SUMMARIZE NUTRITIONAL REQUIREMENT OF COFFEE

# 1. Nitrogen

## 1.1 Roles of Nitrogen in each Growth Stage in Coffee

* Establishment Stage (0–6 months after planting): Supports early root and shoot development, encourages lateral root formation for efficient nutrient uptake
* Vegetative Growth Stage**:** Promotes shoot elongation, canopy expansion, and leaf formation to build biomass for future productivity.
* Pre-Flowering/Budding Stage (2–3 years, after the first rains): Supports the differentiation of flower buds, ensures strong flowering potential.
* Flowering Stage (Flower opening to pollination, ~2 weeks): Maintains flower retention and promotes successful pollination. Minimal direct N application (excessive N can delay flowering). Instead, focus on balanced nutrition.
* Early Fruit/Pod Formation (Pinhead stage, ~1 month post-flowering): Supports early fruit cell division and retention.
* Fruit Development and Maturation (Cherry expansion, 3–5 months after flowering): Supports bean expansion, sugar accumulation, and overall fruit quality, avoid excessive vegetative growth.
* Pre-Harvest/Ripening Stage (Final 1–2 months before harvest): Minimal N application to avoid vegetative regrowth; focus on quality enhancement. No direct N application; maintain residual soil fertility.

## 1.2 Interaction with Other Elements

* **Nitrogen and Phosphorus (P)**: Essential for root development. An imbalance (high N, low P) can lead to excessive vegetative growth at the expense of root and reproductive structures.
* **Nitrogen and Potassium (K)**: High nitrogen levels require balanced potassium to support fruit filling, sugar translocation, and disease resistance. K deficiency under high N leads to poor bean development and weak branches.
* **Nitrogen and Calcium (Ca)**: Excessive nitrogen, especially in ammonium form, can reduce calcium uptake, weakening cell walls and increasing disease susceptibility.
* **Nitrogen and Magnesium (Mg)**: A balance between N and Mg is crucial for chlorophyll formation; excessive N without adequate Mg can lead to leaf yellowing.
* **Nitrogen and Sulfur (S)**: Sulfur is necessary for nitrogen metabolism and protein synthesis; deficiency reduces nitrogen-use efficiency.
* **Nitrogen and Micronutrients (Zn, B, Cu, Fe, Mn)**: High nitrogen application can dilute micronutrient concentrations, leading to deficiencies that affect flowering and fruit retention.

## 1.3 Key Considerations for Regenerative Nitrogen Management

* **Soil pH Management**:
  + Regular application of organic matter, biochar, and calcium sources (e.g., lime) to prevent soil acidification from prolonged nitrogen use.
  + Avoid over-fertilize with NH4+
* **Integrated Nutrient Cycling**: Use **leguminous shade trees (Leucaena, Gliricidia)** and **cover crops (***Cajanus cajan, Crotolaria sp***)** to naturally cycle nitrogen into the soil.
* **Efficient Nitrogen Sources**: Favor **fish fertilizer, vermicompost, and compost** over synthetic urea to improve long-term soil fertility.
* **Precision Nutrient Timing**: Apply nitrogen when the crop actively needs it, avoiding excess during fruit maturation to reduce environmental losses.
* **Water-Efficient Practices**: Maintain **mulches and agroforestry systems** to conserve soil moisture, improving nitrogen-use efficiency.

# 2. Potassium

## 2.1 Roles of Potassium in each Growth Stage in Coffee

* Regulates **stomatal function**, improving water use efficiency and drought tolerance.
* Enhances **photosynthesis** by activating enzymes and improving chlorophyll function.
* Essential for **carbohydrate translocation**, helping in energy transport from leaves to developing fruits.
* Improves **disease resistance** by strengthening cell walls and reducing pathogen attack.
* Enhances **root development**, leading to better nutrient uptake.
* Promotes **fruit quality**, including size, weight, uniformity, and cup quality.
* Regulates **protein synthesis**, ensuring proper metabolism and growth.
* Plays a crucial role in **turgor pressure maintenance**, keeping leaves and stems upright.
* Increases **resilience to environmental stress**, such as high temperatures and salinity.

Roles for each Growth Stage

* Establishment Stage (0-6 months after planting): required for early root and shoot development.
* Vegetative Growth Stage (6-18 months after planting): supports leaf expansion and root growth.
* Pre-Flowering/Budding Stage (2-3 months before flowering): crucial for floral bud initiation and energy transfer.
* Flowering Stage: K requirement is very high; K supports pollen viability, flower retention, and energy transfer.
* Early Fruit/Pod Formation Stage (After flowering, early cherry development): K requirement is very high; promotes fruit set, reduces drop, and ensures nutrient translocation.
* Fruit Development and Maturation Stage (Cherry expansion and sugar accumulation): K requirement is Extremely high; affects fruit size, sugar content, and quality.
* Pre-Harvest/Ripening Stage (Last month before harvest): K requirement is high; supports final fruit filling, color development, and sugar accumulation.

## 2.2 Interaction of Potassium with Other Elements

* **Nitrogen (N)**: High potassium levels improve nitrogen use efficiency, promoting balanced vegetative and reproductive growth.
* **Phosphorus (P)**: K enhances phosphorus uptake, improving root development and early plant vigor.
* **Calcium (Ca) & Magnesium (Mg)**: Excess K can lead to deficiencies in Ca and Mg due to competitive uptake. Proper balance is essential.
* **Boron (B)**: K and B work together in pollen formation and fruit set. Deficiencies in either can reduce yields.
* **Zinc (Zn) & Iron (Fe)**: Adequate K improves micronutrient absorption, especially under acidic soil conditions.

## 2.3 Sustainable solutions

* **Regenerative practices** focus on **organic matter recycling, microbial inoculants, and agroforestry integration** to provide slow-release K.
* **Potassium sulfate (K₂SO₄)** is the preferred inorganic source due to its **low chloride content** and compatibility with organic systems.
* Apply **biochar + mycorrhizal fungi** to improve nutrient retention.
* Use natural K supplementation such as bananas, pseudostems, wood ash,...
* Frequent foliar sprays combined with soil applications ensure consistent K availability without excessive leaching.

# 3. Phosphorus

## 3.1 Essential Role in Different Coffee Growth Stages

* Establishment Stage (Seedling & Transplanting)
  + Stimulates **strong root growth** and early plant vigor.
  + Supports **early mycorrhizal associations** for better phosphorus uptake.
  + Encourages **resistance to transplant shock**.
* Vegetative Growth (1-2 Years After Planting)
  + Essential for **branching, shoot elongation, and canopy expansion**.
  + Supports **chlorophyll synthesis and photosynthesis efficiency**.
  + Prepares the tree for **strong reproductive development** in the following seasons.
* Pre-Flowering / Budding Stage
  + Essential for **bud differentiation and early flower formation**.
  + Enhances **energy storage (ATP) for reproductive processes**.
  + Improves **water and nutrient transport efficiency**.
* Flowering Stage
  + Supports **pollination success and flower retention**.
  + Enhances **early fruit initiation** by boosting carbohydrate metabolism.
  + Prevents **flower abortion under stress conditions**.
* Early Fruit / Pod Formation Stage
  + Critical for **cell division in developing coffee cherries**.
  + Strengthens **nutrient flow from leaves to fruits**.
  + Maintains **metabolic energy levels** during rapid fruit expansion.
* Fruit Development & Maturation
  + Essential for **bean filling and nutrient translocation**.
  + Ensures **optimal sugar accumulation** for high-quality coffee beans.
  + Maintains **energy balance for sustained growth**.
* Pre-Harvest / Ripening Stage
  + Enhances **bean uniformity and final quality**.
  + Improves **stress tolerance** under fluctuating environmental conditions.
  + Supports **final energy transfer for full bean development**.

## 3.2 Interaction with Other Nutrients:

* + **Nitrogen (N):** A balanced N:P ratio is needed for proper root-to-shoot growth. Excess nitrogen without sufficient phosphorus can lead to excessive vegetative growth at the expense of root and reproductive development.
  + **Potassium (K):** Works with phosphorus to improve **flowering, fruit setting, and quality**. A proper K:P ratio prevents excessive vegetative growth and ensures reproductive efficiency.
  + **Calcium (Ca) & Magnesium (Mg):** High calcium levels can **reduce phosphorus availability** in acidic soils, while magnesium supports phosphorus utilization in ATP formation.
  + **Zinc (Zn) & Iron (Fe):** Deficiencies in these micronutrients can limit phosphorus uptake due to their involvement in enzyme activation.
  + **Aluminum (Al) Toxicity (Common in Acidic Soils):** Excess aluminum binds phosphorus, making it unavailable to coffee plants, necessitating soil amendments like lime or organic matter to increase pH.

## 3.3 **Regenerative Practices for Phosphorus Management**

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* Proper **nutrient balancing** with nitrogen, potassium, and trace minerals is **critical** to optimize phosphorus efficiency.
* Regenerative solutions, including **biofertilizers, organic amendments, and cover cropping**, **improve soil phosphorus availability while maintaining soil health**.
* Regenerative coffee production relies on **natural phosphorus sources (e.g., rock phosphate, bone meal, compost), microbial inoculants, and soil-building practices** to reduce dependency on synthetic fertilizers while sustaining productivity. Add bone meal or rock phosphate to the compost pile and spread it in the garden.

# 4. Calcium

## 4.1 Physiological Roles of Calcium in Coffee Plants Across Growth Stages

* Establishment Stage
  + Essential for **root elongation** and **early shoot development**.
  + Promotes **strong cellular structure**, preparing for vegetative growth.
* Vegetative Growth Stage (1–3 years)
  + Critical for **rapid shoot and leaf expansion**.
  + Supports **vascular tissue development**, ensuring **efficient nutrient transport**.
* Pre-Flowering/Budding Stage
  + Promotes **flower initiation** and **bud differentiation**.
  + Works with **Boron (B) for pollen viability**.
* Flowering Stage
  + Enhances **pollen tube formation**, reducing **flower abortion**.
  + Ensures **uniform flowering and fruit set**.
* Early Fruit/Pod Formation Stage
  + Reduces **fruit drop** by strengthening **fruit walls**.
  + Supports **early bean development**.\
* Fruit Development & Maturation Stage
  + Maintains **bean integrity**, preventing **hollow beans**.
  + Reduces **fruit cracking** and **improves cup quality**.
* Pre-Harvest/Ripening Stage
  + Ensures **even ripening** and **fruit firmness**.
  + Improves **bean density & shelf life**

## 4.2 Interactions with Other Elements

* **Calcium & Magnesium (Ca-Mg)**
  + Excessive **Ca can inhibit Mg uptake**, leading to **chlorosis**.
  + Balanced **Ca:Mg ratio (~3:1)** ensures **optimal nutrient absorption**.
* **Calcium & Potassium (Ca-K)**
  + Competes with **K for root uptake**; imbalance can reduce **fruit quality**.
  + Proper **Ca-K balance** enhances **bean filling and cup quality**.
* **Calcium & Phosphorus (Ca-P)**
  + High **Ca levels can form insoluble Ca-P compounds**, reducing **P availability**.
  + Best applied separately or in a **balanced formulation**.
* **Calcium & Boron (Ca-B)**
  + Essential for **pollen germination and fruit set**.
  + Deficiency in **either element** leads to **flower abortion and poor fruit retention**.
* **Calcium & Nitrogen (Ca-N)**
  + **Synergistic effect**—Ca improves **N assimilation**, boosting **vegetative growth**.
  + Overuse of **ammonium-based fertilizers** (NH₄⁺) can reduce **Ca availability**.

## 4.3 **Regenerative Practices for Calcium Management**

* **Soil pH Optimization** – Maintain at **5.5–6.5** for **maximum Ca availability**.
* **Mulching Practices** – Retains **moisture & prevents leaching of Ca**.
* **Regenerative Techniques** – Incorporating **biochar, cover crops, and organic matter** improves **long-term Ca cycling**.
* **Banana Peel Tea (Foliar, 500 mL/ha) or natural sources such as: eggshells, clam shells**  – Supplies **Ca & K**.
* **Composted Chicken Manure** – Enhances **Ca & organic matter**.
* **Calcium-Boron (Foliar)** – Ensures **pollination success**.

# 5. Magnesium

## 5.1 Magnesium (Mg) in Coffee Physiology across growth stages

* Establishment Stage (Seedling/Nursery)
  + Supports early **chlorophyll production** for leaf expansion and seedling vigor.
  + Essential for **root development**, ensuring efficient nutrient uptake.
* Vegetative Growth (1-3 Years Post-Planting)
  + Critical for **leaf expansion and photosynthesis**.
  + Supports **nitrogen assimilation**, enhancing vegetative growth.
* Pre-Flowering/Budding Stage
  + Supports **energy transfer** for flower initiation.
  + Ensures **hormonal balance** for synchronized budding.
* Flowering Stage
  + Essential for **carbohydrate translocation** to developing flowers.
  + Enhances **pollen viability and fertilization**.
* Early Fruit/Pod Formation (Pinhead Stage)
  + Promotes **cell division and fruit set stability**.
  + Supports **early fruit expansion** and nutrient translocation.
* Fruit Development & Maturation
  + Essential for **sugar transport and fruit filling**.
  + Enhances **antioxidant enzyme activity**, improving bean quality.
* Pre-Harvest/Ripening Stage
  + Supports **bean density and final sugar accumulation**.
  + Maintains **leaf retention and post-harvest recovery**.

## 5.2 Interaction with Other Elements

* **Synergistic Effects**
  + Enhances **nitrogen (N) uptake** and utilization, improving plant growth and productivity.
  + Works with **phosphorus (P)** to strengthen root development and early plant vigor.
* **Antagonistic Effects**
  + Excess **potassium (K)** can lead to Mg deficiency, as both compete for uptake.
  + High **calcium (Ca) levels**, particularly in acidic soils, can reduce Mg availability.
  + Imbalanced Mg can disrupt **boron (B) absorption**, affecting flowering and fruit set.

## 5.3 **Regenerative Practices for Magnesium Management**

* + Apply **biochar + compost extract** for gradual Mg release.
  + Use **fish fertilizer** to enhance Mg and K synergy.
  + Reduce **synthetic inputs**, allowing natural soil Mg cycling before harvest..
  + Foliar spray **MgSO₄ + amino acids** to strengthen flowering intensity.
  + Supplement with **dolomitic lime** (CaMg(CO₃)₂) if soil is acidic.

# 6. Sulfur

## 6.1 Sulfur’s Role in Coffee Physiology

* Establishment (0–12 months)
  + Low to moderate; needed for root establishment and enzyme activation.
  + Supports initial leaf chlorophyll production for stronger seedlings.
* Vegetative Growth
  + Moderate; critical for protein synthesis, root expansion, and canopy development.
  + Helps in nitrogen assimilation to boost biomass accumulation.
* Pre-Flowering & Budding (First signs of bud formation)
  + High; needed for **flower primordia formation** and energy metabolism.
  + Supports nitrogen efficiency, reducing flower abortion risk.
* Flowering (Full bloom stage)
  + Very high; required for **pollen viability**, flower retention, and hormonal regulation.
  + Works with boron (B) and zinc (Zn) to improve fruit set.
* Early Fruit/Pod Formation (Pinhead stage to pea-sized fruit)
  + High; critical for protein formation in developing beans.
  + Supports enzyme production for carbohydrate partitioning into fruits.
* Fruit Development & Maturation (Green to cherry stage)
  + Moderate; aids in **bean density and quality** formation.
  + Helps in chlorophyll retention and photosynthesis regulation.
* Pre-Harvest/Ripening (Cherry maturation)
  + Moderate; ensures **uniform ripening** and **cup quality** by improving bean composition.
  + Works with potassium (K) to enhance **sugar accumulation**.

## 6.2 Sulfur’s Interaction with Other Elements

* + Works **synergistically with nitrogen (N)** in protein formation, optimizing plant growth.
  + Improves **phosphorus (P) uptake**, which is crucial for root development and flowering.
  + Balances **potassium (K) use**, preventing imbalances that may affect yield quality.
  + Interacts with **magnesium (Mg) and calcium (Ca)** to support enzyme activation.
  + Helps regulate **iron (Fe) and zinc (Zn) availability**, preventing micronutrient deficiencies.
  + Sulfate (SO₄²⁻) form enhances **soil microbial activity**, aiding organic matter decomposition.

## 6.3 **Regenerative Practices for Sulfur Management**

* **Agroforestry Systems**
  + Shade-grown coffee with **Acacia and Gliricidia trees** naturally cycling sulfur.
* **Biofertilizers & Fermented Organic Inputs**
  + **Fermented shrimp shells** (rich in sulfur and chitin for disease resistance).
  + **Indigenous Microorganism (IMO) culture** from rice husk and molasses.
* **Cover Crops & Intercropping**
  + **Crotalaria spp. & Pueraria phaseoloides** to fix organic sulfur and nitrogen.
* **Natural Mineral Amendments**
  + **Gypsum (CaSO₄) in small doses** to improve soil texture and microbial activity.
* **Soil Drench**: **Compost + rock phosphate** to enhance nutrient release.
* **Regenerative Inputs**: Agroforestry system integration (leguminous shade trees for natural S cycling).
* **Foliar Application**: **Fermented fish amino acids** to boost nutrient uptake.

# 7. Boron

## 7.1 Boron Requirements and Roles of Boron for Each Growth Stage in Coffee Physiology

* Establishment Stage (0-1 year): Low to moderate; necessary for root development and early tissue differentiation.
* Vegetative Growth (1-3 years): Moderate; supports cell division, leaf expansion, and stem elongation.
* Pre-Flowering/Budding Stage: High; crucial for pollen viability and bud formation.
* Flowering Stage: Very High; directly affects pollination success and fruit set.
* Early Fruit/Pod Formation (Pinhead Stage): High; ensures proper cell division and early fruit development.
* Fruit Development and Maturation: Moderate to High; required for sugar transport and cell expansion in cherries.
* Pre-Harvest/Ripening Stage: Moderate; final role in fruit firmness and sugar accumulation.

## 7.2 Boron Interaction with Other Elements

* **Calcium (Ca)**: Works together in cell wall stability; an imbalance may lead to weak cell walls, affecting fruit set and quality.
* **Potassium (K)**: High potassium levels can limit boron uptake, leading to deficiencies.
* **Magnesium (Mg)**: Essential for chlorophyll production, but excess magnesium may interfere with boron absorption.
* **Nitrogen (N)**: Excess nitrogen can reduce boron availability, affecting flowering and fruit setting.
* **Phosphorus (P)**: High phosphorus can sometimes reduce boron uptake due to competition for uptake pathways.
* **Zinc (Zn)**: A balanced ratio is needed; excess zinc may inhibit boron absorption and vice versa.

## 7.3 **Regenerative Practices for Boron Management**

* **Organic Potassium Source**: Enhances sugar accumulation and fruit quality.
* **Molasses-Based Microbial Tea**: Improves soil microbial health and nutrient availability.
* **Boron Foliar Spray (0.3%)**: Applied before flowering to improve pollen tube elongation.
* **Fermented Fish Amino Acids + Micronutrient Blend**: Provides nitrogen, boron, and essential minerals.
* **Green Manure from Leguminous Plants**: Enhances soil microbial activity and nutrient cycling.
* **Boron Foliar Spray (0.3%)**: Applied before flowering to improve pollen tube elongation.

# 8. Other micronutrient: Fe, Cu, Mn, Zn, Mo

## 8.1 Micronutrient Roles in Coffee Physiology and Interactions

Iron (Fe)

* **Function:**
  + Essential for chlorophyll synthesis and photosynthesis.
  + Facilitates electron transport in respiration and enzyme activation.
  + Influences nitrogen metabolism and protein formation.
* **Interactions:**
  + High **P** can limit Fe availability.
  + Fe deficiency leads to interveinal chlorosis, especially in young leaves.
  + Excess Fe can interfere with **Mn** and **Zn** uptake.

Copper (Cu)

* **Function:**
  + Plays a role in lignin synthesis for strong vascular tissues.
  + Involved in enzyme systems related to oxidation-reduction reactions.
  + Enhances plant defense mechanisms against pathogens.
* **Interactions:**
  + High Cu levels can inhibit **Fe**, **Zn**, and **Mn** absorption.
  + Excess Cu can lead to toxicity, causing reduced root growth.
  + Cu deficiency results in leaf curling and weak stems.

Manganese (Mn)

* **Function:**
  + Important for chloroplast formation and photosynthesis.
  + Supports enzyme activation in carbohydrate metabolism.
  + Contributes to disease resistance by strengthening plant cell walls.
* **Interactions:**
  + High **Fe** or **Ca** levels reduce Mn uptake.
  + Mn toxicity (common in acidic soils) causes brown spots on leaves.
  + Mn deficiency leads to chlorosis similar to Fe deficiency but with a more speckled appearance.

Zinc (Zn)

* **Function:**
  + Affects hormone synthesis, particularly auxins for shoot and root growth.
  + Vital for enzyme function and protein synthesis.
  + Enhances coffee cherry development and uniform ripening.
* **Interactions:**
  + High **P** and **Fe** levels can reduce Zn uptake.
  + Zn deficiency leads to stunted growth and small, misshapen leaves.
  + Zn excess can impair **Fe** and **Cu** absorption.

Molybdenum (Mo)

* **Function:**
  + Essential for nitrogen fixation and nitrate reduction in coffee plants.
  + Helps in amino acid and protein formation.
  + Supports pollen viability and seed development.
* **Interactions:**
  + Mo deficiency is rare but can impair **N** metabolism, causing nitrogen deficiency symptoms.
  + High **S** levels can reduce Mo uptake.

## 8.2 Micronutrient Requirements by Growth Stage

### 8.2.1. Establishment

* **Micronutrient Needs:**
  + **Fe & Zn**: Promote root growth and early shoot formation.
  + **Mn & Cu**: Support early enzymatic activities and disease resistance.
  + **Mo**: Enhances nitrogen utilization in young plants.
* **Fertilizer Program:**
  + **Foliar sprays** of **Fe, Zn, and Mn** chelates (organic-based).
  + **Compost liquid with micronutrient supplementation** (fermented with mycorrhizae).
  + **Biochar application** to retain moisture and improve micronutrient availability.

### 8.2.2. Vegetative Growth

* **Micronutrient Needs:**
  + **Fe & Mn**: Essential for chlorophyll production and photosynthesis.
  + **Zn & Cu**: Support branching and leaf expansion.
  + **Mo**: Required in small amounts for nitrogen metabolism.
* **Fertilizer Program:**
  + **Rock phosphate** combined with Zn-fortified biofertilizer.
  + **Liquid seaweed extract** enriched with Fe and Mn.
  + **Fermented organic compost** with Cu supplementation.

### 8.2.3. Pre-Flowering/Budding

* **Micronutrient Needs:**
  + **Fe & Zn**: Boost energy production for flower bud formation.
  + **Cu & Mn**: Strengthen vascular tissues for nutrient transport.
  + **Mo**: Ensures effective nitrogen utilization.
* **Fertilizer Program:**
  + **Fish fertilizer** enriched with trace minerals (Fe, Zn, Cu).
  + **Manganese sulfate** as a foliar application for improved flowering.
  + **Microbial inoculants** to improve micronutrient availability.

### 8.2.4. Flowering

* **Micronutrient Needs:**
  + **Zn & Cu**: Essential for pollen viability and flower set.
  + **Fe & Mn**: Support high energy demand for flowering.
  + **Mo**: Enhances reproductive success by aiding nitrate assimilation.
* **Fertilizer Program:**
  + **Fermented molasses-based biofertilizer** with Fe, Zn, and Cu.
  + **Silica-rich organic amendments** to enhance flower resilience.
  + **Foliar spray with micronutrient-enriched humic acid.**

### 8.2.5. Early Fruit/Pod Formation (fruit set and initial growth)

* **Micronutrient Needs:**
  + **Zn & Cu**: Regulate fruit cell division and early development.
  + **Mn & Fe**: Improve chlorophyll stability and carbohydrate production.
  + **Mo**: Maintains nitrogen efficiency in fruit expansion.
* **Fertilizer Program:**
  + **Biochar-based slow-release Fe & Mn fertilizers**.
  + **Liquid compost** enriched with Cu and Zn.
  + **Humic-fulvic acid complex** for micronutrient chelation.

### 8.2.6. Fruit Development and Maturation

* **Micronutrient Needs:**
  + **Fe & Zn**: Essential for sugar accumulation and bean development.
  + **Cu & Mn**: Improve cell structure and prevent premature fruit drop.
  + **Mo**: Sustains nitrogen assimilation for protein synthesis.
* **Fertilizer Program:**
  + **Fermented plant extracts (banana, papaya, and moringa)** for Cu & Zn.
  + **Rock dust application** for slow-release Fe and Mn.
  + **Fish fertilizer** with micronutrient supplementation.

### 8.2.7 Pre-Harvest/Ripening

* **Micronutrient Needs:**
  + **Fe & Zn**: Improve uniform fruit ripening and quality.
  + **Mn & Cu**: Strengthen fruit skin and prevent shriveling.
  + **Mo**: Supports final nitrogen mobilization to beans.
* **Fertilizer Program:**
  + **Organic potassium-magnesium sulfate (KMgS)** with Zn & Fe fortification.
  + **Molasses-based microbial spray** to enhance micronutrient uptake.
  + **Biofertilizer with chelated trace elements** to support final fruit maturation.

## 8.3 Regenerative Fertilizer Program

* **Soil Health Focus:**
  + Use of **biochar, compost, and vermicompost** to retain micronutrients.
  + Integration of **cover crops (legumes) and mulching** to improve soil structure.
* **Microbial Solutions:**
  + Application of **Trichoderma, mycorrhizal fungi, and Azospirillum** to enhance nutrient solubilization.
  + **Fermented plant teas** from local materials (banana, moringa, seaweed).
* **Balanced Micronutrient Management:**
  + **Periodic foliar sprays** of **fermented fish hydrolysate with Fe, Mn, Zn, Cu**.
  + **Slow-release rock-based mineral amendments** for long-term soil fertility.
  + **Alternating compost teas with humic acid and microbial inoculants** every 2-3 months.
* **Intercropping with nitrogen-fixing trees** (Gliricidia, Leucaena) to provide Mo for natural nitrogen cycling.

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# 9. Fertilizer program (Tay Nguyen Institute Of Agricultural And Forestry Science And Technology)

## 9.1 Establishment and juvenile phase

| Year | Amount of pure ingredient per ha | | |
| --- | --- | --- | --- |
| N | P2O5 | K2O |
| First year (Replanting) | 60 | 100 | 30 |
| Second year | 120 | 100 | 100 |
| Third year | 150 | 100 | 130 |

## 9.2 Production phase (fourth year onward)

### 9.2.1 The amount of Nitrogen to be supplied is based on soil analysis results and yield

| Yield (ton GBE/ha) | Test result Nts (%) | Amount of Nitrogen (kg/ha/year) |
| --- | --- | --- |
| 3,1-4 | < 0,10 | 320 |
| 3,1-4 | 0,01 - 0,15 | 300 - 230 |
| 3,1-4 | 0,15 - 0,20 | 275 - 210 |
| 3,1-4 | 0,20 - 0,25 | 255 - 185 |
| 3,1-4 | > 0,25 | 210 |

Note: For every additional ton of coffee beans, apply an additional 50-70 kg of nitrogen (N) per hectare.

### 9.2.2. The amount of P₂O₅ to be supplied is based on soil analysis results and yield

| Yield (ton GBE/ha) | Test result P₂O₅ mg/100g | Amount of fused phosphate (kg/ha/year) |
| --- | --- | --- |
| 3,1-4 | < 3,00 | 125 - 130 |
| 3,1-4 | 3,00 - 4,50 | 115 - 125 |
| 3,1-4 | 4,51 - 6,00 | 105 - 115 |
| 3,1-4 | 6,00 - 9,00 | 100 - 105 |
| 3,1-4 | 9,00 - 25,00 | 50 - 70 |
| 3,1-4 | > 25 | 20 |

Note: For every additional ton of coffee beans, apply an additional 10 - 15 kg of P₂O₅ per hectare.

### 9.2.3. The amount of K₂O to be supplied is based on soil analysis results and yield

| Yield (ton GBE/ha) | Test result K2O mg/100g | Amount of K2O (kg/ha/year) |
| --- | --- | --- |
| 3,1-4 | < 10 | 300 |
| 3,1-4 | 10 - 15 | 270 - 125 |
| 3,1-4 | 15 - 20 | 240 - 115 |
| 3,1-4 | 20 - 25 | 210 - 110 |
| 3,1-4 | 26 - 60 | 150 - 80 |
| 3,1-4 | > 60 | 0 |

Note: For every additional ton of coffee beans, apply an additional 60 - 80 kg of K2O per hectare.

### 9.2.4 Amount of Ca, Mg, S and Micronutrient Zn need based on yield

| Nutrient | Amount | Yield ranging from 3 to 4 tons GBE/ha/year | Yield more than 4 tons GBE/ha/year |
| --- | --- | --- | --- |
| CaO | kg/ha | 80 - 100 | 110 - 130 |
| MgO | kg/ha | 50 - 70 | 80 - 90 |
| S | kg/ha | 23 - 30 | 30 - 40 |
| Zn | kg/ha | 5 - 10 | 5 - 10 |