I. Agricultural plants

Cultivated plants are specifically selected and grown to produce fruits or other products that are directly usable by the consumer. This contrasts with wild forest plants, where species grow naturally without human intervention, and the fruits are generally not exploited commercially.

In agriculture, most cultivated species are **herbaceous plants**, such as lettuce (*Lactuca sativa*), potato (*Solanum tuberosum*), tomato (*Solanum lycopersicum*), and parsley (*Petroselinum crispum*) — all typical examples of crops from market gardening (horticulture of vegetables and herbs).

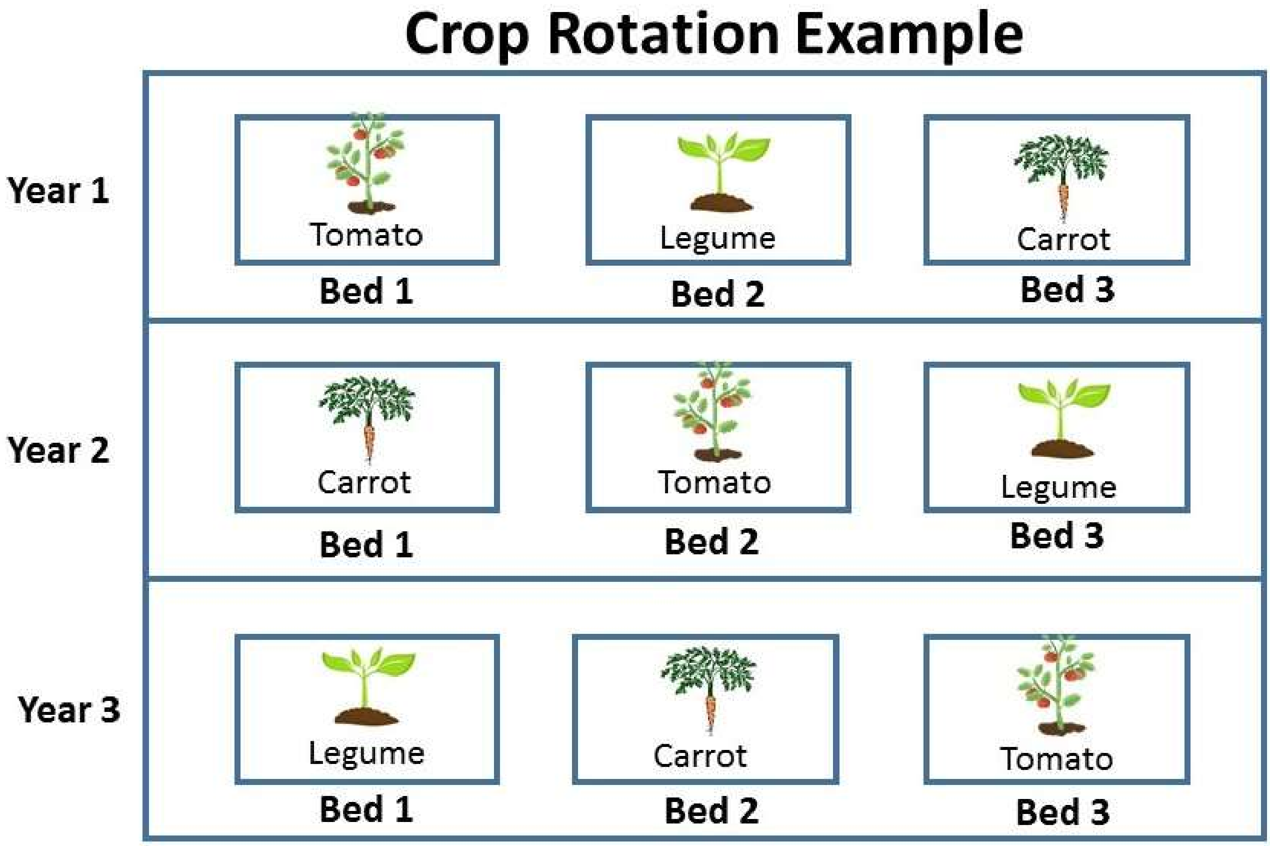
Fig 1 : Horticulture and Vegetable Farming

Some cultivated species are shrubs, which are woody plants usually less than 5–6 meters tall, branching from the base. Examples include blueberries (*Vaccinium spp.*) and raspberries (*Rubus idaeus*). Other cultivated species are trees, grown for fruit production in **arboriculture**. Examples include the date palm (*Phoenix dactylifera*), cherry (*Prunus avium*), quince (*Cydonia oblonga*), and olive tree (*Olea europaea*).

1. *Relationships between cultivated plants: crop rotation and cropping systems*

1.1 Introduction to Crop Rotation and Cropping Systems

Crop rotation and diversified cropping systems are essential practices in sustainable agriculture, promoting soil health, boosting crop yields, and enhancing environmental resilience. According to the *Sustainable Agriculture Research and Education (SARE)* guidelines, crop rotation helps manage soil nutrients, disrupt pest cycles, and reduce the reliance on chemical inputs. For example, alternating crops, including legumes that fix nitrogen, helps improve soil fertility and prevent pest build-up. These methods are especially beneficial for organic farms, where reduced chemical inputs are a priority



1.2 Crop Rotation: Enhancing Soil Health and Pest Management

a. Principles of Crop Rotation

- **Diverse Crop Families**: Crop rotation involves planting different crops from varied families in sequence to prevent nutrient depletion and reduce pest pressure.
- **Incorporating Legumes**: Leguminous plants such as beans or peas fix nitrogen, enriching soil fertility for subsequent crops.
- **Seasonal and Ecological Considerations**: Rotating crops based on seasonality and ecological needs maximizes land use and improves yields.

b. Benefits of Crop Rotation

- **Soil Health**: Rotating crops increases microbial diversity and activity in the soil, which helps maintain soil fertility and structure.
- **Pest and Disease Control**: Crop rotation disrupts pest and disease cycles, reducing the need for chemical treatments.
- **Weed Management**: Rotating with crops that have different growth habits can also reduce the prevalence of weeds.

c. Best Practices for Crop Rotation:

- Rotate crops such as maize with legumes (e.g., beans) to enrich nitrogen levels and prevent pest buildup.
- Avoid planting the same crop family repeatedly on the same land to reduce pest and disease risks.
- Plan rotations that consider both nutrient needs and market demand for different crops.

1.3 Cropping Systems: Diversification for Sustainability

a. Definition and Types of Cropping Systems

A **cropping system** refers to the planned use and management of crops within a specific field over time, including the spatial and temporal arrangement of crops to optimize productivity, sustainability, and resource use efficiency. Key types include:

- **Monocropping (Monoculture):**
  The continuous cultivation of a single crop species on the same land year after year. While simple to manage, this system often leads to nutrient depletion, higher pest and disease incidence, and reduced long-term productivity.
  Example: Continuous wheat (Triticum aestivum) or rice (Oryza sativa) monoculture.

- **Intercropping:**
  The simultaneous cultivation of two or more crop species on the same field to utilize resources efficiently and improve ecological balance.
  Example: Maize (Zea mays) intercropped with common beans (Phaseolus vulgaris) to enhance nitrogen fixation and reduce pest pressure.

- **Mixed Cropping:**

  The non-systematic growing of multiple crops in the same field, without clear row arrangements or distinct planting times. It minimizes risk and ensures yield stability under uncertain conditions. *Example: Millet and cowpea grown together in semi-arid regions.*

https://doi.org/10.1007/s13593-020-00629-0

- **Crop Rotation:**

The sequential cultivation of different crops on the same land in successive seasons. This improves soil fertility, breaks pest and disease cycles, and enhances yield stability. *Example: Rotating cereals (e.g., wheat) with legumes (e.g., chickpea) to replenish soil nitrogen.*

- **Agroforestry:**

A land use system that integrates trees and shrubs with crops and/or livestock. It enhances soil fertility, biodiversity, and climate resilience.
Example: Planting Gliricidia sepium or Faidherbia albida among maize fields to improve soil organic matter and reduce evaporation.

b. Benefits of Diversified Cropping Systems

- **Enhanced Biodiversity and Pest Control:**

Diverse systems support beneficial organisms (predators, pollinators) and reduce the risk of pest outbreaks compared to monocultures.

- **Improved Soil Fertility and Structure:**

Systems like crop rotation and agroforestry promote nutrient cycling (e.g., nitrogen fixation by legumes) and reduce erosion and compaction.

- **Better Water Use and Drought Tolerance:**

Mixed root structures and shaded microclimates (as in agroforestry) improve water retention and reduce evapotranspiration.

- **Climate Change Adaptation:**

Diverse cropping systems buffer against climate shocks, such as floods or droughts, and ensure greater yield stability over time.

- **Economic Risk Mitigation:**

Multiple crops provide farmers with more than one source of income and reduce the economic impact of single crop failures.

c. Agronomic Examples

- **Rotating Maize with Legumes:**

  In sub-Saharan Africa, rotating maize with soybean or cowpea helps fix atmospheric nitrogen and improves maize yield in the subsequent season.

- **Agroforestry in Coffee Systems:**

  In East Africa and Latin America, shade trees such as *Inga* or *Erythrina* are interplanted with coffee to enhance microclimate conditions, reduce weeds, and increase biodiversity.

- **Relay Intercropping in Asia:**

  In rice-based systems, farmers plant mung bean or groundnut before the rice harvest is completed, maximizing land use and improving soil health.

Conclusion

The integration of crop rotation and diversified cropping systems enhances agricultural sustainability by improving soil health, boosting biodiversity, and increasing resilience to pests, diseases, and climate change. These systems support a holistic approach to farming that is both environmentally and economically beneficial.

2. Seeds in Agronomy

1. Introduction to Seeds

Seeds are the fundamental reproductive units of flowering plants and represent the starting point for any crop production system. In agronomy, high-quality seeds determine the success of agricultural operations by ensuring optimal germination, uniform crop stands, and improved resistance to environmental stresses.

Photomicrograph of various seeds (Wikipédia)

Examples:

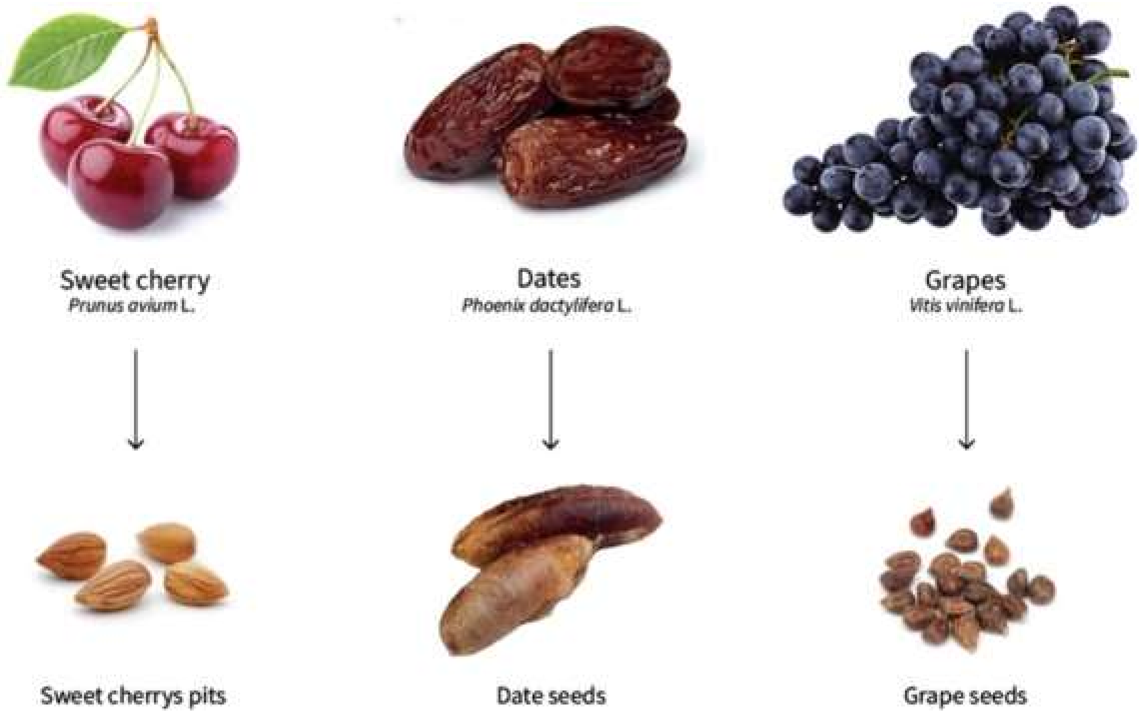
- In rice cultivation, certified seeds of *Oryza sativa* improve yield potential by 20–30% compared to farm-saved seeds (FAO, 2020).
- Hybrid maize (*Zea mays*) seeds offer better drought tolerance and uniform growth than open-pollinated varieties (Singh et al., 2021).

2. Seed Classification

a. Botanical Classification

Seeds are categorized based on botanical families, which influence their physiology and cultivation techniques:

- **Poaceae:** wheat, maize, rice
- **Fabaceae:** soybean, chickpea, lentils
- **Solanaceae:** tomato, eggplant, potato (vegetative seeds)



Agronomic Application: Fabaceae improve soil nitrogen through symbiotic fixation with *Rhizobium* spp.

b. Physiological Classification

- **Orthodox seeds:** tolerate drying and can be stored long-term (e.g., wheat, rice).
- **Recalcitrant seeds:** sensitive to desiccation and require immediate planting (e.g., cocoa, coffee).

Example: Wheat seeds are stored in long-term seed vaults like the Svalbard Global Seed Vault (Westengen et al., 2013).

c. Usage-Based Classification

- **Farm-saved seeds:** retained by farmers for reuse.
- **Commercial seeds:** distributed through certified supply chains.
- **Hybrid seeds:** derived from controlled crosses, often with heterosis benefits.

Example: Hybrid maize can yield 30–50% more than traditional varieties (Singh et al., 2021).

3. Morphology of Seeds

a. External Morphology

- **Seed coat (testa):** protective barrier against pathogens.
- **Micropyle:** entry point for water during germination.
- **Hilum:** scar from attachment to the fruit.

Example: Soybean seeds with hard coats may require scarification to break dormancy.

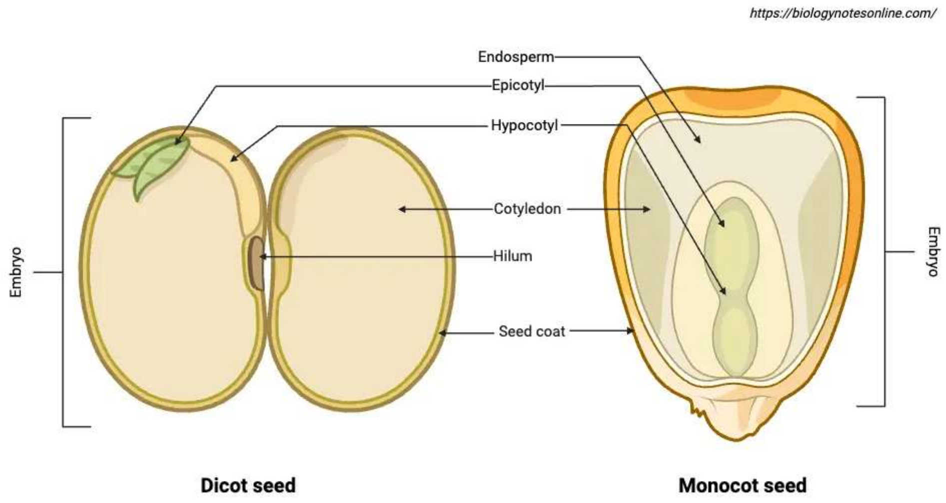


Fig : Structure of seeds

b. Internal Morphology

- **Cotyledons:** storage tissues (monocots: 1; dicots: 2).
- **Embryo:** includes plumule, radicle, and shoot meristem.
- **Endosperm:** additional food storage, prominent in cereals.

Relevance: Wheat seeds rich in endosperm are prized for producing high-quality flour.

4. Seed Physiology

a. Germination

The germination process involves:

1. **Imbibition** (water uptake)
2. **Enzymatic activation** (e.g., amylase breaks down starch)
3. **Radicle emergence**

Optimal Conditions:

- Water, oxygen, proper temperature (e.g., 20–25°C for wheat)
- Extreme heat (>35°C) can denature key enzymes (Bewley et al., 2013)

b. Dormancy

- **Physiological dormancy:** hormonal regulation (ABA).
- **Physical dormancy:** impermeable seed coat.

Breaking Dormancy:

- **Stratification:** cold treatment
- **Scarification:** abrasion of seed coat

Example: Alfalfa (*Medicago sativa*) often requires mechanical scarification to improve germination.

c. Seed Vigor

Vigor reflects a seed's ability to germinate quickly and establish a robust seedling under suboptimal conditions.

Example: In direct-seeded maize systems, high-vigor seeds ensure rapid emergence and reduce weed competition.

5. Seed Quality Attributes

a. Viability

The percentage of seeds capable of germinating.

- Tested via germination tests in controlled environments.
- Acceptable viability:
  - Wheat ≥85%
  - Maize ≥90% (ISTA, 2022)

b. Germinative Power

- Indicates the percentage of seeds that germinate under optimal conditions.
- Higher germinative power equals better field performance.

c. Germinative Energy

- Assesses the speed and uniformity of early germination (e.g., 3 days post-sowing).
- Vital for crops like maize and sunflower where early vigor determines success.

d. Specific Purity

- Proportion of the seed lot consisting solely of the desired species.
- Certified wheat seed: ≥99% purity (ISTA).

e. Varietal Purity

- Ensures all seeds belong to the same cultivar.
- Crucial in hybrids like F1 tomatoes, where genetic segregation affects traits.

f. Health

- Seeds should be free from fungal or bacterial pathogens.
- Treatments: fungicides (e.g., thiram), biological agents (e.g., *Trichoderma* spp.)

Example: Fungicide-treated pea seeds significantly reduce seedling rot from *Fusarium* spp.

6. Seed Preparation

a. Cleaning and Sorting

Removes impurities, broken seeds, and weed seeds.

- Tools: gravity separators, air-screen cleaners, optical sorters.
- **Example:** Optical sorters are widely used in Asian rice mills to remove immature grains.

b. Treatment

- **Chemical:** fungicides (e.g., metalaxyl), insecticides (e.g., imidacloprid).
- **Biological:** rhizobial inoculants for legumes.
- **Pelleting:** enhances uniform sowing and precision agriculture.

c. Storage

- Ideal conditions: <12% moisture, <15°C temperature.
- Containers: hermetic bags (e.g., PICS) for insect protection.

Example: In West Africa, PICS bags effectively preserve cowpea seeds without pesticides (Baributsa et al., 2010).

7. Seed Production and Multiplication

a. Varietal Obtainment

- **Breeding techniques:**
  - Selection: Identifying superior phenotypes (e.g., drought-tolerant wheat)
  - Hybridization: Crossing inbred lines (e.g., maize hybrids)
  - Biotechnology: Genetic engineering and marker-assisted selection

Example: IR64 rice, developed by IRRI, combines yield potential with disease resistance.

b. Seed Production Chain

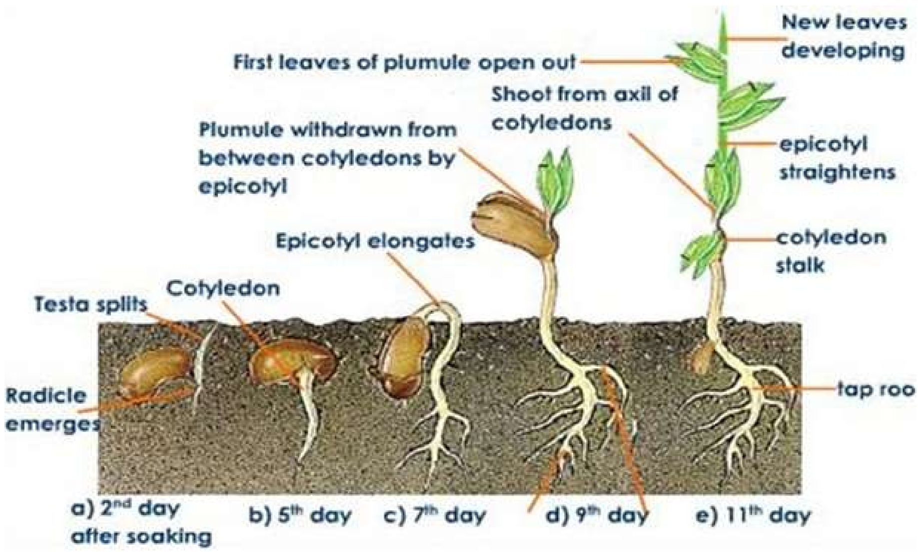
1. **Breeder seed:** genetic base, maintained by research institutions.
2. **Foundation seed:** multiplied under controlled conditions.
3. **Certified seed:** distributed to farmers.

3. *The Plant Growth Cycle: From Germination to Maturation* 🌱

The plant growth cycle encompasses a series of developmental phases, each marked by distinct physiological, biochemical, and morphological transformations. These stages—germination, vegetative growth, flowering, fruiting, and maturation—are tightly regulated by genetic and environmental factors and are critical to understanding crop development and management in agronomy.

3.1 Germination

The cycle begins with **seed germination**, the transition from a quiescent embryo to a metabolically active seedling. Germination is initiated by water imbibition, followed by enzymatic activation that mobilizes stored reserves, primarily starches and proteins, within the endosperm or cotyledons. These resources support the growth of the embryonic axis, culminating in radicle protrusion, which is the first visible sign of germination. Temperature, oxygen availability, and water potential are critical external regulators of this process. For example, in *Zea mays* (maize), optimal germination occurs at 25–30°C with adequate soil moisture, and emergence is typically observed within 3–5 days under field conditions (Bewley et al., 2013).



Phytohormonal Regulation of Seed Germination 🌱

Seed germination is a **hormonally regulated balance** between dormancy maintenance and growth activation. The two most critical hormones in this process are **abscisic acid (ABA)** and **gibberellins (GAs)**, which act antagonistically. Additionally, **ethylene**, **auxins**, **brassinosteroids**, and **cytokinins** also contribute, modulating different aspects of germination and seedling establishment.

🔷 **Abscisic Acid (ABA): The Dormancy Keeper**

ABA is the primary hormone that **promotes seed dormancy** and **inhibits germination**. It accumulates during seed maturation and enforces dormancy by preventing the expression of genes related to reserve mobilization and cell elongation. ABA levels decline when environmental conditions favor germination.

- For example, in *Arabidopsis thaliana*, ABA-deficient mutants (e.g., *aba1*) show precocious germination, while ABA-insensitive mutants (e.g., *abi3*) germinate even under stress conditions that would normally suppress germination (Finkelstein et al., 2002).

🔷 Gibberellins (GAs): The Germination Promoters

GAs are essential for **breaking dormancy** and promoting **radicle protrusion**. They stimulate the production of hydrolytic enzymes such as **α-amylase** in the aleurone layer of cereal seeds, which degrade starch into sugars to fuel embryo growth.

- In barley (*Hordeum vulgare*), GAs synthesized in the embryo move to the aleurone layer and trigger α-amylase production, a classic model of hormonal control in seed germination (Yamaguchi, 2008).

🔷 Ethylene: Modulator of ABA-GA Balance

Ethylene interacts with ABA and GAs to **enhance germination**, particularly under stress. It can counteract ABA's inhibitory effect and is known to improve germination in water-stressed or compacted soils.

- In tomato (*Solanum lycopersicum*), ethylene production increases during germination, and application of ethylene precursors like ACC (1-aminocyclopropane-1-carboxylic acid) can enhance seedling emergence (Linkies & Leubner-Metzger, 2012).

🔷 Other Hormones

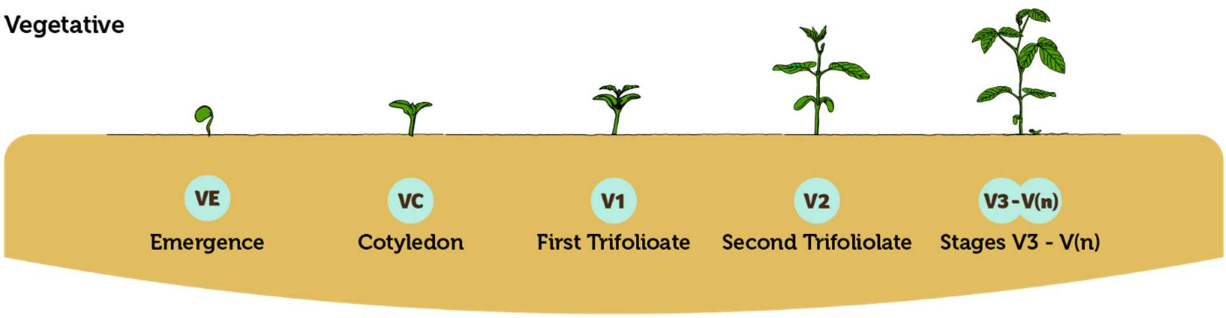
- **Brassinosteroids (BRs)** promote germination by antagonizing ABA and supporting GA action. They are known to stimulate cell expansion and elongation in the embryo.
- **Cytokinins (CKs)** can promote germination under some conditions, possibly by interacting with light and temperature signals.
- **Auxins** generally do not promote germination directly but are involved in post-germinative root and shoot elongation. However, high auxin levels may synergize with ABA to suppress germination in some contexts (Liu et al., 2007).

🧪 Summary Table

Hormone	Role in Germination	Interaction
ABA	Inhibits germination, promotes dormancy	Antagonizes GA
GA	Promotes germination and enzyme release	Suppresses ABA
Ethylene	Enhances germination, especially under stress	Inhibits ABA
Brassinosteroids	Promote germination and seedling growth	Boost GA effect
Cytokinins	Can promote germination (context-dependent)	Varies
Auxins	Modulate root/shoot growth post-germination	May synergize with ABA

3.2 Vegetative growth stage

Following germination, the plant enters the **vegetative growth stage**, characterized by rapid cell division and elongation, primarily in **the meristematic regions**. During this period, the development of leaves, stems, and roots establishes the structural and physiological foundation for subsequent growth. The vegetative phase is crucial for canopy formation, photosynthetic activity, and nutrient uptake, all of which directly influence biomass accumulation and yield potential. Phytohormones such as auxins and gibberellins play key roles in regulating internode elongation and leaf expansion. In cereal crops like *Triticum aestivum* (wheat), the vegetative stage includes tillering and stem elongation (Zadoks stages 21–39), which determine the number of productive shoots and are closely tied to nitrogen availability and photoperiod (Zadoks et al., 1974).



3.3 Flowering

As the plant accumulates sufficient resources and experiences appropriate environmental cues—particularly changes in photoperiod and temperature—it transitions to the **reproductive phase**, initiating **flowering**. This developmental switch involves a complex reprogramming of the shoot apical meristem into a floral meristem, governed by genetic pathways such as the photoperiod, vernalization, and autonomous pathways. Flowering marks a critical juncture in the plant's lifecycle as it enables gamete formation and subsequent fertilization. Crops like *Helianthus annuus* (sunflower) are particularly sensitive to day length and nutrient status during this stage; flowering synchrony directly affects pollination success and seed set (Rauf, 2008). In agronomic practice, the timing of flowering also determines the crop's vulnerability to abiotic stress such as drought or heat waves.

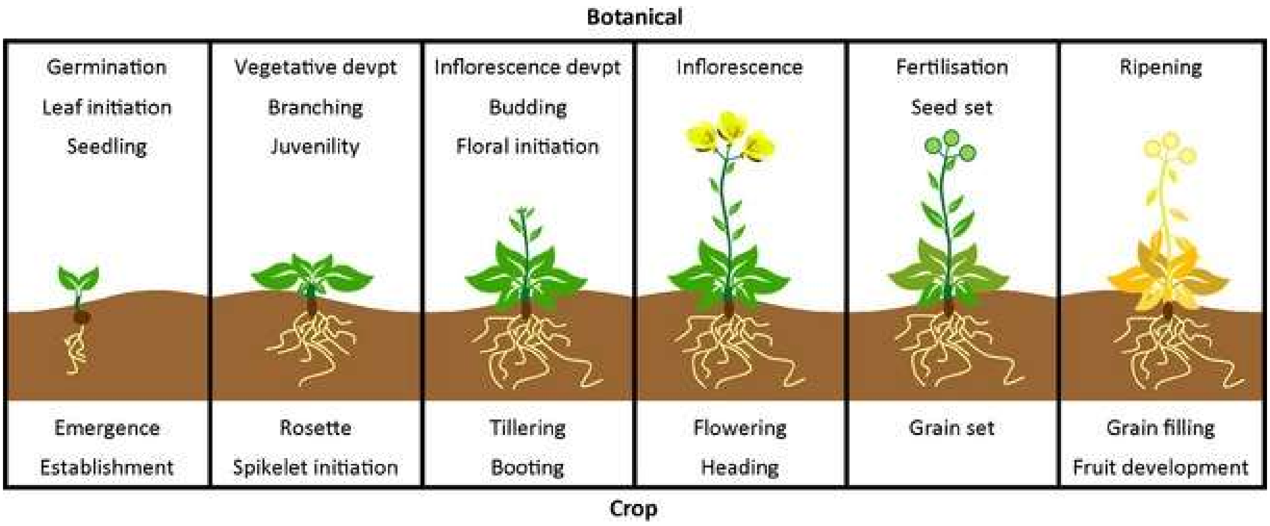
3.4 Fruiting

Upon successful fertilization, plants enter the **fruiting stage**, during which fertilized ovules develop into seeds enclosed in fruits. This phase is marked by active cell division and expansion in the ovary tissues, as well as the translocation of assimilates (sugars, amino acids) from source tissues (leaves) to sink tissues (developing fruits and seeds). The hormonal interplay, especially involving auxins, cytokinins, and gibberellins, orchestrates these developmental processes. In *Solanum lycopersicum* (tomato), fruit development is highly temperature-sensitive; optimal night temperatures between 15–20°C are essential for fruit set and retention. Temperatures above 30°C can lead to flower abortion and poor fruit quality (Adams et al., 2001).

3.5 Maturation

The final stage of the plant growth cycle is **maturation**, during which the fruits and seeds reach physiological and morphological maturity. This stage is characterized by seed desiccation, accumulation of storage reserves, and the senescence of vegetative tissues. During maturation, nutrients such as nitrogen and phosphorus are remobilized from senescing leaves and stems to the developing seeds. In legumes like *Glycine max* (soybean), pod color change and leaf yellowing are used as indicators of physiological maturity, signifying readiness for harvest and optimal seed viability (Fehr & Caviness, 1977). Moreover, senescence, although often perceived as a degenerative process, is an essential phase that ensures nutrient recycling and successful reproductive completion.

Understanding the dynamics of the plant growth cycle is fundamental for agronomists, as it underpins critical management decisions such as fertilization timing, irrigation scheduling, pest control interventions, and optimal harvesting. Each developmental stage has specific physiological requirements and vulnerabilities, and precise agronomic practices tailored to these stages can significantly enhance crop performance, resilience, and yield.



4. The Cropping Cycle 🧩

4.1 Definition and Importance

- **Cropping cycle**: The complete duration from the **planting/sowing** to the **harvest** of a crop.
- This includes **all developmental stages**: germination, vegetative growth, flowering, fruiting, and senescence.
- **Importance**:
  - Allows for **proper scheduling** of farm operations.
  - Essential for **multi-cropping**, **intercropping**, and **seasonal planning**.
  - Affects **yield potential**, **input needs**, and **market timing**.

Example: 📝

- Lettuce: ~45–60 days (short cycle, suitable for intensive production).
- Maize: ~90–130 days depending on variety and climate.

- Olive trees: perennial, with annual fruiting cycles.

4.2 Phases of a Cropping Cycle (In details on point 3 of this course) 🌿

Each crop passes through the following stages:

a. Germination
- Activation of seed metabolism.
- Influenced by water, temperature, oxygen, and seed viability.

b. Vegetative Growth
- Formation of roots, stems, and leaves.
- High demand for nutrients and water.

c. Flowering (Reproductive phase)
- Development of flowers and reproductive organs.
- Critical period for yield determination.

d. Fruiting / Grain filling
- Transformation of flowers into fruits/seeds.
- Nutrient translocation is key here.

e. Maturity and Senescence
- Physiological maturity reached.
- Leaves yellow, moisture content drops.
- Harvest timing is crucial to avoid yield loss.

Example for wheat: 📊

- Sowing → Germination → Tillering → Stem elongation → Heading → Grain filling → Maturity (~6–8 months).

4.3 Classification by Duration 🌟

Cropping cycles vary widely:

Crop Type	Duration	Examples
Short cycle	< 3 months	Lettuce, spinach, radish
Medium cycle	3–6 months	Wheat, maize, rice
Long cycle	> 6 months	Sugarcane, cotton, banana
Perennial crops	Several years (annual harvest)	Olive, grapevine, tea

4.4 Factors Influencing the Cropping Cycle

- **Species and variety** (early vs late-maturing)
- **Climatic conditions** (temperature, photoperiod)
- **Soil fertility and irrigation**
- **Agricultural practices** (e.g., transplanting vs direct seeding)

Example: 📝
- Rice grown in tropical climates can have 2–3 cycles per year (if irrigated).
- In temperate zones, winter wheat has a longer cycle than spring wheat.

4.5 Applications in Farm Planning ⚙️

- **Multiple cropping systems** (e.g., relay cropping, intercropping)
- **Greenhouse cultivation**: enables year-round short-cycle production.
- **Crop succession**: fast-maturing crops enable another cycle in the same year.

Case study: 💡

- In Algeria, early potatoes (planted in January, harvested in May) are followed by maize or sunflower.

4.6 Experimental Analysis of Cropping Cycles 🧪

- Monitoring **growth stages (phenology)** using thermal time (degree days).
- Use of **GDD (Growing Degree Days)** to predict stages and manage inputs.

🧮 *Formula*:

$$GDD = \sum \left(\frac{T_{max}+T_{min}}{2} - T_{base}\right)$$

Where:

- Tmax = daily maximum temperature (°C)
- Tmin = daily minimum temperature (°C)
- Tbase = **base temperature** below which the crop does not grow (°C)

Growing Degree Days (GDD) What is GDD? 🌡️

Growing Degree Days are a measure of **heat accumulation** used to predict **plant development stages**, such as germination, flowering, or maturity.
Plants grow when temperatures are **above a certain threshold** (called the **base temperature**). GDD helps track how much "useful heat" a plant receives over time. 📌

📍 If the average temperature is **below the base temperature**, GDD = 0 for that day.

🌱 **Base Temperature Examples**

Crop	Base Temperature (°C)
Wheat	0–4
Maize	10
Rice	10
Potato	7
Tomato	10

Cumulative GDD 📈

- GDDs are **accumulated** over the growing season.
- When the **total GDD** required by a crop is reached, it reaches a certain **growth stage**.

Example (Maize): 📝

- Base temp = 10°C
- GDD required for flowering ≈ 600
- GDD required for maturity ≈ 1200–1400
  So, if daily GDD ≈ 20, it will take around 60–70 days to reach maturity.

Why GDD is Useful ? 📊

- Predicts **key phenological stages**: emergence, flowering, fruiting, harvest.
- Aids in **pest and disease forecasting** (e.g., insect life cycles also depend on temperature).
- Helps **schedule irrigation, fertilization, pesticide application**.

Limitations 🚫

- GDD does **not account for**:
    - **Extreme temperatures** (e.g., heat stress above 30–35°C).
    - **Water stress** or **nutrient deficiencies**.
    - **Photoperiod sensitivity** in some crops.

Real-life Example: Wheat in Algeria 🌍
Let's say a spring wheat variety needs 1200 GDD to reach harvest:

- Base temperature: 5°C
- Average daily GDD: 15
- Estimated crop duration:
  1200/15=80 days

  This helps farmers plan sowing dates to avoid harvesting during high summer heat.

4.7 Summary and Practical Implications 📘

- Mastering the cropping cycle is essential for **timely sowing, fertilization, pest control**, and **harvest**.
- Integrates knowledge of **plant physiology, ecology, and economics**.
- Enables **higher productivity**, especially under **climate constraints**.

The **difference between a cropping cycle and crop rotation** lies mainly in their **time scale** and **agronomic purpose**:

1. Cropping cycle:

- **Definition**: The **cropping cycle** refers to the **life span of a cultivated plant**, that is, the time between **sowing (or planting)** and **harvest**.
- **Example**: Soft wheat has a cropping cycle of about 6 to 8 months. Lettuce can have a cycle of only 2 months.
- **Purpose**: It helps in planning agricultural operations (irrigation, fertilization, harvesting, etc.).

2. Crop rotation:

- **Definition**: **Crop rotation** refers to the **distribution of crops over time and space** on a given field. It can be annual or span several years.
- **Types**:
    - **Simple rotation**: one crop per year.
    - **Three-year rotation**: rotation over 3 years, e.g., cereals/legumes/fallow.
- **Purpose**: Helps maintain soil fertility, reduce pests and diseases, and optimize yields.

Summary table:

Term	Definition	Duration	Example
Cropping cycle	The development duration of a plant	Months	Wheat: 6–8 months
Crop rotation	Organization of crops over time and space	Years	Year 1: wheat, Year 2: peas, Year 3: fallow

5. Nutritional Associations Between Plants and Microflora 🌱

5.1 Definition

These associations refer to **mutualistic (or sometimes symbiotic)** relationships where **plants and microorganisms** (mainly bacteria and fungi) **exchange nutrients** for mutual benefit.

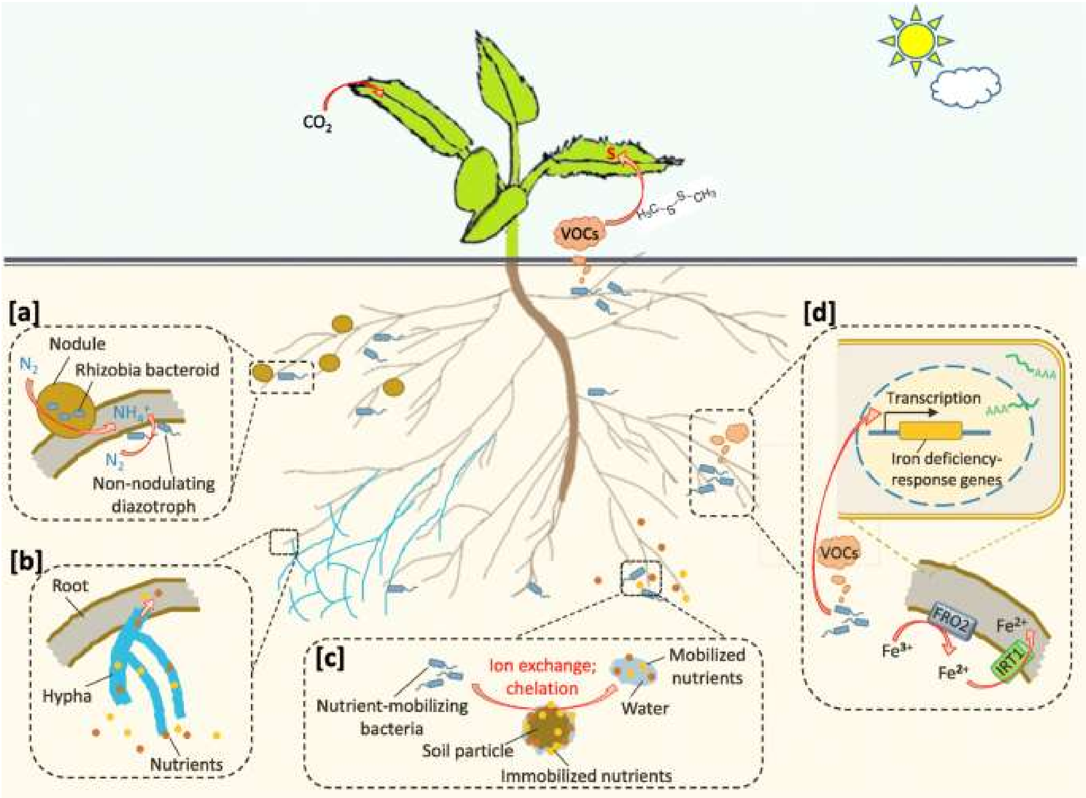


Fig. Microbe-enhanced plant acquisition of macronutrients and micronutrients. Beneficial microbes enhance plant nutrient acquisition via multiple mechanisms, including but not limited to [a] N_2 fixation by rhizobia in nodules or by non-nodulating diazotrophs; [b] Nutrient uptake and delivery through mycorrhizal mycelia that reaches additional soil beyond the root; [c] Mobilization of soil-fixed nutrients through ion exchange or chelation by bacterial or fungal secretions, such as organic acids and siderophores; [d] Microbe-induced transcriptional regulation of plant genes involved in nutrient uptake, such as Arabidopsis Fe deficiency responses that are induced by bacteria volatile organic compounds (VOCs). Microbes may also enhance plant S nutrition via certain S-containing VOCs, such as dimethyl disulfite, which can be assimilated by the aerial portion of plants. https://link.springer.com/article/10.1007/s44154-021-00027-w

5.2 Main Types of Nutritional Associations 🔍

5.2.1 Rhizobium–Legume Symbiosis (Biological Nitrogen Fixation) 🌿

- **Microorganism**: *Rhizobium* spp. (bacteria)
- **Plant hosts**: Legumes (e.g., soybean, peas, lentils)

- **Nutritional benefit**:
    - *Rhizobium* fixes **atmospheric nitrogen (N_2)** into **ammonia (NH_3)** → used by the plant.
    - In return, the plant supplies **carbohydrates** from photosynthesis to the bacteria.
- **Structure formed**: **Root nodules**
- *Key for nitrogen input in low-input farming systems.* ✅

5.2.2 Mycorrhizal Associations 🍄

There are two main types:

a. Arbuscular Mycorrhizal Fungi (AMF)

- **Fungi**: *Glomeromycota*
- **Hosts**: Most terrestrial plants (e.g., wheat, maize, tomato)
- **Function**:
    - Fungi increase **phosphorus (P)** and **micronutrient** uptake by expanding the absorptive root area.
    - Plant provides **sugars** to the fungus.
    - Also improves **drought** and **disease resistance**.

b. Ectomycorrhizal Fungi

- **Hosts**: Forest trees (e.g., oak, pine, beech)
- **Function**: Form a sheath around roots and help in **nitrogen and phosphorus** uptake from organic matter.

5.2.3 Plant Growth-Promoting Rhizobacteria (PGPR) 🧫

- **Microbes**: *Azospirillum*, *Pseudomonas*, *Bacillus* spp.
- **Benefits**:
    - **Solubilize phosphate**, fix nitrogen, produce **plant hormones** (auxins, cytokinins).
    - Improve **root growth**, **stress tolerance**, and **nutrient uptake**.

5.2.4 Endophytic Microbes 🌾

- Live **inside plant tissues** (roots, stems, leaves).
- Can help with **nutrient acquisition**, **stress resistance**, and even **pest suppression**.
- Often include **nitrogen-fixing bacteria** in grasses (e.g., *Herbaspirillum*, *Acetobacter*).

5.3 Agronomic Applications 🌍

- Biofertilizers: using Rhizobium or PGPR as inoculants.
- Reducing chemical fertilizer use.
- Improving soil fertility and sustainability.
- Enhancing resilience to drought, salinity, and disease.

🔬 Summary Table

Association Type	Microbe	Nutrients Involved	Host Plants	Benefit
Rhizobium-Legume	*Rhizobium*	Nitrogen (N)	Legumes	N fixation
Mycorrhizae (AMF)	*Glomeromycota*	Phosphorus (P), Zn, Cu	Most plants	Improved uptake
Ectomycorrhizae	Basidiomycetes	N, P from organic matter	Trees (pine, oak)	Forest nutrient cycling
PGPR	*Azospirillum*, etc.	N, P, hormones	Cereals, vegetables	Growth promotion
Endophytes	Various	N, minerals	Grasses, cereals	Stress tolerance