydrates:**
  White rice, cassava, lentils, and black beans are major carbohydrate sources, providing both starch and dietary fibre. Pequi and pineapple add natural sugars. Okra, cherry tomatoes, salad greens, palm hearts, and jiló contribute smaller amounts of carbohydrates, mainly fibre.
- **Proteins:**
  Black beans and lentils are the primary plant-based protein sources. Spinach, arugula, and other salad vegetables contribute minor amounts of protein.
- **Fats:**
  Olive oil and pequi are the main fat sources. Pequi contains monounsaturated fats, while olive oil contributes healthy unsaturated fats. Small contributions may also come from palm hearts.
- **Fibre:**
  High levels of dietary fibre come from legumes (black beans, lentils), okra, cassava, salad greens, cherry tomatoes, jiló, and pineapple. Okra in particular also adds soluble fibre (mucilage).

This dish is **balanced**:

- **Carbohydrates** from rice, cassava, and legumes.
- **Proteins** mainly from legumes.
- **Fats** from olive oil and pequi.
- **Fibre and micronutrients** from vegetables, fruits, and jiló

[H]