Essential Mineral Nutrients in Plants

Plants require a number of inorganic mineral elements for their **normal growth, development, metabolism, reproduction, and completion of the life cycle**. These elements are absorbed mainly from the soil in the form of ions through the root system. The mineral elements that are indispensable for plant growth are called **essential mineral nutrients**.

Definition

An **essential mineral nutrient** is a mineral element that is indispensable for the normal growth and development of a plant and whose absence prevents the plant from completing its life cycle.

Criteria for essentiality

An element is considered essential when it satisfies the following criteria:

1. **Completion of life cycle:** In its absence, the plant cannot complete its normal life cycle.
2. **Specific function:** The deficiency cannot be corrected by supplying another element.
3. **Direct physiological role:** The element must be directly involved in plant metabolism or an essential structural or physiological function.

Classification of Essential Mineral Nutrients

Essential mineral nutrients are generally classified according to the **quantity required by plants**.

1. Macronutrients

Macronutrients are required in relatively large quantities, generally more than **0.1% of plant dry matter**.

They include:

Macronutrient	Symbol	Major functions
Nitrogen	N	Proteins, nucleic acids, chlorophyll
Phosphorus	P	ATP, nucleic acids, phospholipids
Potassium	K	Osmotic regulation, enzyme activation, stomatal movement
Calcium	Ca	Cell wall formation, membrane stability, signalling
Magnesium	Mg	Central atom of chlorophyll, enzyme activation
Sulfur	S	Sulfur-containing amino acids and proteins

The first three—**N, P and K**—are often called **primary macronutrients**, while Ca, Mg and S are called **secondary macronutrients**.

2. Micronutrients

Micronutrients are required in very small quantities, generally **less than 0.01% of plant dry matter**, but they are equally essential.

The major micronutrients are:

Micronutrient	Symbol	Major functions
Iron	Fe	Electron transport, chlorophyll synthesis
Manganese	Mn	Photosynthesis, enzyme activation
Zinc	Zn	Enzyme activity, auxin metabolism
Copper	Cu	Electron transport, enzymes
Boron	B	Cell wall formation, reproductive development
Molybdenum	Mo	Nitrate reduction, nitrogen fixation
Chlorine	Cl	Osmotic balance, photosynthesis
Nickel	Ni	Urease activity and nitrogen metabolism

Important: The requirement for an element is small in quantity but its physiological importance can be very large.

Nutrient Sensing and Signalling in Plants

Plants are continuously exposed to fluctuations in the availability of mineral nutrients such as **nitrogen (N), phosphorus (P), potassium (K), sulfur (S), iron (Fe), zinc (Zn)** and other essential elements. Therefore, plants must not only acquire nutrients but also **sense their availability, transmit information about nutrient status, and adjust physiological and developmental processes accordingly**. This coordinated process is known as **nutrient sensing and signalling**.

1. Concept of Nutrient Sensing

Nutrient sensing is the ability of plant cells to detect changes in the concentration or availability of nutrients and to convert this information into biochemical signals.

The sensing system allows plants to answer three major questions:

1. **What nutrient is available?**
2. **How much nutrient is available?**
3. **How should growth and metabolism be modified according to nutrient availability?**

Nutrient sensing therefore connects the **external nutritional environment** with the **internal metabolic and developmental status** of the plant.

General sequence

Nutrient availability → Nutrient sensor/receptor → Signal transduction → Transcriptional/metabolic response → Physiological adaptation

2. Components of Nutrient Signalling

Nutrient signalling generally involves several interconnected components.

A. Nutrient sensors

Sensors detect nutrient concentration or nutritional status.

Examples include:

- Nutrient transporters that also function as sensors
- Protein complexes
- Kinases and phosphatases
- Nutrient-responsive transcription factors
- Metabolic intermediates

An important concept is that **a transporter may have a dual function—transporting a nutrient and sensing its availability**.

B. Signal transduction

Once nutrient status is perceived, the information is transmitted through signalling pathways involving:

- Protein kinases
- Phosphatases
- Second messengers
- Calcium signalling
- Reactive oxygen species (ROS)
- Hormones
- Changes in cellular metabolites

C. Transcriptional regulation

Nutrient signals ultimately modify the activity of transcription factors.

This leads to changes in expression of genes involved in:

- Nutrient uptake
- Transport
- Assimilation
- Metabolism
- Root architecture
- Stress responses
- Growth and development

4. Nitrogen and TOR Signalling

The **Target of Rapamycin (TOR)** pathway is a major regulator of cellular growth.

TOR integrates information about:

- Nutrient availability
- Energy status
- Carbon availability
- Growth signals

When nutrients are sufficiently available, TOR promotes:

- Protein synthesis
- Ribosome biogenesis
- Cell proliferation
- Growth

Thus:

Adequate nutrients → TOR activation → anabolic metabolism → growth

When nutrients are limited, growth-promoting processes are suppressed.

5. Phosphorus Sensing and Signalling

Phosphorus is absorbed mainly as inorganic phosphate (**Pi**).

Pi is required for:

- ATP
- Nucleic acids
- Phospholipids
- Phosphorylation reactions
- Membrane metabolism

Because phosphate availability is frequently limiting in soils, plants possess sophisticated phosphate sensing and signalling systems.

PHR1–miR399–PHO2 Pathway

One of the important phosphate-starvation signalling pathways involves:

PHR1 → miR399 → PHO2 → phosphate homeostasis

PHR1

PHR1 (PHOSPHATE STARVATION RESPONSE 1) is a major transcription factor involved in phosphate-starvation responses.

Under phosphate deficiency, PHR1 activates genes associated with phosphate starvation.

It also promotes the expression of **miR399**.

miR399

miR399 is a small regulatory RNA that suppresses the expression of **PHO2**.

PHO2

PHO2 encodes an E2 ubiquitin-conjugating enzyme involved in regulating proteins associated with phosphate transport and homeostasis.

Therefore:

Low Pi → PHR1 activation → miR399 production ↑ → PHO2 suppression → phosphate uptake/homeostasis responses