Soil Fertility and Fertilizers
What is soil Fertility?

- The capacity to supply **nutrients** required for plant growth.
- Study on this subject is called Plant Nutrition
Nutrients become available through organic matter decomposition, chemical weathering of minerals, airborne additions, and fertilizers.

**ESSENTIAL AND BENEFICIAL NUTRIENTS**
Essential Nutrients

*Essential for plants to complete* the life cycle (germination, growth, flowering, fruiting and seed production).

The function of the nutrient cannot be replaced.

The nutrient has a direct role in metabolism or become part of the structure.
Essential Plant Nutrients: Total number of nutrients is 17:

i) **Macro-nutrients**: Required in high amount (9 nutrients)
   
   \[ C, H, O, N, P, K, Ca, Mg, \text{ and } S \]

ii) **Micro-nutrients**: Required in small amount (8 nutrients)
   
   \[ Fe, Mn, Cu, Co, Zn, Mo, B \text{ and } Cl \]
Beneficial Nutrients or elements:

Beneficial nutrients improve plant growth. Their absence still allow plant to complete the life cycle.

*Si*, *Na*, and *V*
Source of nutrients

C, H, O: Air and water

P, K, Ca, Mg, Cu, Fe, Mn, Zn, B, Co: Soil

N, S: Soil and atmosphere
Nutrient Absorption

Available Nutrient: nutrient in soil solution and exchangeable nutrients. Forms of nutrients taken up by plants:
## Forms of nutrients

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Available Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>CO₂</td>
</tr>
<tr>
<td>H</td>
<td>H₂O, OH⁻, H⁺</td>
</tr>
<tr>
<td>O</td>
<td>CO₂, OH⁻, H₂O, O²⁻, CO₃²⁻, SO₄²⁻</td>
</tr>
<tr>
<td>N</td>
<td>NO₃⁻, NH₄⁺</td>
</tr>
<tr>
<td>P</td>
<td>H₂PO₄²⁻, HPO₄²⁻</td>
</tr>
<tr>
<td>K</td>
<td>K⁺</td>
</tr>
<tr>
<td>Ca</td>
<td>Ca²⁺</td>
</tr>
<tr>
<td>Mg</td>
<td>Mg²⁺</td>
</tr>
<tr>
<td>S</td>
<td>SO₄²⁻</td>
</tr>
<tr>
<td>Element</td>
<td>Charge Formulas</td>
</tr>
<tr>
<td>---------</td>
<td>----------------</td>
</tr>
<tr>
<td>Fe</td>
<td>Fe^{2+}, Fe^{3+}</td>
</tr>
<tr>
<td>Mn</td>
<td>Mn^{2+}</td>
</tr>
<tr>
<td>Cu</td>
<td>Cu^{2+}</td>
</tr>
<tr>
<td>Co</td>
<td>Co^{2+}</td>
</tr>
<tr>
<td>Zn</td>
<td>Zn^{2+}</td>
</tr>
<tr>
<td>B</td>
<td>H_{2}BO_{3}^{2-}, H_{3}BO_{3}^{-}</td>
</tr>
<tr>
<td>Mo</td>
<td>MoO_{4}^{-}</td>
</tr>
<tr>
<td>Cl</td>
<td>Cl^{-}</td>
</tr>
<tr>
<td>Si</td>
<td>Si(OH)_{4}</td>
</tr>
<tr>
<td>Na</td>
<td>Na^{+}</td>
</tr>
<tr>
<td>V</td>
<td>VO_{3}^{-}</td>
</tr>
</tbody>
</table>
1. Nitrogen

- **Nitrogen Fertilizer** - management of Nitrogen requires an understanding of the Nitrogen Cycle.
- Nitrogen is dynamic in the soil and forms of $N$ will change depending on the soil conditions.

Reed Palm - N Def on left
1. Nitrogen

- $\text{NH}_4^+$ and $\text{NO}_3^-$ forms taken up by plants
- Loss of N can occur: 1) leaching of $\text{NO}_3^-$, 2) volatilization of $\text{NH}_4^+$ to $\text{NH}_3$ (high pH soils),
- 3) immobilization by plant or microbe uptake,
- 4) Denitrification
Nitrogen Cycle
1. NITROGEN

Kekurangannya akan menghalang tumbuhan untuk melengkapkan edaran hidupnya (percambahan, tumbesaran, berbunga, berbuah dan penghasilan bijibenih).

Peranan unsur tersebut tidak boleh diganti oleh unsur yang lain.

Unsur memainkan peranan terus dalam proses metabolisma tumbuhan.

Ketiadaan unsur berguna tidak menjejaskan edaran hidup tumbuhan.
NITROGEN

• Bertanggungjawab dalam pembentukan klorofil
• mempercepatkan proses tumbesaran
• menambahkan hasil daun, buah dan benih
• menambahkan mutu hasil pertanian
**Simptom kekurangan N**

- tanaman kurang subur dan kecil
- daun menjadi kecil dan kekuningan/klorosis
  - daun bawah/tua menjadi lecur dan mati sebelum cukup matang sementara daun atas masih hijau
- hasil tanaman rendah
2. Phosphorus

- Phosphorus is low in total amount in the soil and low in solubility and is readily fixed by Fe and Al at low pH and Ca at high pH.

- $\text{H}_2\text{PO}_4^-$ and $\text{HPO}_4^{2-}$ forms taken up by plants
Crops need more P than is dissolved in the soil solution at any one time, therefore, this P in the solution phase must be replenished many times during the growing season.

The ability of a soil to maintain adequate levels of phosphorus in the solution phase is the key to the plant available P status of the soil. The solid phase P is both organic and inorganic.
-2. **Fosforus**

- mempercepatkan pengeluaran akar, bunga dan buah
- mempercepatkan kematangan pokok

menguatkan tangkai buah
- memberikan tenaga yang perlu diperingkat awal
- tumbesaran
- penting untuk pembentukan DNA dan RNA
- **Simptom kekurangan** P
  - proses tumbesaran bantut dan pokok kelihatan kurus
  - daun menjadi kurang hijau dan urat daun menjadi -
  - *warna ungu* terutamanya di bawah, tepi dan hujung daun serta ganggang daun.
  - pembentukan akar merosot
  - bijirin kurang berisi
  - hasil buah sangat berkurangan
3. Potassium

- Potassium is found in minerals such as feldspars and micas (90% of Soil K)
- K is fixed inside of clay minerals (9% of soil K)
- K is on the soil exchange sites (1%)
- K is in the soil solution (0.1%)

3. Kalium
- mobil
- membantu mempercepatkan tumbesaran tisu meristem.
- menambahkan kekuatan pokok dan ketahanan terhadap penyakit.
- untuk metabolisme kanji, protein dan mengaktifkan enzim.
3. Potassium Fertility (Potash)

Potassium (K⁺) is a problem on acid soils, soils with low CEC and with irrigation or high rainfall where leaching can readily occur.

K is not a pollutant - even if leached from soil, K does not cause environmental problems.
Simtom Kekurangan K

daun tua menunjukkan bintik “necrotic” atau tepinya seakan terbakar, bergulung, bergigi, urat tengah masih hijau.

• daun muda berpigmen merah atau kekuningan di antara urat daun dan permukaannya berkilat.
• kehilangan daun sebelum matang di mana hujung dan tepi daun menjadi kuning atau kemerahan sehingga menjadi lecur dan mati.
• tumbesaran pokok terbantut.
• pokok mudah rebah terutama pokok bijirin.
• buah menjadi kecil, hasil rendah dan kualiti simpanan merosot.
4. Ca, 5. Mg

**Calcium and Mg** - when soils are low in Ca, Mg, they have a pH problem and by adding lime or dolomite the pH and Ca, Mg problem is corrected.

Magnesium deficiency on corn
• **Kalsium**
  - kemobilan terhad.
  - mempercepatkan pengeluaran dan tumbesaran akar.
    - menambahkan kecergasan dan keteguhan daun dan batang.
  - membantu memperbaiki biji benih.
    - diperlukan untuk pengeluaran selaput dinding sel dan tisu bagi mengkuhkan tumbuhan.
- diperlukan untuk aktiviti biokimia bakteria seperti rhizobia kekacang.
- untuk mengawal penyakit seperti layu daun pada tanaman koko.

**Simptom kekurangan Kalsium**
- tumbesaran mata tunas terganggu
- akar menjadi pendek, bercabang, reput dan busuk.
- tumbuhan menjadi layu.
- daun menjadi kekuningan, kecil dan berbentuk seperti mangkuk.
- hujung daun terbakar.
- pembentukan buah terganggu, ovule dan bunga gugur.

5. *Magnesium*
- mobile
- Required for production of chlorofil.
- Helps in production of oil, fats and sugars.
• **Magnesium deficiency symptoms**
• Tissues in between veins or edges turn yellow and red, will dry and die.
• Edges of leaves will roll and leaves drop before maturity.
• Stem will become weak.
Magnesium deficiency in oil palm
HEALTHY leaves shine with a rich, dark green color when adequately fed.

PHOSPHORUS (phosphate) shortage marks leaves with reddish-purple, particularly on young plants.

POTASSIUM (potash) deficiency appears as a firing or drying along the tips and edges of lowest leaves.

NITROGEN hunger sign is yellowing that starts at tip and moves along middle of leaf.

MAGNESIUM deficiency causes whitish stripes along the veins and often a purplish color on the underside of the lower leaves.
6. SULFUR

Sulfur - Most soils in Malaysia would not respond to additions of Sulfur because of adequate levels and atmospheric deposition.
6. **Sulfur**

- Not mobile.
- Maintain green colour.
- Helps in nodule production on legume plants.
- Hasten production of seed.
- Promotes plant health.
Simtom kekurangan S
-tumbesaran tumbuhan merosot/terbantut, pokok menjadi kurus dan lampai.

-serupa seperti kekurangan N, tetapi daun sebelah atas pokok/daun muda yang menjadi kuning dahulu.
- pokok lambat matang.
- buah berwarna hijau cerah.
Micronutrients

- Manganese - Mn
- Iron - Fe
- Boron - B
- Zinc - Zn
- Copper - Cu
- Molybdenum - Mo
- Chlorine - Cl
- Cobalt - Co
- Nickel - Ni

grape leaf symptoms of boron deficiency; right: boron toxicity)
Micronutrients

- Correcting pH problems for most soils will correct micronutrient deficiencies
- Most common is Iron on alkaline soils or with plants that like acid conditions.
Soil fertility and its management

- Nutrients can be supplied naturally in soil through:
  - weathering of minerals
  - Decomposition of organic matter.
  - Usually not sufficient for plants

- Therefore nutrients have to be supplied from sources known as
  FERTILIZERS
Types of Fertilizers

Organic Fertilizers
Originated from plants and animals. Contains C, H, and O and one or more other nutrients

Eg : Green manure: POME (Palm Oil Mill Effluent) and EFB

Animal Manure : chicken dung, cattle manure, guano etc.
Palm Oil Mill Effluent as fertilizers
2. Chemical Fertilizers

Inorganic fertilizer (commercial fertilizer) containing (macronutrients such as NPK and micronutrients).

E.g. NPK compound, Urea, MOP, Rock Phosphate,
1. Fertilizer mixture

- Fertilizer contains NPK which is physically mixed
- E.g.: Urea + TSP + MOP
2. Compound Fertilizer

- Fertilizer containing NPK which is chemically mixed.
- E.g: Nitrophoska green, Nitrophoska blue, Nitrophoska Red
<table>
<thead>
<tr>
<th>Fertilizer</th>
<th>Nutrients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% N</td>
</tr>
<tr>
<td>Ammonium nitrate NH4NO3</td>
<td>33.5</td>
</tr>
<tr>
<td>NH3 (Anhydrous Ammonia)</td>
<td>82.0</td>
</tr>
<tr>
<td>Ammonium sulphate (NH4)2SO4</td>
<td>20.0</td>
</tr>
<tr>
<td>Urea CO(NH2)2</td>
<td>45</td>
</tr>
<tr>
<td>Superphosphate (SP)</td>
<td></td>
</tr>
<tr>
<td>Triple Superphosphate (TSP)</td>
<td></td>
</tr>
<tr>
<td>Muriate of Potash (MOP) KCl</td>
<td></td>
</tr>
<tr>
<td>Material</td>
<td>Mol. Wt.</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>Sulphate Potash (SOP) K₂SO₄</td>
<td>50.0</td>
</tr>
<tr>
<td>Potassium nitrate KNO₃</td>
<td>13.0</td>
</tr>
<tr>
<td>Calcium Carbonate CaCO₃</td>
<td></td>
</tr>
<tr>
<td>Gypsum, CaSO₄</td>
<td></td>
</tr>
<tr>
<td>Calcium nitrate, Ca(NO₃)₂</td>
<td>16.0</td>
</tr>
<tr>
<td>Dolomite (Ca, Mg)CO₃</td>
<td></td>
</tr>
<tr>
<td>Kieserite MgSO₄.7H₂O</td>
<td></td>
</tr>
</tbody>
</table>
Fertilizer Grade

Numbers which are written on a bag of fertilizer shows the nutrient contents

Eg: 15-15-15 iaitu:

- (Fertilizer grade)
  - The plant nutrient content %
  - E.g
    : 15% N, 15% P₂O₅, 15% K₂O.
Fertilizer ratio

The ratio of plant nutrient in fertilizer

Eg. : 15-15-15 Grade

1:1:1 Ratio
Pengiraan Kandungan Nutrien dalam baja
Contoh: Gred Baja 15-15-15
Berat Baja 50 kg

Kandungan nutrien:

\[
\begin{align*}
N &= (15/100) \times 50 = 7.5 \text{ kg} \\
P_{2}O_{5} &= (15/100) \times 50 = 7.5 \text{ kg} \\
K_{2}O &= (15/100) \times 50 = 7.5 \text{ kg}
\end{align*}
\]
Hubungan antara $P_2O_5$ dan $P$:

\[
\text{% P} = \text{% }P_2O_5 \times 0.436^* \\
\text{% }P_2O_5 = \text{% }P \times 2.291
\]

- Hubungan antara $K_2O$ dan $K$:

\[
\text{% K} = \text{% }K_2O \times 0.83 \\
\text{% }K_2O = \text{% }K \times 1.2
\]

Nota: $^* = \text{Faktor penukaran (Conversion factor)}$ (Dengan mengambil kira $P = 31$, $O = 16$, $K = 39$)
Latihan membuat baja campuran

• Gred baja diperlukan 10-8-8
Sumber bahan baja Urea - 45% N
TSP - 48% P$_2$O$_5$
MOP - 60% K$_2$O

• Berat yang diperlukan 100 kg
Jumlah nutrien dalam 100 kg:
N = \( \frac{10}{100} \times 100 = 10 \text{ kg} \)
\[ \text{P}_2\text{O}_5 = \left( \frac{8}{100} \right) \times 100 = 8 \text{ kg} \]
\[ \text{K}_2\text{O} = \left( \frac{8}{100} \right) \times 100 = 8 \text{ kg} \]

Maka: Urea yang diperlukan:
45 kg N dalam 100 kg urea
10 kg N dalam \( \frac{100}{45} \times 10 = 22.5 \text{ kg urea} \)

TSP yang diperlukan:
48 kg \( \text{P}_2\text{O}_5 \) dalam 100 kg TSP
8 kg \( \text{P}_2\text{O}_5 \) dalam \( \frac{100}{48} \times 8 = 16.6 \text{ kg TSP} \)
• \( \%P \times 2.29 = \%P_2O_5 \) (and \( P_2O_5 \div 2.29 = \%P \));
  • \( 1 \div 2.29 = .44 \) (Or \( \%P_2O_5 \times .44 = \%P \))
• use \( \%K \times 1.2 = \%K_2O \) (and \( \%K_2O \div 1.2 = \%K \));
  • \( 1 \div 1.2 = .83 \) (or \( \%K_2O \times .83 = \%K \))

For Example: A 30 kg sack of fertilizer (25 - 5 - 5), is applied to your garden.
• The amount of N applied = .25 \( \times \) 30 = 7.5 kg N
• amount of \( P_2O_5 \) applied = .05 \( \times \) 30 = 1.5 kg & \( P = .44 \times 1.5 = 0.66 \) kg P
• amount of \( K_2O \) applied = .05 \( \times \) 30 = 1.5 kg & \( K = .83 \times 1.5 = 1.245 \) kg K
• MOP yang diperlukan:
  60 kg K₂O dalam 100 kg MOP
  8 kg K₂O dalam \((100/60) \times 8 = 13.3\) kg MOP
  Jumlah bahan: \(22.5 + 16.6 + 13.3 = 52.4\) kg

  Bahan pemenuh (filler) diperlukan: \(100 - 52.1 = 47.9\) kg.

Contoh bahan pemenuh: pasir, habuk papan, dll.
QUICK TEST

• If you apply a 40 kg sack of 20-5-10 how many kg of N, P$_2$O$_5$, and K$_2$O did you apply?
Calculation

• If you need 85 kg of N for Corn how many kg of this fertilizer (20-5-10) do you need?
  85/.20 = 425 kg fertilizer

• How many kg of elemental K will you apply with the 85 kg of N.
  425 x .1 = 42.5 kg K₂O and 42.5 x .83 = 35.275 kg K
Plate No. 1. Developing symptoms of potassium deficiency. Leaf tips dry up and scattered olive-green spots develop, starting from the tips. The spots increase in size and turn later into reddish brown.
Photo: Courtesy M. de Nuce de Lamothe, IRHO, Abidjan.

Plate No. 2. At a more advanced stage the yellow and reddish brown spots move upwards on the leaflets, leaving only the basal part and some sections along the midrib green. The photosynthetic rate of such leaves is severely reduced.
Photo: Courtesy of M. de Nuce de Lamothe, IRHO, Abidjan.
Plate No. 3. Highly advanced stage of potassium deficiency. The entire leaf has turned into an orange-yellow colour and leaflets dry up, starting from the leaf tips.

Plate No. 4. View of 6 year old tree that received 0.3 kg of Nitrogen and 0.5 kg of P₂O₅ per year but no Potassium Chloride. Note thin stem, small, pale, hanging fronds, poor nut set and small nut size.
Photos: Courtesy Philippine Coconut Authority, Agric. Res. Dept.
Plate No. 5. View of 6 year old tree from the same experiment as the tree shown in Plate No. 4. In addition to 0.3 kg of N and 0.5 kg of P$_2$O$_5$ this tree received 1.5 kg of K$_2$O as Potassium Chloride. Note the heavier stem, strong, dark-green fronds the higher number and larger size of nuts. Yellowish trees in the background are from plots without KCl.

Plate No. 6. Orange spotting. Pale yellow or chlorotic spots appear along the pinae of older fronds in the canopy. As the syndrome aggravates these spots coalesce and turn orange to dark orange. This is the most common form of potash hunger. Photo: Dr. H.B. van Heekull
Plate No. 7. Diffuse yellowing or decolouration. This kind of potassium deficiency symptom develops in acid peat areas or on sandy soils subjected to water stress.

Photo: Dr. Na Siew Kee

Plate No. 8. Advanced stage of potassium deficiency on oil palms grown on acid, peaty soils. Lowest fronds are entirely desiccated.

Photo taken by Dr. H.R. von Uexkull at the Chemara Oil Palm Res. Sta., Layang Layang, Johore.
Plate No. 10. Panicles and leaves of potassium deficient plants. Note:
a) Dark green colour, brown spots and necrosis on the flag leaf.
b) Very uneven ripening.
c) High percentage of empty grains.
Photo: M. Ismunadjji, CRIA, Bogor.

Plate No. 11. Roots, stems and panicles of potassium deficient plants treated with NP only (left side) and healthy plants treated with NPK. Note:
a) Darker colour of potash deficient roots.
   (Root rot)
b) Very thin stems of potash deficient plants.
c) Rotting of leaf sheaths of potash deficient plants caused by stem rot.
d) Short flag leaf and short poorly filled panicle.
Photo: M. Ismunadjji, CRIA, Bogor.
Plate No. 13. Excessive iron uptake as a result of insufficient potassium supply on poorly drained soil may lead to a physiological disorder called "bronzing". Picture from fertilizer experiment at Ciheba, W. Java.

Upper photo: "B" 120 kg N, 60 kg P₂O₅, 60 kg K₂O (NP) plot. Note bronzing symptoms and uneven heading. Grain yield: 2.480 kg/ha.

Lower photo: "D" Healthy plants on plots receiving 120 kg K₂O in addition to N and P. Grain yield: 4.290 kg/ha.

Photo: H.R. von Uexkull, Singapore

Plate No. 12. On poorly drained soils potassium deficient plant lose their oxydizing power. As a result excessive amounts of ferrous iron, hydrogen sulphide etc. enter the roots, causing physiological disorders and root rot.

Upper photo — roots from potash deficient plants.

Lower photo — roots from plants well supplied with potassium.

Photo: Dr. G. Troldenier, Buntehof Agric. Expt. Sta.

Plate No. 15 Various stages of potassium deficiency in rubber tree leaves. Potassium deficiency starts with a diffused marginal paleness of the laminae. As the deficiency intensifies the marginal border become yellower and mottled areas coalesce. Finally, necrosis sets in, starting from the leaf tips and spreading along the margins. Photo: E. Pushparajah, RRIM, Kuala Lumpur.
Plate No. 16. In young unbranched trees first symptoms of potassium deficiency occur on leaves in the lower storey. Leaf size is often reduced and defoliation of the older leaves can occur.
Photo: E. Pushparajah, RRI, Malaysia.

Plate No. 17. In older branched trees potassium deficiency symptoms often start from the top of the canopy where such canopy is exposed to sunlight.
Photo: E. Pushparajah, RRI, Malaysia.
Plate No. 19. Sugar cane plants deficient in potassium have a reduced number of active leaves. Lower leaves become chlorotic and inefficient in photosynthetic activity. Photo shows from left to right leaves from K-deficient and from normal plants. The K-deficient plant has only 11 active leaves and from leaf No. 7 onwards the leaves become increasingly chlorotic. +K leaves stay green and active up to leaf No. 14.

Plate No. 20. In potassium deficient plants both old and young leaves appear to have developed from a common point - a characteristic of a cane plant that is not growing (short internodes). Leaves are short and narrow as compared to healthy ones (left and right).

Photo: Courtesy Dr. H.F. Clements, Hawaii Agric. Expt. Sta., University of Hawaii.
Kekurangan N - Daun getah berubah warna dari hijau ke hijau pucat dan seterusnya kepada kekuningan.

Kekurangan P - Bahagian bawah daun getah menjadi kuning gangsa.

Kekurangan K - Tanda-tanda klorosis dan nekrosis terjadi di bahagian tepi dan hujung daun getah.

Kekurangan Ca - Tanda-tanda melecur dibahagian hujung dan tepi daun getah.
Kekurangan Mg – Warna kekuningan di antara urat-urat daun.

Kekurangan S – Daun berubah warna menjadi kuningh dan tanda nekrosis terjadi bermula di bahagian hujung daun.

Kekurangan N – Tanda klorosis dan nekrosis bermula dari bahagian hujung dan tengah daun.

Kekurangan P – Tepi atau seluruh permukaan daun berwarna ungu.
Kekurangan K – Tanda kekuningan klorosis dan nekrosis bermula dari bahagian hujung dan tepi

Kekurangan Mg – Tanda klorosis terjadi di antara urat-urat daun.

Kekurangan Ca – Daun muda berwarna kekuningan dan hujung daun mati.

Kekurangan S – Pertumbuhan tanaman padi terbantut, saiz daun kecil dan seluruh permukaan daun berwarna kuning.
Phosphorus deficiency on corn is indicated by purplish discoloration.

Manganese deficiency on kidney beans. Leaf Veins remain green as the intervein areas lose their green color and turn yellow.

Severe Fe deficiency on sorghum plants. Small plots were sprayed with Fe to overcome the disorder and restore chlorophyll production and green colour.

Brown Spot in rice induced deficiency.
Left is nitrogen section of corn leaf and cut open section of stem that remains uncolored when treated with diphenylamine, indicating low nitrate level in plant sap. On right the leaf is dark produces a dark green and diphenylamine produces a dark blue color indicative of high nitrate level in plant sap.

Mg deficiency on coffee. Veins remain green and intervein areas turn yellow.

Potassium deficiency on corn. Lower leaves have yellow margins.

Excess soluble salt symptoms on geranium. The leaf margins turn yellow and become necrotic.