# 4R NUTRIENT STEWARDSHIP GUIDEBOOK

## LEARNING MODULES FOR EXTENSION AGENTS

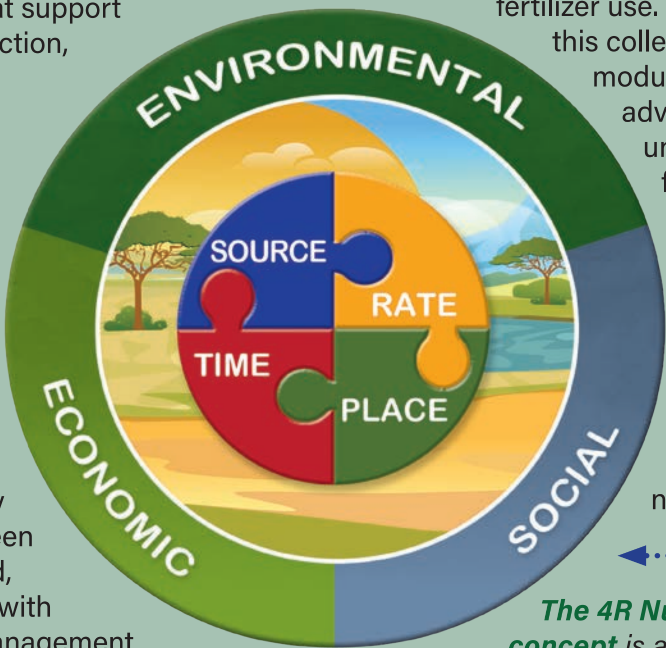
AFRICAN PLANT NUTRITION INSTITUTE

## THE 4R NUTRIENT STEWARDSHIP CONCEPT

Effective fertilizer use, as guided by 4R Nutrient Stewardship, is important for developing sustainable smallholder cropping systems that support improved food production, increased income for farmers, and enhancement and maintenance of soil fertility.

Fertilizers supply the nutrients required by crops. More and better-quality food and cash crops can be produced with fertilizers. The fertility of soils, which has been largely over-exploited, can also be restored with fertilizers. Correct management of fertilizers based on the 4Rs can therefore result in better social, economic and environmental outcomes for farms, villages, communities, and entire countries in Africa.

This guidebook has been developed as a resource for extension agents, agro-dealers and other stakeholders working with smallholder farmers in Africa. It provides a detailed overview of each of the 4Rs of fertilizer use. The purpose of this collection of learning modules is to ensure these advisors have a good understanding of the four principles of 4R Nutrient Stewardship, thereby equipping them with the knowledge required to communicate the best ways for farmers to use fertilizers and other nutrient resources.




***The 4R Nutrient Stewardship concept*** *is an approach that was developed to communicate the Right ways to manage fertilizers based on four principles: applying the right source of fertilizers, at the right rate, at the right time in the growing season, and in the right place. It provides a basis for defining strategies for effective use of nutrients.*

**4R NUTRIENT STEWARDSHIP GUIDEBOOK**

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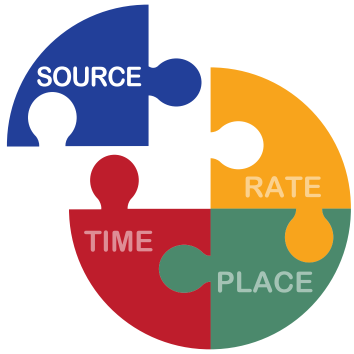
# 4R NUTRIENT STEWARDSHIP GUIDEBOOK

## LEARNING MODULES FOR EXTENSION AGENTS

## MODULE 1

# RIGHT SOURCE




**RIGHT SOURCE:**

APPLYING THE CORRECT FERTILIZER AND ORGANIC RESOURCES THAT PROVIDE GROWING CROPS WITH ALL NUTRIENTS REQUIRED FOR GOOD GROWTH AND MATURITY.

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Solution

# 1. SCIENTIFIC PRINCIPLES BEHIND RIGHT SOURCE

Different soil conditions and farming practices require the use of different nutrients for best results. To determine the right source, the following scientific principles should be considered:

## Scientific Principles to Determine the Right Source are:

- **Consider rate, time and place of application:** The rate, time and place of application has an influence on the right source of fertilizer. For example, where high nutrient application rates are required, fertilizers with high nutrient concentrations are best suited. Where fertilizer application is required at planting, such as for cereal crops like wheat and maize, compound NPK fertilizers that supply a wide range of nutrients are best suited. For top-dressed applications, straight fertilizers such as urea that only supply N are best suited.

  With regard to place of application, solid fertilizers are best suited for soil-based applications, while liquid fertilizers are best suited where foliar (leaf) applications are required.

- **Supply nutrients in plant-available form:** Right source should ensure that nutrients are applied in plant-available form, or are in a form that converts into a plant-available form in a timely manner to ensure quick and efficient uptake by plants.

- **Suit soil physical and chemical properties:** Right source should consider differences in soil physical and chemical properties for different soil types and farm environments. For example, surface application of urea should be avoided on high pH soils so as to reduce N losses in form of ammonia.

- **Recognize how the application of one nutrient affects the availability or uptake of another nutrient:** Right source should ensure enhanced availability and uptake of other nutrients. For example, the co-application of N and P enhances the uptake of P. The complementing effects of using both manure and mineral fertilizer sources should also be considered.

- **Recognize blend compatibility:** Right source should consider compatibility of nutrients when mixing different nutrients. For example, certain combinations of nutrient sources attract moisture when mixed, limiting uniformity of application of the blended material. During blending, it should also be ensured that fertilizer granules are of a similar size to ensure uniform application in the field and prevent segregation of blended fertilizers.

- **Recognize benefits and sensitivities to associated elements:** Most nutrients often have an accompanying ion that may be beneficial, neutral or harmful to the crop. For example, the chloride ($Cl^-$) that accompanies K in muriate of potash is beneficial to maize, but can decrease the quality of of some crops (e.g., tobacco and some fruits).

# 2. ESSENTIAL PLANT NUTRIENTS

Essential plant nutrients refer to nutrients that are required by plants to effectively complete their lifecycle. All plants require at least **17 essential nutrients.**

Each of these essential nutrients has unique functions for metabolism and plant growth. However, the amount of each specific nutrient required by plants varies greatly.

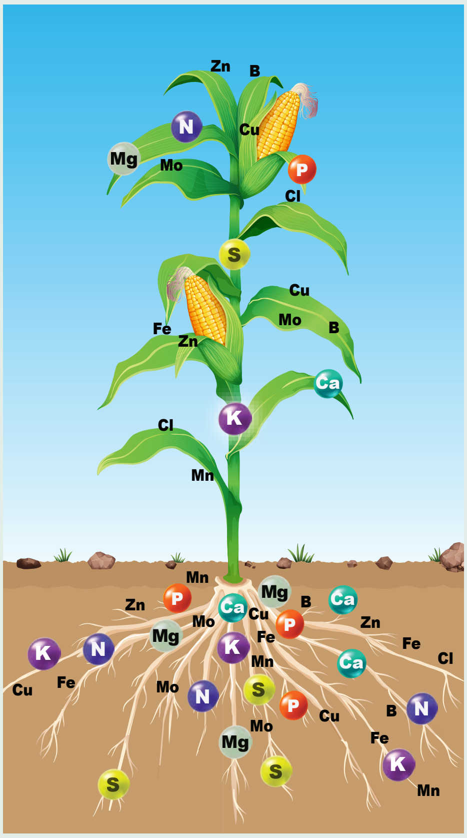
Of these essential nutrients, **carbon (C), hydrogen (H) and oxygen (O) are derived from the air and are referred to as non-mineral nutrients.**

The other **14** essential nutrients are referred to as **'mineral nutrients',** and are derived from the soil or supplied through fertilizers or organic manure.

Mineral nutrients are divided into two main groups namely **macronutrients** and **micronutrients**.

**Table 1:** List of essential plant nutrients, their primary plant-available form, and main form in soil reserves.

| Nutrient | Chemical symbol | Primary form for plant uptake | Main form in soil reserves |
|---|---|---|---|
| **Macronutrients** | | | |
| Nitrogen | N | Nitrate ($NO_3^-$) or Ammonium ($NH_4^+$) | Organic matter |
| Phosphorus | P | Phosphate ($HPO_4^{2-}$, $H_2PO_4^-$) | Organic matter, Soil minerals |
| Potassium | K | Potassium ion ($K^+$) | Minerals |
| Sulphur | S | Sulphate ($SO_4^-$) | Organic matter, Soil minerals |
| Magnesium | Mg | Magnesium ($Mg^{2+}$) | Soil minerals |
| Calcium | Ca | Calcium ion ($Ca^{2+}$) | Soil minerals |
| **Micronutrients** | | | |
| Chlorine | Cl | Chloride ($Cl^-$) | Soil minerals |
| Iron | Fe | Iron ($Fe^{2+}$) | Soil minerals |
| Manganese | Mn | Manganese ion ($Mn^{2+}$) | Soil minerals |
| Zinc | Zn | Zinc ion ($Zn^{2+}$) | Soil minerals |
| Copper | Cu | Copper ion ($Cu^{2+}$) | Organic matter, Soil minerals |
| Boron | B | Boric acid ($H_3BO_3$) | Organic matter |
| Nickel | Ni | Nickel ion ($Ni^{2+}$) | Soil minerals |
| Molybdenum | Mo | Molybdate ($MoO_4^{2-}$) | Organic matter, Soil minerals |



## 2.1 Macronutrients

Macronutrients are required by plants in large quantities for good growth and productivity. They are divided into two sub groups namely **primary macronutrients** and **secondary macronutrients.**

**Primary macronutrients include:**
nitrogen (N), phosphorus (P), and potassium (K), and are required by plants in larger quantities (i.e., >30 kg/ha).

**Secondary macronutrients include:**
sulphur (S), magnesium (Mg), and calcium (Ca), and are required by plants in smaller quantities (i.e., 5 - 30 kg/ha).

## 2.2 Micronutrients

Micronutrient are required by plants in very small quantities. However, plants must have them when and where they need them for good growth and yield.

Most soils usually have sufficient quantities of micronutrients and they often don't need to be applied in the form of fertilizers. A shortage of macronutrients or micronutrients causes plant deficiencies and eventually leads to a decline in crop growth, yield and quality.

**Micronutrients include:**
chlorine (Cl), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), and nickel (Ni).

Where the application of micronutrients is required, special attention and care is needed since there is a narrow margin between applying too much or too little to meet the needs of a crop. Often special compound NPK fertilizers can be prepared to contain combinations of micronutrients designed to fulfill the requirements of crops grown on soils that are known to be deficient.

In many cases, micronutrient shortages are caused by a low (acidic) soil pH, or more often by a soil pH that is too high (neutral to alkaline), thus a change in soil pH may improve the availability of micronutrients.

# 3. SOURCES OF MINERAL NUTRIENTS

Plants require a balanced uptake of all the essential nutrients for good yield and quality. Most soils often lack the appropriate balance of nutrients required for good crop growth and development.

Continuous cropping without application of external nutrient sources such as fertilizer or manure also depletes soil available nutrients that might have been initially available in sufficient quantities.

Soil and plant analysis can help to identify specific nutrients that may be inadequate.

Applying the right source of nutrients helps to ensure the appropriate balance of nutrients required for good crop growth and development. Nutrient sources that are available to farmers include: **fertilizer, animal manure, compost manure, green manure,** and **crop residues.**

## 3.1 Fertilizer

Fertilizer is one of the main forms in which nutrients are brought into the farm. Except for N, all other nutrients supplied by fertilizers are derived from naturally occurring earth minerals that can be mined and processed into forms that are easy to transport and more available to plants.

## 3.2 Legumes

Air contains 79% di-nitrogen gas ($N_2$) which cannot be used directly by plants. However, grain legumes (such as soybean, groundnut, pigeon peas, cowpeas, and beans) and green manure legume plants (such as mucuna and crotalaria) are capable of converting $N_2$ from the air into a form usable by the plants. These legume plants have nodules on their roots which act as 'small factories' that manufacture the nitrogen that they use for their growth (**Fig. 1**). When legumes are added back to the soil, they decay and release N that can then be used by other crops in the rotation, and can also contribute to building soil organic matter.
Cereal crops like maize, rice, wheat, and teff cannot manufacture their own N as they do not have these special nodules in their roots. Such crops can benefit from N fixed by the rotated legumes crops, but still require external sources of N fertilization to achieve high yields.

**Figure 1.** Nodules are 'fertilizer N factories' on the roots of a legume crop.

## 3.3 Animal manures and composts

Animal manures and composts are good sources of plant nutrients when used correctly. Manures contain all nutrients required by plants, but the quantities are usually small compared to the amounts required by plants for high yields.

The amount of nutrients in manure, particularly N, can be increased by feeding livestock with good quality pastures and reducing losses of nutrients during storage and handling.

## 3.4 Other organic materials

Other organic materials such as crop residues release nutrients that they contain during their decay. The quality of an organic material is determined by the nutrients it contains. Organic materials can contain a wide range of nutrients although the amounts are generally small.

Most organic materials found in smallholder farms are of poor quality, and contain small amounts of major nutrients. Despite this low nutrient quality, organic materials are still valuable as a source of organic matter.

*Heathy maize crop provided with a balanced supply of nutrients.*

# 4. BALANCED NUTRITION AND RIGHT SOURCE

Balanced nutrition is the key to higher crop yields and is the basis of selecting the right nutrient source.

The concept of balanced nutrition indicates that a crop requires an adequate supply of all nutrients for optimum growth. If more than one nutrient is in short supply, crop growth is determined by the nutrient that is in lowest supply.

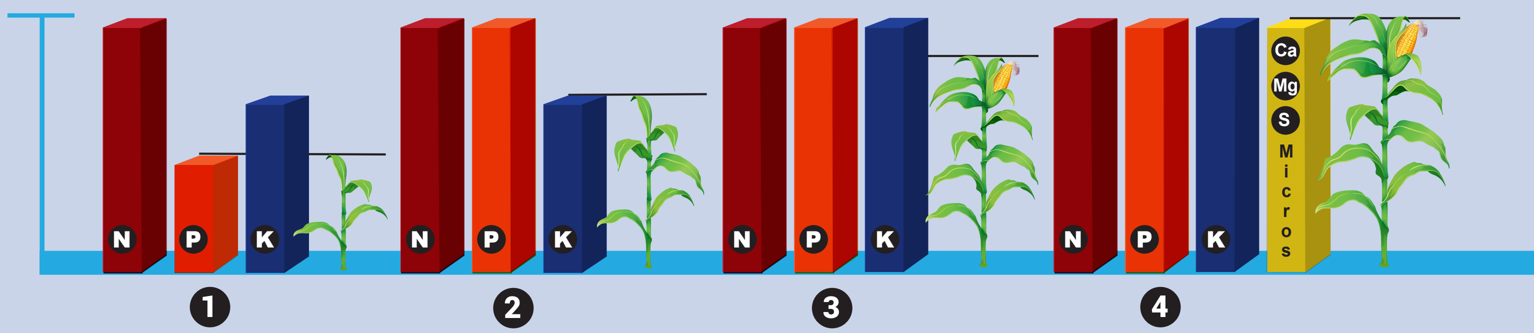
The concept of balanced nutrition is based on Liebig's law of minimum which states that if one of the essential nutrients is deficient, plant growth will be poor even when all other essential nutrients are in sufficient supply.

When a deficient nutrient is supplied, yields may be improved to the point that some other nutrient is needed in greater quantity than the soil can provide. External nutrient sources will then be required to supplement soil supply.

## Simplified illustration of the law of minimum and balanced nutrition concept.

1. When a plant has ample supply of N, moderate supply of K, and low supply of P, crop growth and yield is then proportional to the amount of the most limiting nutrient—in this case P.
2. When the supply of P is improved but the amount of K remains low, crop growth improves but is then limited by the lower supply of K such that crop growth and yield is then proportional to the amount of K which is in this case the limiting nutrient.
3. When available K is enhanced through external supply, all three macronutrients are now available in sufficient quantities and crop growth and yield increases to match the soil nutrient supply.
4. Often secondary macronutrients (S, Ca and Mg) and micronutrients need to be provided in addition to primary macronutrients (N, P and K) in order to remove all nutrient limitations and achieve the attainable yield.

*Crop requirement*



## Leibig's Law of Minimum Illustrated with Nutrients

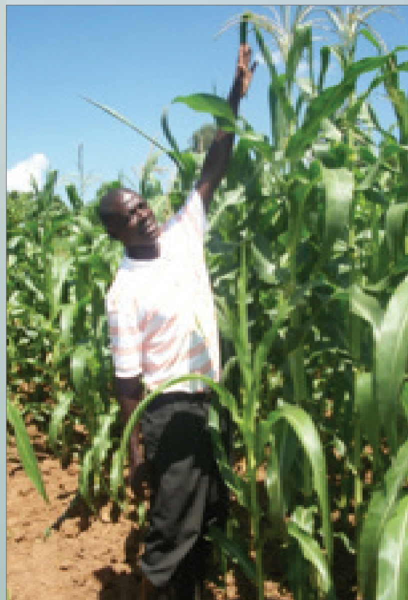
**No Fertilizer**

**P & K**

**N & K**

**N & P**

**N & P & K**



An on-farm study in western Kenya demonstrating the need for balanced nutrition in line with Leibig's law of minimum as illustrated by maize growth in plots with and without nutrients applied. Images were taken on the same day and farm at 7 weeks after planting.

# 5. KNOW YOUR FERTILIZERS

## 5.1 What is fertilizer?

Fertilizer refers to material containing at least one of the essential plant nutrients in chemical form that is soluble in the soil solution phase when applied to the soil and 'available' for plant root uptake.

For a material to be classified as a fertilizer, it should contain at least 5% of one of the essential nutrients in an immediately plant-available form.

## 5.2 Forms of fertilizer

Fertilizer is usually available in solid or liquid form. Most fertilizer is usually supplied in solid form.

Solid fertilizers are usually in the form of granules though others can be in form of pellets or powders depending on the manufacturing process.

Liquid fertilizers are widely used in horticultural and irrigated cropping systems.

## 5.3 Fertilizer nutrient contents and labeling

Fertilizers are normally sold with a grade or guaranteed minimum contents.

The nutrient content of fertilizers is usually indicated on the bag's label as a series of numbers (**Fig. 2**). The first three numbers always refer to the primary nutrients N, P and K. These nutrients are expressed as percent N-$P_2O_5$-$K_2O$, where the contents of P and K are commonly indicated in oxide form (i.e., $P_2O_5$ and $K_2O$). For example, a compound fertilizer labelled 17-17-17 means that the nutrient content of the fertilizer is 17% N, 17% $P_2O_5$ and 17% $K_2O$. Similarly, a fertilizer labelled as 18-46-0 contains 18%, 46% $P_2O_5$ and no K.

If any other nutrient is present, an additional number is given, followed by its chemical symbol. For example, a fertilizer product labelled 15-20-22-0.5B is guaranteed by the manufacturer to contain a minimum of 15% N, 20% $P_2O_5$, 22% $K_2O$, and 0.5% B.


**Figure 2.** Some fertilizer products with labeling showing nutrient contents and concentrations.

**NOTE:** The P and K contents of fertilizer are always presented in the oxide forms. To convert the oxide forms of P and K to their elemental forms, use the following conversion factors:

**For phosphorus:**

$\%P = \%P_2O_5 \times 0.44$

Therefore, for a fertilizer containing 14% $P_2O_5$, calculate the %P as: %P = 14 x 0.44 = **6.2**

**For potassium:**

$\%K = \%K_2O \times 0.83$

Therefore, for a fertilizer containing 14% $K_2O$, calculate the %K as: %K = 14 x 0.83 = **11.6**

These conversions mean that the molecular weight of $P_2O_5$ is 44% P with oxygen ($O_2$) making up the difference; similarly the weight of $K_2O$ is only 83% K.

Labels on fertilizer packaging also indicates the weight of the bag and sometimes includes recommendations for correct handling and storage. Additional labelling details can include the manufacturing date, and the expiry date.

One should be keen to read and understand all details included on the fertilizer bag label to ensure the right source is selected.

## 5.4 Classification of fertilizers

Fertilizers are often classified based on the nutrients they contain, or the method of their formulation.

Fertilizer classifications based on nutrient content include: **single nutrient** or **straight fertilizers, complete fertilizers,** and **incomplete fertilizers.**

Examples of fertilizer classification based on formulation include: **bulk blend fertilizers** and **compound fertilizers**.

### *Single nutrients or straight fertilizers*

These contain only one of the major nutrients (N, P or K). Examples include Urea (46-0-0), Calcium ammonium nitrate or CAN (27-0-0), and Triple superphosphate or TSP (0-46-0).

Straight fertilizers are economical for addressing the shortage of a single macronutrient which is considered as most limiting.

Some straight fertilizers can be easily blended to meet the nutrient demands of a particular field or crop.

### *Complete fertilizers*

These contain all of the major nutrients. An example is NPK fertilizer (15-15-15).

### *Incomplete fertilizers*

These contain only two of the major nutrients. An example is Diammonium phosphate or DAP (18-46-0), which contains only N and P.

### *Bulk blend fertilizers*

These are a physical mixture of two or more fertilizers. Different combinations of dry fertilizers are mixed to meet specific crop and soil conditions.

Bulk blends are adjusted to differing ratios of nutrients for individual crop and soil conditions.

Bulk blends are popular for their lower cost because the lowest costing fertilizer materials can be combined using inexpensive materials. However, not all solid fertilizers are compatible for mixing.

The individual fertilizer components must be chemically and physically compatible for mixing and storing.

Care is also required when handling bulk blends to avoid separation (segregation) of the individual components during handling and spreading.

### *Compound fertilizers*

These fertilizers contain two or more nutrients that are chemically combined within a single particle. Each fertilizer granule therefore contains a mixture of nutrients.

Compound fertilizers provide a uniform distribution of nutrients from each particle.

Compound fertilizers are easier to handle or apply. They offer simplicity in making fertilizer decisions where application of multiple nutrients is commonly required.

*Compound fertilizer granule types (cross-section)*

**Table 2: Properties of common fertilizers, their agricultural use and management.**

| Fertilizer | Properties | Agricultural uses | Management |
|---|---|---|---|
| **Calcium ammonium nitrate (CAN)** | - Contains 27% N; also supplies small amounts of Ca<br>- Grey or light brown in colour depending on the coating used | - Can be used as a basal source of N but is mainly used as a top-dressing fertilizer<br>- Most suitable N fertilizer for semi-arid regions | - Should be stored in a closed dry room<br>- Must be covered with soil at application |
| **Urea** | - Contains N only at 46% N<br>- Most concentrated solid N-supplying fertilizer<br>- White in colour with round granules<br>- Usually has a lower cost per unit than other N fertilizers<br>- Highly water soluble<br>- Hygroscopic (readily takes up and retains moisture) | - Good for topdressing | - Must be covered by soil at application to avoid volatile losses of ammonia to the air<br>- Should be incorporated it into the soil immediately after application<br>- Should be packed in moisture proof bags and well stored |
| **Ammonium sulphate** | - Contains 21% N and 23% S<br>- Usually white in colour with small sugar like granules | - Very useful where there is need for both N and S<br>- Preferred for use in irrigation systems such as rice systems where nitrate-based N fertilizers such as CAN are not suitable due to denitrification losses under water logged conditions<br>- Useful in increasing the effectiveness of post-emergence herbicide sprays in weed control<br>- Can be applied at sowing but best suited for top dressing after crop emergence | - It should not be applied in highly acid sulphate soils due to risk of sulphide injury<br>- Should be incorporated into soils upon application to avoid losses |
| **Single superphosphate (SSP)** | - Contains 16 to 20% of $P_2O_5$, 12% of S and 18 to 21% Ca<br>- Is grey ash in appearance with good storage qualities | - Good source of P, S and Ca | - Requires no special handling procedures<br>- Phosphorus does not move fast with water in soil, and so should be applied near root zone of plants |
| **Triple superphosphate (TSP)** | - Contains 46% $P_2O_5$ and 15% Ca<br>- The most concentrated form of straight P fertilizer<br>- Soluble in water<br>- Usually grey in colour with large granules | - Is suitable on most soil types<br>- In addition to P, it also supplies calcium | - It contains traces of free phosphoric acid hence must be properly packed<br>- Should be applied at the right rate, time and well covered to minimize losses to water bodies through surface runoff<br>- Does not move fast in soil hence should be applied near root zone of plants |
| **Diammonium Phosphate (DAP)** | - Incomplete compound fertilizer<br>- Contains 18% N and 46% $P_2O_5$<br>- Most widely used P fertilizer<br>- Usually dark brown with large round granules<br>- Highly soluble and dissolves quickly in soil to release plant-available phosphate and ammonium | - Suitable for basal supply of N and P | - Should be well stored under dry conditions<br>- Avoid placing high concentrations of DAP near germinating roots to avoid damage to seedlings and plant roots |
| **NPK** | - Complete compound fertilizer<br>- Available in different compositions with varying amounts of N, P and K as per region- or crop-specific nutrient requirements | - Suitable for basal supply of N, P and K | - Should be well stored under dry conditions<br>- Care should be taken to confirm nutrient contents as per the label and composition of NPK fertilizers vary compared to those of other common fertilizers which are usually constant |

# Examples of Common Fertilizers






# 6. NUTRIENT UPTAKE AND RIGHT SOURCE

Nutrients need to be in their plant-available forms for plant uptake to occur.

Nutrients are only taken up by roots when they are dissolved in the soil water. Insoluble nutrients are not immediately useful for plant nutrition.

Since plant roots can only acquire nutrients that are dissolved in water, their solubility is an important consideration for plant nutrition. Therefore, the total nutrient content of a soil does not always reflect the soluble nutrient supply available for uptake.

Factors that restrict root growth will also reduce nutrient uptake. For example, soils that are cold, dry, acidic, or compacted may all result in reduced nutrient uptake.
Plants mostly take up inorganic forms of nutrients, and the source of the nutrient makes no difference during uptake by the root or for plant growth. For example, nitrate comes from many sources in the soil, but the plant does not distinguish between them (**Fig. 4**).

Once taken up by the plant, the nutrient source is no longer important. Addition of organic matter can change soil properties, but the nutrients that are mineralized (i.e., P, S and micronutrients) are the same as those from fertilizer.

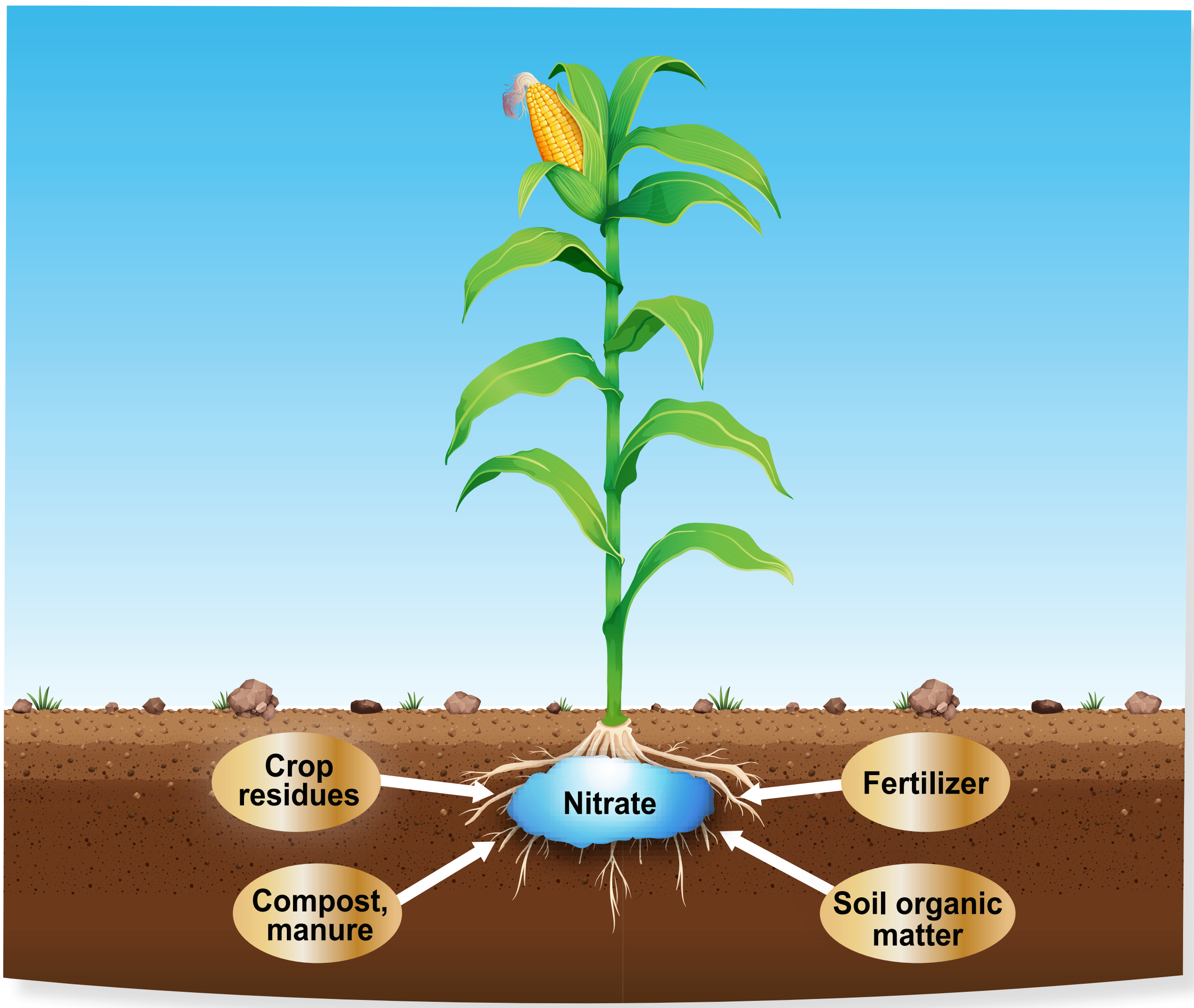



**Figure 4.** Once in the soil, the source of nitrate makes no difference during uptake by roots for plant growth.

# 7. KEY CONSIDERATIONS FOR RIGHT SOURCE

There is no one "right source" for every soil and crop condition. Each crop, soil and farmer has different needs and objectives. When deciding on the right source, a variety of local and site-specific factors must be considered. These individual economic, production and site-specific issues will be different for each farmer and perhaps different for separate fields too. The factors to consider include:

- **Consider the rate of application:** Different fertilizers and organic resources contain different types of nutrients and at different concentrations. For example, fertilizers usually contain higher concentrations of nutrients such as N compared to organic resources. Therefore, when high nutrient rates are desired, fertilizers may serve as a better source compared to organic resources.

- **Consider time of application:** Different nutrient sources release nutrients at different rates. For example, organic resources such as manure release nutrients slowly compared to fertilizers. Therefore, where nutrients are required to be applied several weeks before planting, organic resources may serve as the right nutrient source whereas fertilizers would be the right nutrient source where application is required at planting time.

- **Consider the place of application:** Depending on where nutrients are required to be applied, different sources may serve as the right source. For example, for foliar applications of micronutrients, fully soluble straight micronutrient sources would serve as the right source. When field application of micronutrients is required, granular compound fertilizers containing micronutrients would be the appropriate source.

- **Soil physical and chemical properties:** For example, avoid nitrate application in flooded soils or surface application of urea on high pH soils.

- **Nutrient interactions:** Application of one nutrient can affect availability or uptake of another nutrient. For example, N application increases P uptake.

- **Beneficial versus potential harmful effects:** Most nutrients often have an accompanying nutrient ion that may be beneficial, neutral, or harmful to the crop. For example, the chloride (Cl) that accompanies K in muriate of potash is beneficial to maize but harmful to crops such as tobacco.

- **Fertilizer availability:** Ensure that recommended sources are available to the farmer. It is not practical to recommend fertilizers that are not available in a farmer's area.

- **Cost of Source:** Sources that give best value for money in terms of kilograms of nutrients supplied per unit cost offer best value.

- **Nutrient availability:** Ensure that the selected source matches nutrient release with peak periods of plant demand.

- **Balanced Nutrition:** Avoid focusing only on macronutrients, although they are required in the largest quantity.

- **Other soil conditions:** Correct other problems that may limit nutrient uptake, such as acidity, compaction or salinity.

# Photo Gallery

*Effects of phosphorus-limiting conditions on maize growth in the foreground as demonstrated by the stunted maize growth and phosphorus-deficiency symptoms, compared with maize growth under sufficient phosphorus-supply conditions.*

*Effects of potassium-limiting conditions on maize growth in the foreground as demonstrated by the weak maize growth and potassium-deficiency symptoms, compared with maize growth under sufficient phosphorus-supply conditions.*

*Benefits of applying the right source as demonstrated by good maize growth on the left compared with poor maize growth under no nutrient's application in under low soil fertility conditions.*

# Notes

# Notes

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# Notes

# Module 1: Right Source Quiz

1. Which are the 4R rights of fertilizer management?

   a) Right fertilizer, right seed, right time, right place.
   b) Right time, right source, right farm, right place.
   c) Right source, right rate, right time, right place.
   d) Right source, right rate, right time, right price.

2. What does the right source mean?

   a) Applying the right amount of fertilizer and organic nutrient resources.
   b) Applying fertilizers and organic resources at the right time.
   c) Applying fertilizers and organic resources in the right place.
   d) Applying the correct fertilizer and organic nutrient resources.

3. Which of the following is one of the core scientific principles that define right source?

   a) Apply only plant-available forms of nutrients.
   b) Suit soil physical and chemical properties.
   c) Avoid applying associated elements.
   d) Ignore blend compatibility.

4. An element is considered essential to plant growth if

   a) The soil contains only small amounts of it.
   b) Plants require it in its elemental form.
   c) It is capable of being taken up by plants.
   d) All plants require it to complete their life cycle.

5. Which one of the following is not a macronutrient?

   a) Nitrogen
   b) Calcium
   c) Zinc
   d) Potassium

6. Which one of the following is not a micronutrient?

   a) Iron
   b) Magnesium
   c) Boron
   d) Copper

7. Which one of the following is a straight fertilizer?

   a) DAP
   b) UREA
   c) CAN
   d) NPK

8. Compound fertilizers can be useful for

   a) Single-nutrient applications.
   b) Supplying differing ratios of nutrients to meet specific needs.
   c) Eliminating potential segregation of nutrients.
   d) Supplying macronutrients without micronutrients.

9. What are the nutrient contents of a fertilizer labeled as 10-23-12-5S?

   a) 10% N, 10% P, 10% K and 5%S
   b) 10% N, 23% P, 12% K and 5%S
   c) 10% N, 23% P, 10% K and 5%S
   d) 10% N, 10% P, 10% K and 0.5%S

10. What would be the proper labeling for a fertilizer that contains 7% Sulphur, 13% Phosphorus, 12% Nitrogen and 15% Potassium to the nearest decimal?

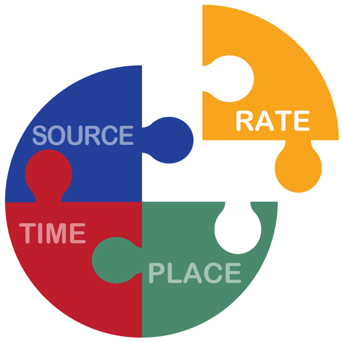
    a) 7-13-12-15S
    b) 7S-30P-12N-15K
    c) 12N-30 $P_2O_5$-18 $K_2O$-7S
    d) 12-30-18-7S

**For the answers, take the on-line quiz at:**
https://www.apni.net/courses/4rs-for-extension-agents/

# 4R NUTRIENT STEWARDSHIP GUIDEBOOK

## LEARNING MODULES FOR EXTENSION AGENTS

## MODULE 2
# RIGHT RATE




**RIGHT RATE:**

SUPPLYING GROWING CROPS WITH THE RIGHT AMOUNT OF NUTRIENTS FOR HEALTHY GROWTH AND DEVELOPMENT.

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4R Solution

# 1. SCIENTIFIC PRINCIPLES BEHIND RIGHT RATE

Once the right source of nutrients is determined, it should provide the required plant nutrients in sufficient quantities, balanced proportions, available forms, and at the time when plants require them most. Applying the right rate of the selected source of nutrients ensures that required plant nutrients are supplied in sufficient and balanced proportions in line with the crop's nutrient uptake requirements.

Ensuring the right rate of fertilizer application is important as under- or over-application of a particular nutrient may affect crop production, incomes, and soil health. For example, under-application of nutrients can result in low yields, poor quality of produce, and greater depletion of soil fertility. On the other hand, over-application of nutrients can result in reduced profits, pollution of soil and water systems, and lodging in crops such as rice, teff, and wheat.

To determine the right rate, the following scientific principles should be considered:

- Consider source, time, and place of nutrient application.
- Assess plant nutrient demand.
- Assess soil nutrient supply.
- Consider all available nutrient sources.
- Predict fertilizer use efficiency.
- Consider impact on soil fertility.
- Consider the economics of nutrient application rates.

## 1.1 Consider source, time, and place of nutrient application

The source, time, and place of nutrient application all have an influence on the right rate of fertilizer application. For example, where a slow-release source is selected, a higher nutrient application rate may be recommended to ensure sufficient quantities of nutrients are plant-available at the time when plants require them, as nutrients are expected to be released slowly.

The timing of fertilizer application also has an implication on the right rate. Where several fertilizer applications are planned over the course of the growing season, lower nutrient application rates per application can be recommended compared to where only one application is planned, as split fertilizer applications ensure more efficient use of applied nutrients.

Fertilizer placement also has an influence on the right rate of nutrient application, as different placement methods result in differences in quantities of nutrients available for uptake by crops. For example, spot application of fertilizer requires lower nutrient application rates compared to broadcasting, as spot application results in zones of high nutrient concentration close to the plants' roots as compared to broadcasting where nutrients are spread more evenly across the soil surface.

## 1.2 Assess plant nutrient demand

Nutrient demand refers to the total amount of nutrients that will need to be taken up by the crop during the growing season for good growth and yield to be attained.

Assessment of the nutrients required by a crop helps to match nutrient supply with plant nutrient demand, and allows for determination of the right nutrient application rate. Different crops require different amounts of nutrients for healthy growth and maturity. Different varieties of a crop may also differ in their nutrient requirements and response to fertilizer application.

The quantity of nutrients required also depends on the crop yield targeted. High target yields require higher nutrient application rates as plants need to take up more nutrients to produce high yields. In general, primary macronutrients (N, P and K) are required in the greatest amounts as compared to secondary macronutrients or micronutrients.

The total amount of nutrients required by a specific crop can be estimated by multiplying a farmer's target yield for that specific crop by the amounts of nutrients removed for each ton of yield. The higher the target yield, the greater the nutrient requirement will be.

The target yield selected for a particular crop should however be realistic in relation to the attainable yield under good crop and nutrient management for the same crop variety in that particular location.

A simple approach towards setting a target yield is to choose a yield value that is somewhere between the average yield and the highest yield that has been achieved recently in that specific field, or in surrounding fields with similar characteristics.

**Table 1:** Nutrient removal rates by different crops at different yield levels.

| Crop | Grain yield, t/ha | Nutrient removed, kg/ha | | |
|---|---|---|---|---|
| | | N | $P_2O_5$ | $K_2O$ |
| Maize | 1 | 24 | 12 | 18 |
| | 2 | 48 | 24 | 36 |
| | 4 | 96 | 48 | 72 |
| | 6 | 144 | 72 | 108 |
| Rice | 2 | 32 | 17 | 50 |
| | 4 | 64 | 34 | 100 |
| | 6 | 98 | 50 | 150 |
| Wheat | 2 | 48 | 18 | 44 |
| | 4 | 96 | 36 | 88 |
| | 6 | 144 | 54 | 132 |
| Teff | 1 | 25 | 12 | 20 |
| | 2 | 50 | 24 | 40 |
| | 3 | 75 | 36 | 60 |
| Sorghum/Millet | 1 | 20 | 12 | 30 |
| | 2 | 40 | 24 | 60 |
| | 4 | 60 | 48 | 120 |
| Soybean | 1 | 80 | 18 | 40 |
| | 2 | 160 | 36 | 80 |
| | 3 | 240 | 54 | 120 |
| Beans | 1 | 65 | 15 | 35 |
| | 2 | 130 | 30 | 70 |
| | 3 | 195 | 45 | 105 |
| Groundnuts | 1 | 70 | 12 | 28 |
| | 2 | 140 | 24 | 56 |
| | 3 | 210 | 36 | 84 |

***NOTE:*** *While nutrient removal values in the above table are a good indicator of the plant nutrient needs at the respective yield levels, other factors have to be taken in place in order to determine the actual fertilizer requirement. These factors include: soil nutrient reserves, nitrogen fixation by legume crops, and losses of applied nutrients. While legumes such as soybean, beans, and groundnuts remove larger quantities of N compared to cereals such as maize, legumes require only small fertilizer N applications due to their ability to manufacture their own N through their roots.*

## 1.3 Assessing soil nutrient supply capacity

A portion of the nutrients required for plant growth can be met by what is supplied by the soil, while the rest can be supplied using fertilizer. Assessment of the soil nutrient supply capacity therefore helps to determine the amount of nutrients to be supplied using fertilizers.

Methods for assessing **soil nutrient supply include soil testing, plant sample analysis,** and **fertilizer response experiments.**

**Soil testing** measures the amount of nutrients available for plants to take up. The higher the level of a soil test in plant available nutrients, the larger the potential soil supply capacity, and the lower the amount of nutrients required to be supplied through fertilizers.

- Soil testing should mainly focus on plant available nutrients as these are the most important for uptake by plants.
- Soil tests should also assess other factors that affect nutrient availability such as soil pH and soil texture.
- To get the most reliable results from a soil test, soil samples should be taken before planting, but after the previous crop has been harvested.
- Where soil testing is an option, extension staff can help farmers to correctly collect, package and submit samples for analysis.
- Where possible, soil testing should be conducted every 3 to 5 years to ensure that nutrients are maintained at sufficient levels.

**Plant sample analysis** can also provide an indication of which nutrients are deficient in plants. Plant sample analysis helps to confirm a diagnosis made from visual nutrient deficiency symptoms and to also identify hidden hunger (deficiency) where no symptoms appear.

- Plant sample analysis is particularly useful for assessing the nutrient status of perennial crops such as coffee, tea, and oil palm.
- Collection, processing and analysis of plant samples is however more complicated than soil sampling and testing, and should be done with the support of researchers.

**Fertilizer response experiments** such as **Nutrient Omission Trials (NOTs)** are also useful in assessing the soil nutrient supply capacity. In such experiments, the capacity of soil in a particular field to supply a certain nutrient is assessed by comparing crop yield in a plot where that nutrient is omitted while other major nutrients are supplied, with yield in a plot where all major nutrients have been supplied.

***If crop yield in the omission plot with the nutrient under evaluation is very low compared to the plot with all nutrients supplied, then the soil supply capacity for that particular nutrient is low. Conversely, if crop yields are similar, then the soil has sufficient quantities of that particular nutrient.***

Data from recently concluded fertilizer response experiments in a particular area can be used as a general indicator of the soil nutrient supply capacity for surrounding fields under similar geographical and management characteristics. Fertilizer response experiments should however be conducted with support from researchers to ensure they are correctly set up.

**Other soil nutrient assessment methods** may be used where soil testing and plant sample analysis are not available, or affordable, to smallholder farmers. Farmers can use alternative methods such as crop production history, **visual plant deficiency symptoms,** and **knowledge of soil types** to assess soil nutrient supply capacity.

**Crop production history** can help to assess the soil nutrient capacity of a particular field. For example, soils where crops have been grown for many seasons with minimal application of fertilizer or manure can be expected to have a low soil nutrient supply capacity, while soils that receive regular applications of large quantities of high-quality manure can be expected to have a high soil nutrient supply capacity.

**Knowledge on soil types** can also be used to develop estimates of soil nutrient supply potential by assessing key factors such as soil organic matter levels and soil texture.

**Soil organic matter** contains most nutrients required for plant growth. Therefore, the higher the soil organic matter level, the higher the soil nutrient supply potential of the soil. It should however be noted that nutrients in soil organic matter exist in very small quantities, and even for soils with high soil organic matter contents, complementing nutrient supply with fertilizers is often required.

**Soil texture** is mainly determined by the proportion of clay, silt and sand contents in a particular soil. Clay-rich soils have a greater capacity to retain nutrients and soil organic matter than soils with low clay contents. Clay soils therefore generally have a greater nutrient supply potential than sandy soils.

## 1.4 Consider all available nutrient sources

When determining the right nutrient application rate, the contribution of all available nutrient sources needs to be considered. These nutrient sources include **crop residues and green manures, animal manures and composts,** and **legume crops.**

**Crop residues** contain substantial quantities of plant nutrients. Recycling of such residues back to the soil increases the nutrient content of soil.

**Compost and animal manures** can also help to increase soil nutrient content. However, it can be difficult to transport these resources away from the local source.

*The quantity of nutrients in crop residues and other organic resources can vary widely, and is substantially lower than that supplied by inorganic sources such as mineral fertilizers. Average nutrient contents for some organic resources commonly available in smallholder farming are listed in the* ***Table 2****.*

**Table 2:** Average nutrient contents for organic resources commonly available to smallholder farming systems.

| Crop material | % N | % P | % K |
|---|---|---|---|
| Groundnut (leaves) | 3.0 | 0.17 | 2.4 |
| Soybean (leaves) | 3.6 | 0.15 | 2.4 |
| Beans (leaves) | 2.9 | 0.30 | 2.8 |
| Cowpea (leaves) | 2.9 | 0.11 | 2.1 |
| Rice (leaves/stems) | 1.0 | 0.06 | 1.4 |
| Maize (leaves/stems) | 0.9 | 0.07 | 0.7 |
| Wheat (leaves/stems) | 0.6 | 0.07 | 1.1 |
| Teff (leaves/stems) | 0.6 | 0.12 | 1.2 |
| **Manure type** | **% N** | **% P** | **% K** |
| Cow | 1.2 | 0.23 | 0.9 |
| Goat | 1.3 | 0.39 | 0.8 |
| Chicken | 2.5 | 1.58 | 3.3 |

**Legume crops and green manures** can contribute significant amounts of N to growing crops and should also be considered when evaluating all available nutrient sources. Part of the N in grain legume residues is manufactured, or "fixed", within the roots of the legume crops and is not removed from the soil.

Therefore, when grain legumes are retained in the field, they provide N for the crop planted in the following season. Where cereal crops like maize and wheat are grown in rotation with a legume, adjustments of the recommended N application rate can be made to account for the contribution of N supplied by the legume crop.

However, the amount of N manufactured by different legumes varies widely with some having low N manufacturing potential and may only have a small N contribution to the soil. Some of the factors that influence potential N contribution by grain legumes include: **N-fixing capacity, inoculation,** and **nutrient management.**

**Nitrogen-fixing capacity** of legumes can be low (beans), medium (groundnut), and high (soybean, cowpea, pigeon pea).

**Inoculation** with specific rhizobia is required for some legumes such as soybean. If such legumes are not inoculated, the amount of N that is manufactured will be small.

**Nutrient management** of legumes requires adequate quantities of P, K, and secondary nutrients for good N-fixation and plant growth to occur.

***Soybean and other legumes commonly have a positive influence on soil N fertility and crop yield through the recycling of their residues and conservation of soil N.***

## 1.5 Predicting fertilizer use efficiency

**Fertilizer use efficiency (FUE)** refers to the effectiveness with which plants use applied fertilizer. The more efficiently crops utilize fertilizer, the lower the application rate required for good growth and development. Determining how much of applied fertilizer is recovered by the crop is therefore a major factor in determining the right nutrient application rate. Even with best management practices based on 4R Nutrient Stewardship, the amount of the applied fertilizer utilized by the crop will be always less than 100%. Loss of nutrients supplied through fertilizers mainly occurs through **leaching, soil fixation, microbial immobilization,** and **volatilization.**

**Leaching** washes away water-soluble nutrients from the soil due to rainfall or irrigation water.

**Fixation** is a process where applied nutrients react with other minerals in the soil to form insoluble compounds that are unavailable to plants. For example, P-fixation is common in low pH soils.

**Microbial immobilization** occurs when microbes convert applied nutrients from inorganic to organic forms (through incorporation into their cells), making nutrients unavailable for uptake by crops.

**Volatilization** occurs when applied N is lost into the atmosphere in form of gaseous ammonia ($NH_3$).

Fertilizer application practices and local area conditions such as weather and soil-type influence how crops utilize applied fertilizers. For example, application of N-based fertilizer followed by very heavy rainfall results in a higher risk of N loss through leaching and erosion.

Application of 4R practices helps to improve the amount of fertilizers utilized by crops by minimizing the loss of nutrients through the nutrient loss processes described above.

Fertilizer use efficiency can be estimated through the use of **agronomic efficiency (AE)**.

**Agronomic efficiency** refers to the amount of yield increase per unit of fertilizer applied. This can be calculated as the number of bags of grain that are produced for each bag of fertilizer. AE is calculated as follows:

**AE = (Y – Y0) / F**

Where:

1. Y = crop yield with fertilizer applied;
2. Y0 = crop yield with no fertilizer applied; *and*
3. F = amount of fertilizer nutrient applied.

**Example:** If a farmer obtains 5000 kg of maize grain in a section of a farm where 150 kg of N plus other nutrients were applied, and 2000 kg of maize in a similar-sized section of the same farm where other nutrients were supplied but no nitrogen was applied, the agronomic efficiency for N (AEN) will be:

$$AE_N = (Y_N - Y0_N) / F$$
$$AE_N = (5000 - 2000) / 150$$
$$AE_N = 20$$

Once AE has been determined, efforts can be made to increase fertilizer use efficiency through adoption of appropriate 4R practices aimed at minimizing loss of applied nutrients and enhancing uptake of nutrients applied.

Agronomic efficiency can also be used to estimate the amount of nutrients to be supplied through fertilizer application so as to achieve a certain yield target. If current yield and target yield are known, the amount of fertilizer can be calculated as:

**AF = (Y – Y0) / AE**

Where:

1. Y = expected crop yield with fertilizer applied;
2. Y0 = crop yield with no fertilizer applied; *and*
3. AE = agronomic efficiency.

**Example:** If a farmer wants to obtains 6000 kg of maize grain in a field where agronomic efficiency of nitrogen ($AE_N$) is 15, and yield without N is 2000 kg, the amount of fertilizer to be applied shall be:

$$AF_N = (Y_N - Y0_N) / AE_N$$
$$AF_N = (6000 - 2000) / 20$$
$$AF_N = 200 \text{ kg}$$

***NOTE:*** *The target crop yield should not surpass the locally attainable yield under best crop and nutrient management practices.*

## 1.6 Considering impact on soil fertility

Plant nutrition affects the quality of the soil in several ways. First, when plant nutrients are present at levels that support good crop growth, the amount of organic carbon contributed by plants to the soil is greater than when plant growth is limited by nutrients. Secondly, many nutrients are retained in soils, and the rate of their addition influences the levels of their availability in the soil over time. For example, P and K are retained in the soil and repeated addition over time can influence their plant availability.

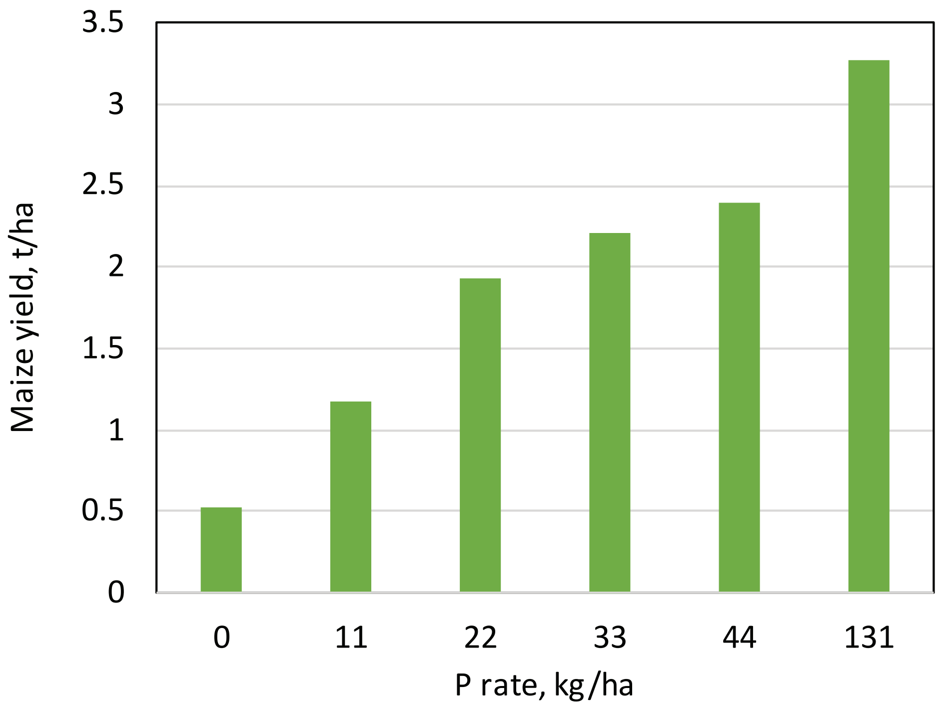
- If soils have high levels of these nutrients (good soil fertility), nutrient application rates can be **less** that crop removal.
- Conversely, if soils have low levels of these nutrients (low soil fertility), nutrient application should supply **more** nutrients than crop removal. When soils have the desired levels of nutrients, application rates should **maintain** or match the amounts removed by crops.
- For P- or K-fixing soils, additional amounts of P or K should be applied to compensate for fixation. It is recommended to test soils every 3 to 5 years for retained nutrients such as P and K, to determine if P and K application rates should exceed, equal, or be less than the amount of nutrients removed by crop harvest.

## 1.7 Considering the economics of nutrient application rates

In order to align with a farmer's goal to maximize income from crop production, nutrient application rates should be most profitable in terms of fertilizer nutrient application costs, and the added income resulting from the extra yield generated from the nutrient application. This rate is referred to as the **economic optimum nutrient rate (EONR)**, and is defined as the nutrient application rate that results in the greatest monetary return to the applied nutrient from the current crop.

### Key Points on EONR

- The EONR is usually less than the **agronomic optimum nutrient rate (AONR)** which is the minimum rate that results in maximum crop yield.
- The EONR declines if input costs increase and commodity prices remain stable. On the other hand, EONR increases if commodity prices increase while input prices remain stable.
- Aiming to achieve EONR is a recommended approach for nutrients like N and S, which are mobile in the soil and are not retained year-to-year.
- For nutrients that are retained in the soil such as P and K, benefits of nutrient application are long-term in nature. Costs for P and K application can therefore be distributed over several seasons. For example, P and K applications aimed at building soil fertility are usually above the EONR for a single season crop response, but may become economical over a longer time period when the responses in the subsequent seasons are considered.



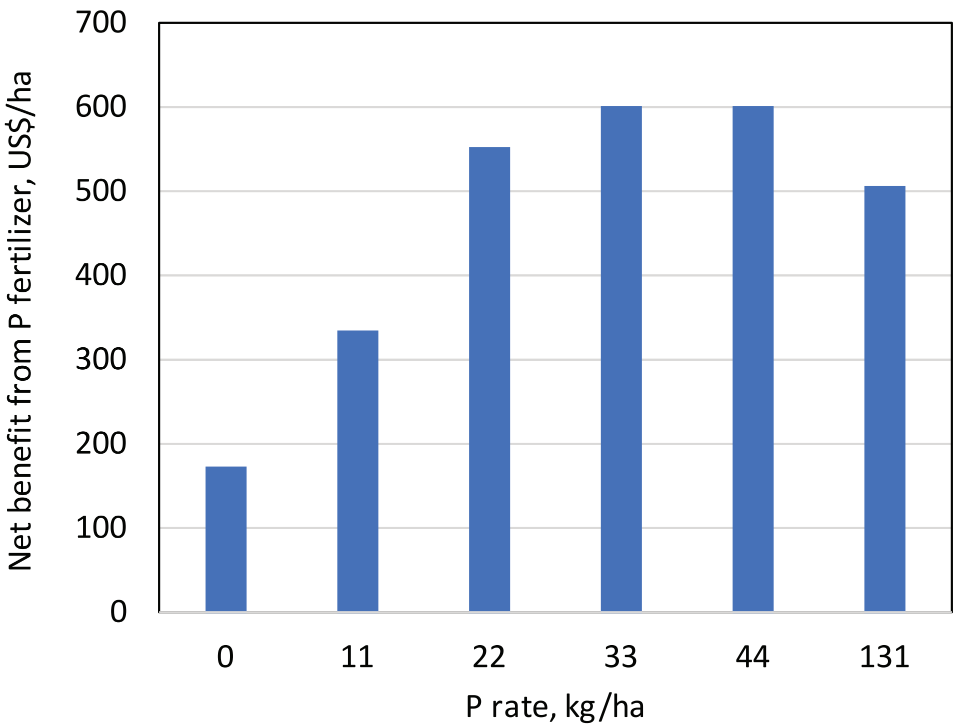




**Figure 1.** Crop yield response data in the top chart demonstrates that a P application rate of 131 kg/ha resulted in the largest maize yield; however, the bottom chart indicates that application of 33 kg/ha was most profitable.

### *Practical examples: Calculating fertilizer requirement from fertilizer recommendations*

The amount of fertilizer to be applied in a particular field is calculated by considering the recommended nutrient application rate in kg/ha, the size of the field, and the nutrient content of the available fertilizer. Fertilizers are usually supplied in 50 kg bags, farmers can therefore determine the number of fertilizer bags required by dividing the total amount of fertilizer required by 50 kg.

## Nitrogen fertilizer calculations

A farmer is advised to apply 40 kg N/ha to his maize crop during top-dressing using calcium ammonium nitrate (CAN) as the fertilizer source.

1. How many kg of CAN should he apply in his field which is 2 ha in size?
2. How many bags of CAN should he buy from a fertilizer dealer?

## Solution:

- The farmer is advised to apply 40 kg N/ha but CAN fertilizer only contains 27% N. Therefore, the amount of CAN required is:

  = 40 kg/ha ÷ 0.27 = 148 kg CAN/ha

- Since the farmer's field is 2 ha in size, the amount of CAN required to supply 40 kg N/ha to the field is:

  = 148 kg x 2 = 296 kg of CAN

- Lastly, since 1 bag of CAN fertilizer weighs 50 kg, the amount of bags needed is:

  = 296 kg CAN ÷ 50 kg = 6 bags

- Therefore, 6 bags of CAN will be required.

## Phosphorus fertilizer calculations

A farmer is advised to apply 20 kg P/ha to his 5-acre maize field.

**1** How many bags of Triple Super Phosphate (TSP) should he buy?

### Solution:

- The P content in fertilizer is usually labelled in the oxide ($P_2O_5$) form. Therefore, the first step is to convert the recommendation from % P to % $P_2O_5$ by multiplying 2.3 (the conversion factor).

  = 20 kg P/ha x 2.3 = 46 kg $P_2O_5$/ha

- Next, convert the size of the farmer's field from acres to hectares (1 ha = 2.47 acres).

  = 5 acres ÷ 2.47 = 2.02 ha

- Therefore, the total amount of $P_2O_5$ required is:

  = 46 kg $P_2O_5$ x 2.02 ha = 93 kg $P_2O_5$

- Since TSP contains 46% $P_2O_5$, the amount of TSP required to supply 93 kg $P_2O_5$ is:

  = 93 kg $P_2O_5$ ÷ 0.46 = 202 kg of TSP

- Lastly, since 1 bag of TSP weighs 50 kg, the number of bags required to supply 202 kg TSP is:

  = 202 kg TSP ÷ 50 kg = 4 bags

- Therefore the farmer should buy 4 bags of TSP.

## Potassium fertilizer calculations

After soil testing, a farmer is advised to apply 50 kg K/ha to his 0.5 ha banana field.

**1** How much muriate of potash (MOP) should he apply?

### Solution:

- The farmer is advised to apply 50 kg K/ha. Since the K content in fertilizer is usually labelled in the oxide ($K_2O$) form, the first step if to convert the recommendation from % K to % $K_2O$ by multiplying 1.21 (the conversion factor).

  = 50 kg K/ha x 1.21 = 60.5 kg $K_2O$/ha

- Next, determine the amount of $K_2O$ required for the farmer's 0.5 ha field

  = 60.5 kg $K_2O$/ha x 0.5 ha = 30.3 kg $K_2O$

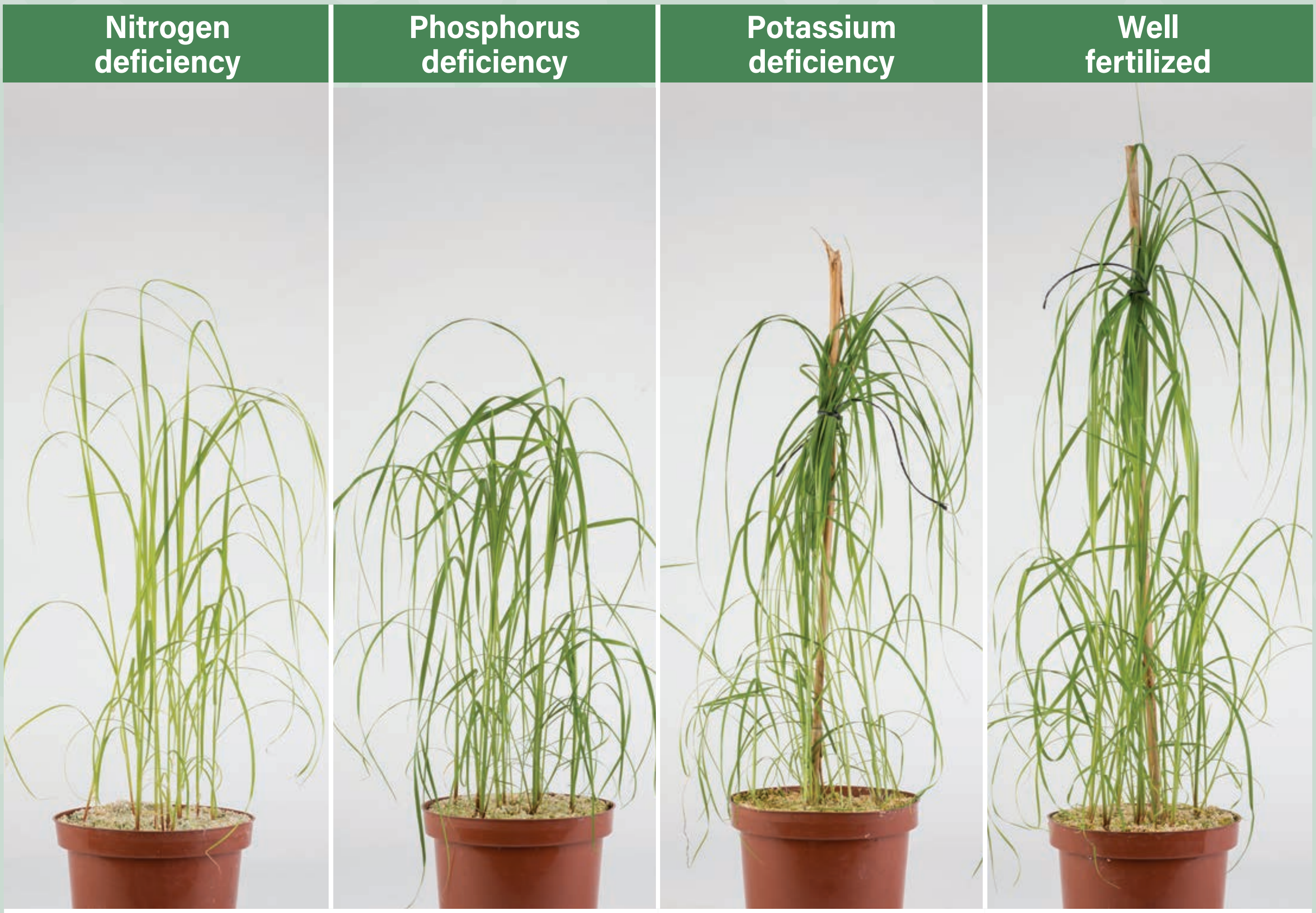
- Since MOP is 60% $K_2O$, the amount required to supply 30.3 kg $K_2O$ is:

  = 30.3 kg $K_2O$ ÷ 0.6 = 50.5 kg MOP

- Therefore, the farmer should buy and apply one 50 kg bag of MOP.

# Nutrient Deficiency Symptoms


***Deficiency symptoms*** *of N, P and K (left-to-right) in maize (top row), rice (middle row), wheat (bottom row).*




***Deficiency symptoms of N, P and K** (left-to-right) in teff. Images courtesy CFPN and IPI - https://www.cfpn.center/ Fanosie Mekonen/Natalie Cohen Kadosh photographers.*

# Notes

# Notes

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# Notes

# Module 2: Right Rate Quiz

1. What does the right rate of fertilizer application refer to?
   a) Supplying crops with the available fertilizer quantity.
   b) Supplying crops with the right type of fertilizer.
   c) Supplying crops with manure and fertilizer.
   d) Supplying crops with the right amount of nutrients for healthy growth and maturity.

2. Which one of the following is an important consideration when determining the right rate of nutrient application?
   a) Considering the size of the field.
   b) Assessing the capacity of the soil to supply nutrients.
   c) Considering the size of fertilizer bags.
   d) Considering the expected harvest time.

3. Which of the following crops would require the highest application of fertilizer nitrogen?
   a) Groundnut
   b) Maize
   c) Soybean
   d) Beans

4. Which of the following crops removes the largest amount of nitrogen from the soil for every ton of yield?
   a) Groundnut
   b) Maize
   c) Soybean
   d) Beans

5. In the long-term, soil available nutrients are maintained at optimum levels in most soils when the amount of nutrient applied
   a) Exceeds crop nutrient uptake.
   b) Is less than crop removal.
   c) Equals crop uptake.
   d) Equals crop removal.

6. Accounting for nutrient contribution from legumes grown when determining the right nutrient rate is important because
   a) Legumes can fix large amounts of P and K.
   b) Crops following a legume don't need any N.
   c) Legumes can fix large amounts of N.
   d) Soil microbes fix N for all crop species.

7. Which of the following is not an important factor influencing the potential nitrogen contribution by grain legume crops?
   a) Nutrient management.
   b) The cereal crop rotated with the legume crop.
   c) The nitrogen fixing capacity of the legume.
   d) Inoculation with rhizobia.

8. During top dressing, a farmer is advised to apply 40 kg nitrogen per hectare to his maize crop growing in a 3-hectare field. How much calcium ammonium nitrate (CAN) fertilizer should he apply?
   a) 444 kg
   b) 148 kg
   c) 296 kg
   d) 40 kg

9. A farmer obtained forty 90 kg bags of maize grain from a half hectare field he supplied with three 50 kg bags of compound fertilizer and ten 90 kg bags of maize grain from another half hectare where he did not apply any fertilizer. What fertilizer use efficiency (FUE) did he achieve?
   a) 2700
   b) 18
   c) 72
   d) 24

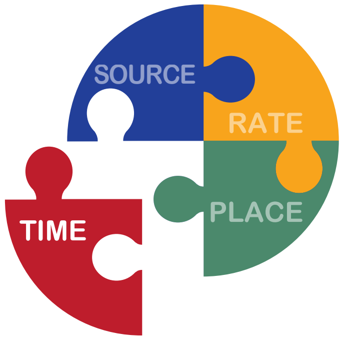
10. In a nutrient omission experiment, wheat grain yield in the NPKS treatment plot was 3 ton per hectare, while a yield of 1.5 ton per hectare was obtained in the treatment plot with PKS applied. Given that the amount of N applied was 100 kg, calculate the nitrogen application rate required to obtain target wheat yield of 4.5 ton per hectare.
    a) 45
    b) 150
    c) 15
    d) 200

**For the answers, take the on-line quiz at:**
https://www.apni.net/courses/4rs-for-extension-agents/

# 4R NUTRIENT STEWARDSHIP GUIDEBOOK

## LEARNING MODULES FOR EXTENSION AGENTS

## MODULE 3
## RIGHT TIME




**RIGHT TIME:**

MATCHING NUTRIENT APPLICATION WITH THE TIMING OF PLANT NUTRIENT UPTAKE.

AFRICAN PLANT NUTRITION INSTITUTE

4R Solution

# 1. SCIENTIFIC PRINCIPLES BEHIND RIGHT TIME

After the right source and right rate of nutrient application have been determined, nutrients should be applied so as to match the timing of plant uptake. Matching nutrient application with plant uptake ensures that plants can access nutrients during periods when they most require them. This ensures efficient use of applied nutrients, and results in optimal crop growth and yield benefits.

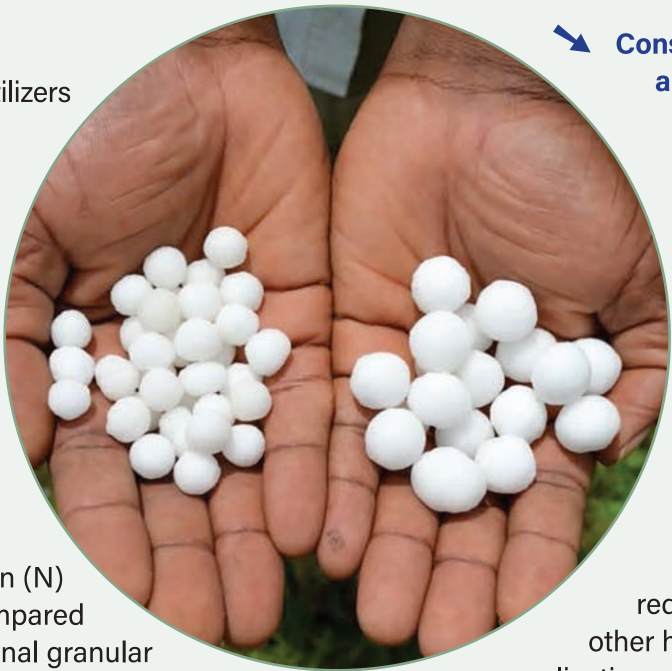
To determine the right time, the following scientific principles should be considered:

- Consider source, rate, and place of nutrient application.
- Assess timing of plant nutrient uptake.
- Assess dynamics of soil nutrient supply.
- Assess the risk of soil nutrient losses.
- Evaluate logistics of field operations.

## 1.1 Consider source, rate, and place of nutrient application

**Consider the source of nutrients:** Nutrient sources differ in their rate of nutrient release, and this has an influence on the right time of nutrient application. For example, organic nutrient sources such as manure release nutrients slowly compared to mineral sources such as fertilizer. Therefore, when using organic sources as the nutrient source for annual crops such as maize, their application should be done well in advance of the planting time (e.g., 2 to 3 weeks before planting) to ensure good synchrony between the release of nutrients from the applied manure, and plant uptake by the growing crop. On the other hand, when using mineral fertilizers as the source of nutrients, their application can be at the time of planting or a few days after emergence.

Slow release fertilizers can extend the period of time that nutrients are made plant-available compared to conventional fertilizer types. For example, urea fertilizer in the form of urea super granules releases nitrogen (N) more slowly compared to the conventional granular urea fertilizer. For crops such as rice, the use of urea super granules can reduce the frequency of applications required to provide sufficient N. Therefore, fertilizer application timings should be adjusted based on the selected form of mineral fertilizer.



***Urea super granules** release N more slowly compared to conventional urea fertilizer.*

**Consider rate of nutrient application:** The planned rate of nutrient application has an influence on the right time of nutrient application. High nutrient application rates of mobile nutrients such as N may require more than one application timings in order to split the total amount into smaller amounts that match plant demand. Split applications are a way to manage nutrient losses and enhance nutrient use efficiency. For example, where the planned N application rate for cereals such as maize, rice, wheat, and teff is greater than 40 kg N/ha, it is recommended to split the application so that part of the N fertilizer is applied as a basal application at the time pf planting, and the rest as a top dressed application after the crop is growing. This practice enhances the recovery of applied N fertilizer by plants, and minimize N losses.

**Consider place of application:** The selection of the nutrient application method has an influence on the proper timing of nutrient application. For example, foliar fertilizer applications allow for rapid uptake of nutrients by plants and can therefore be applied at the exact time that plants require nutrients. On the other hand, soil based fertilizer applications require more time for the nutrients to become both plant available and physically accessible to be taken up by plants. As a result, applications to soil should be applied a few days in advance of the desired uptake period.

## 1.2 Assessing timing of plant nutrient uptake

Assessing crop nutrient uptake dynamics is an important component in determining the right timing of nutrient application as the rate of plant nutrient uptake is not constant throughout the season. Most crops take up nutrients slowly during the early stages of growth, with nutrient uptake increasing to a maximum during the rapid growth phase, and declining as the crop matures. This uptake pattern follows a sigmoid or "S" shaped curve (**Figure 1**).

Nutrient applications timed correctly at specific growth stages are beneficial to crop yield and the quality of the grain produced by cereal and legume crops. Particularly for cereals, application of nutrients such as N based on growth stages helps to match nutrient application with peak nutrient uptake stages. Well timed applications also help to minimize nutrient losses.

For example, in wheat and teff, application of top dress N fertilizer at early tillering stage helps to enhance N uptake and increase yields. For rice, split applications of top dress N fertilizer at tillering stage and at panicle initiation helps to enhance N uptake and increase yield.

For legumes such as groundnuts, additional calcium (Ca) application when groundnut pods are developing is recommended so as to ensure good seed development particularly where soils are deficient in Ca. Application of Ca fertilizers can therefore be timed to coincide with the period just before flowering.

To simplify recommendations for split N applications in cereals, recommendations for split applications are often made in terms of weeks after planting, with the number of weeks after planting selected to match with key growth stages of peak N demand. For example, split N application for maize is often recommended as:

- A third of the recommended N fertilizer rate at planting
- A third of the recommended N fertilizer rate at four weeks after planting
- A third of the recommended N fertilizer rate at eight weeks after planting

However, as crop growth and development differ based on crop variety and growing environment, care should be taken to ensure that time-based recommendations are well in line with specific growth stages for a given crop variety and growing environment.

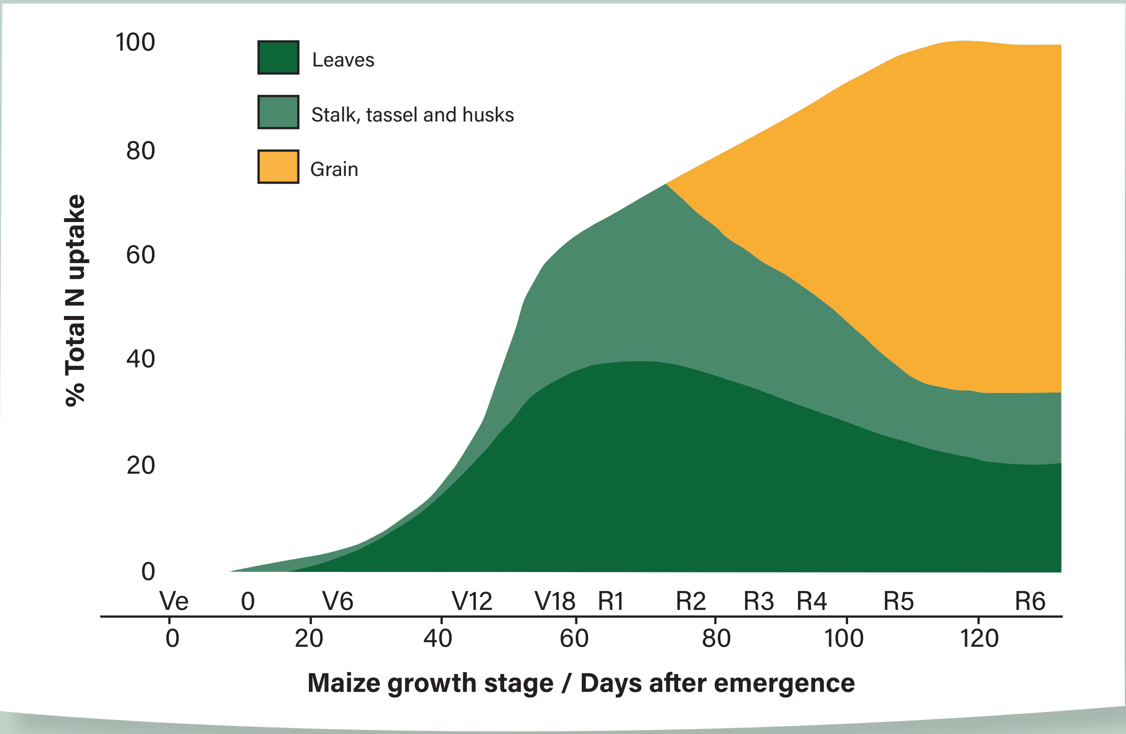



**Figure 1.** Cumulative maize N uptake divided by plant organ. Adapted from: How a Corn Plant Develops, Iowa State, University Special Report No. 48, Nov. 2008

***Maize fertilizer N application** (counter clockwise) at planting, at four weeks after planting, and at eight weeks after planting.*

## 1.3 Assessing dynamics of soil nutrient supply

Most soils have the capacity to supply at least some of the nutrient requirements of a crop. Different soils however possess different capacities to supply nutrients required by crops. In general, sandier soils store and supply less nutrients than soils with finer textures. The same is true for soils that have been cultivated for longer periods with little addition of mineral fertilizer or organic nutrient resources.

While the soil nutrient supplying capacity mainly influences decisions about the right nutrient application rate, it also has an influence on the proper timing of nutrient applications. Generally, the greater the soil's capacity to retain and supply a particular nutrient throughout the growing season, the less the need for critical timing emphasis for the application of that nutrient.

Certain soil properties such as high **phosphorus (P) fixation capacity** also strongly influence the ability of a particular soil to continuously supply plants with applied nutrients. This additionally influences decisions on the right time of nutrient application. A good understanding of the transformations of different nutrients in the soil under different soil and climatic conditions is therefore fundamental to assessing the dynamics of soil nutrient supply, and in making decisions on nutrient applications timing. For example, in many agricultural soils, large applications of P fertilizers can be effective at supplying the P needs of crops grown over several cropping seasons. In such soils, the applied P is held by the soil but remains available to crops grown in the next season. However, acidic soils that are common in high rainfall areas of Africa usually bind the P provided as fertilizer and make it unavailable to plants grown in the subsequent season. In such soils, seasonal application of P fertilizer must be done at planting to enhance uptake by plant roots.

Within a given soil, plant available N is supplied by either mineralization of soil organic matter or by residual nitrate ($NO_3^-$) and ammonium ($NH_4^+$). In arid climates, nitrate can accumulate in soils and be carried over across multiple seasons. Where rainfall is higher, nitrate is more readily removed from soils by leaching and/or denitrification. Losses of applied N are therefore often higher in regions with high rainfall, and application timings in such areas therefore need to be well timed to minimize losses. For example, top dressed N fertilizer application should not be conducted during periods of heavy rainfall or when heavy rains are eminent.

## 1.4 Assessing the risk of soil nutrient losses

Fertilizer applications based on 4R principles should aim at reducing losses of applied nutrients from the soil. Losses of applied N and P from cropping systems are generally of the greatest concern since the loss of each of these nutrients not only has negative economic impacts, but can create specific environmental problems. Understanding the loss mechanisms of each of these nutrients can help in devising application timings that can help to reduce nutrient losses from the soil.

Nitrogen can be lost through several ways including leaching whereby N in form of nitrate is washed through the soil by rain or irrigation water. Nitrogen can also be lost through surface runoff from fields, and or lost into the air as gas. Applied P is mostly lost through surface runoff, with minimal losses through leaching.

Losses of applied P from the soil are therefore best managed through right placement of fertilizer P below the soil surface. On the other hand, losses of applied N can be managed through right timing of N fertilizer applications. For example, sandy soils in high rainfall areas have a high potential for N loss through leaching. To minimize loss of applied N in such environments, application of nitrogen fertilizers should be split into several applications at low rates. Timing of nitrogen fertilizer application should also aim at avoiding periods of very heavy rainfall so as to minimize the risk of leaching losses of applied N.

## 1.5 Evaluating logistics of field operations

The logistics of fertilizer distribution, field operations, and household operations are important factors affecting decisions on right timing. It is important to consider any of these factors, which may affect the timing of fertilizer application when making decisions on the right application time. Specific considerations may include:

- The labour availability for fertilizer application and other field operations. To ensure efficient use of labour, basal fertilizer applications can be conducted during planting so as to make use of the same labour force available during planting.
- Decisions on the specific types and quantities of fertilizers to be used in a particular cropping season should also be made in good time so as to ensure timely purchase of fertilizer. For example, any planned soil or plant analysis to determine fertilizer requirements for the upcoming cropping season should be carried out well in advance.
- The timely availability of fertilizer can be a problem in many smallholder farming areas of Africa. If fertilizer is not available at the time it is required to be applied, it will not be possible to ensure the right application timing. Fertilizer should therefore be purchased well in advance to ensure that the required types and amounts of fertilizer are available for use at the right time.
- The timing of fertilizer applications should also consider weather conditions. For example, top dressing of N fertilizer should be avoided when the soils are dry, during periods of heavy rains, or when heavy rains are imminent. Nitrogen fertilizers should be applied when the soil is moist to enhance uptake by the crop. An assessment of current weather conditions should therefore be used to guide the final decision on the right time for top dressing fertilizer.

# Notes

# Notes

# Module 3: Right Time Quiz

1. What does the right time of nutrients application mean?
    a) Applying nutrients when fertilizers are available
    b) Applying nutrients during planting only
    c) Applying nutrients when deficiency symptoms occur
    d) Applying nutrients when the crop requires them

2. Which of the following is part of the core scientific principles that define right time for a specific set of conditions.
    a) Apply nutrients just before the grain-filling stage
    b) Evaluate logistics of field operations
    c) Assume slow mineralization of soil nutrients
    d) Apply nutrients just before leaching risks increase

3. Which of the following is not important when considering the right time to apply fertilizers?
    a) Consider plant spacing
    b) Consider availability of fertilizers
    c) Consider weather conditions
    d) Consider form of fertilizer available

4. When is the right time for the application of manure as a source of nutrients to a maize crop?
    a) Two weeks after planting
    b) During planting
    c) Two months before planting
    d) Two weeks before planting

5. Timing of nutrient application is most important for
    a) N
    b) P
    c) K
    d) Ca

6. In areas with high rainfall, nitrate is readily removed from soils by
    a) Leaching
    b) Nitrification
    c) Immobilization
    d) Volatilization

7. In soils with very high P fixation capacity, an appropriate timing of P application is
    a) Annually after crop emergence
    b) Annually at planting
    c) Once every two years
    d) Once every three years

8. Which one of the following is not an indicator of a soils' nutrient supply capacity?
    a) The soil's sand content
    b) The size of the farm
    c) The soils capacity to retain applied nutrients
    d) The amount of organic resources previously added

9. Which one of the following most strongly affects the ability of a soil to supply crops with applied phosphorus?
    a) Volatilization of applied phosphorus
    b) Leaching of applied phosphorus
    c) Surface run-off of applied phosphorus
    d) Fixation of applied phosphorus

10. Which of the following is a key logistical consideration when making decisions on the right time for fertilizer application?
    a) The source of fertilizer
    b) Weather conditions
    c) Total crop nutrient uptake requirements
    d) Target yield

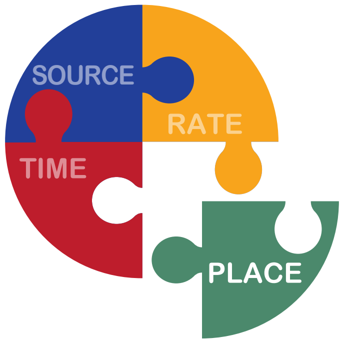
**For the answers, take the on-line quiz at:**
https://www.apni.net/courses/4rs-for-extension-agents/

# 4R NUTRIENT STEWARDSHIP GUIDEBOOK

## LEARNING MODULES FOR EXTENSION AGENTS

## MODULE 4

# RIGHT PLACE




**RIGHT PLACE:**

ADDING NUTRIENTS TO THE SOIL AT A PLACE WHERE CROPS CAN EASILY ACCESS THEM.


AFRICAN PLANT NUTRITION INSTITUTE

4R Solution

# 1. SCIENTIFIC PRINCIPLES BEHIND RIGHT PLACE

Applying nutrients at the right place means adding nutrients to the soil at a place where the crops can easily access them. Proper placement of nutrients allows a plant to develop properly and attain its potential yield, based on the environmental conditions in which it is grown. Right place depends on many factors that include the type of crop, tillage practices, plant spacing, crop growth stage, cropping systems (e.g., crop rotation or intercropping), and weather variability.

To determine the right placement of nutrients, the following scientific principles should be considered:

- Consider source, rate and time of application.
- Consider where plant roots are growing.
- Consider mobility of nutrients in the soil.
- Suit the goals of the tillage system.
- Manage spatial variability.

## 1.1 Consider source, rate, and time of nutrient application

- **Consider the source of nutrients:** The nutrient source selected has an implication on the right placement method. Different forms of fertilizer may be best suited for specific fertilizer placement methods. For example, in irrigated rice cropping systems, urea super granules are best suited for deep placement, while the conventional granular form of urea fertilizer is best suited for application through broadcasting.

- **Consider the rate of nutrient application:** Where large quantities of fertilizer are available, fertilizer application through broadcasting can be conducted. On the other hand, where only small quantities of fertilizers are available, application through banding or spot application is best suited.

- **Consider the time of application:** The time of nutrient application with respect to crop growth has an influence on the right placement. For example, during basal fertilizer application for maize at planting, fertilizer should be applied in the planting hole where seeds shall be planted, while during top-dressing application, fertilizer should be applied by making small holes close to the plant.

## 1.2 Consider where plant roots are growing

For efficient uptake, nutrients need to be placed where they can easily be taken up by growing roots when required.

Different plant species have different root growth patterns, and this has an effect on their individual abilities to access nutrients in various parts of the soil.

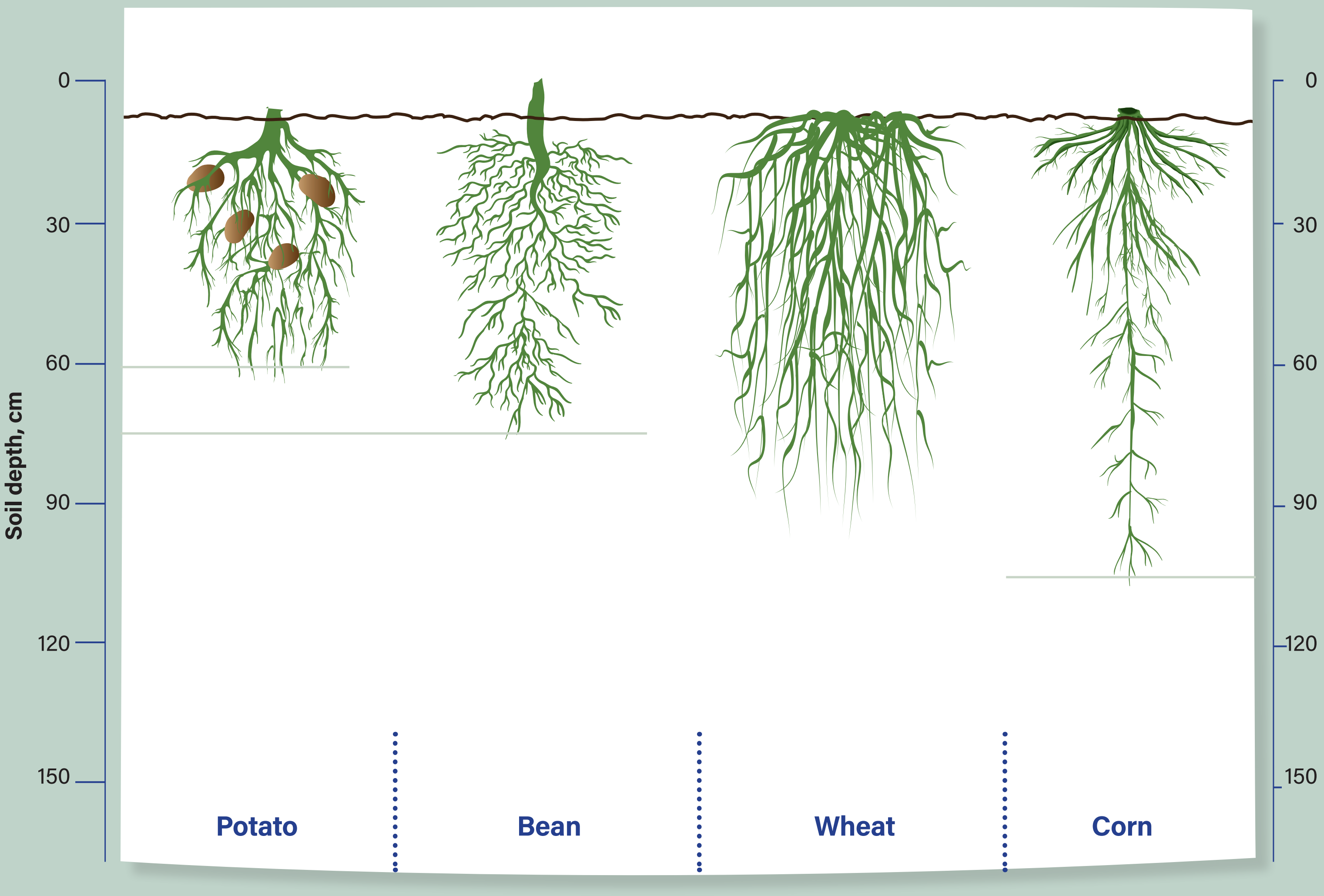



**Figure 1. Rooting characteristics** of different crop types.

## 1.3 Consider mobility of nutrients in the soil

Fertilizer placement should consider the mobility in the soil of nutrients supplied. Nutrients that have low mobility such as phosphorus should be concentrated in bands or holes close to the plants so as to improve availability.

## 1.4 Suit the tillage system under practice

Selected fertilizer placement methods should suit the tillage system under practice. For example, in conservation tillage systems that involve minimal or no tillage, special equipment is often used to apply fertilizer under the soil while maintaining crop residue cover so as to conserve nutrients and water.

Fertilizer placement methods that require covering of applied fertilizer with soil may therefore not be suitable for conservation tillage systems.

## 1.5 Managing spatial variability

Fertilizer placement should also aim at managing differences in soil fertility within or between fields in a farm.

Fields within smallholder farms in Africa often have large differences in soil fertility levels. These differences are often due to factors such as distance from the homestead which results in for example more frequent applications of organic resources to fields closer to the homestead compared to those further away. Overtime, such differences in applications of organic resources often result in substantial differences in soil fertility levels between fields in the same farm.

Knowledge of differences in soil fertility within a farm can therefore help to guide decisions on where to prioritize fertilizer applications. For example, fertilizer application can be prioritized to parts of the field with low fertility so as to manage spatial variability.

Where limited quantities of fertilizer are available, fertilizer application can be prioritized to higher fertility fields that are expected to give a better yield response to fertilizer application, hence better returns on fertilizer use.

***Differences in maize growth** within a field which suggest spatial differences in soil fertility.*

# 2. FERTILIZER PLACEMENT METHODS

Fertilizer placement methods best suited for specific crops and cropping systems are mainly influenced by the planting density and the rooting system of a particular plant. There are four main methods for placement of fertilizer:

1. Broadcasting
2. Banding
3. Spot application
4. Deep placement

## 2.1 Broadcasting

Fertilizer placement through broadcasting involves the uniform application of fertilizer across the surface of the field. Broadcasting aims at applying nutrients to the entire soil surface in a uniform manner.

Fertilizer placement by broadcasting is used when there is need to increase the fertility level of the entire plough layer. In such cases, basal fertilizers are broadcast and incorporated into the soil through tilling or ploughing-in.

Broadcasting is also suitable for fertilizer application to crops grown at a high planting density such as rice, wheat, and teff.

Fertilizer application through broadcasting can be conducted by hand or using fertilizer application equipment. Whether the fertilizer is broadcast by hand or with fertilizer spreading equipment, the spreading should be as uniform as possible.

Fertilizer application through broadcasting is easy to implement with low labour requirements.

***Application of urea*** *fertilizer through broadcasting during top-dressing in a teff field.*

## 2.2 Banding

Banding involves the placement of fertilizer in bands or furrows at a depth of about 5 to 8 cm below the soil surface.

Placement through banding is mainly used when fertilizer placement near the planting rows is required.

Banding is preferably used for crops planted in rows, where there are relatively large spaces between rows, but relatively small spaces between plants as is common for beans, soybeans, lentils, and groundnut.

Banding is an effective fertilizer placement method on P-fixing soils.

Banding is also an effective placement method when the amounts of fertilizer available are too small to be broadcast on soils with a low fertility level.

To ensure uniform distribution of banded fertilizer, the amount of fertilizer to be placed in each row should be determined in advanced and measured out in an appropriate container.

The fertilizer applied in each band should be placed under, or beside the seed, and covered with soil. Direct contact between seed or the germinating plant should be avoided, especially when fertilizers containing ammonium are used, as this may cause scorching of seeds or young plants.

***Placement of basal fertilizer*** *through banding in planting furrows.*

***Soybean seeds*** *sown in a furrow beside banded basal fertilizer.*

## 2.3 Spot application

Spot application involves the placement of small amounts of fertilizer close to each planting hole at planting, or close to each plant during the growing season.

Spot application is suitable for crops grown at wide spacing such as maize.

Spot application is the most effective method of fertilizer placement when very low rates of fertilizer are used.

To ensure uniform distribution of fertilizer during spot application, small dollop cups of different sizes that are calibrated to achieve various application rates should be used to apply fertilizer. Where dollop cups are not available, farmers can use small containers (such as bottle tops) to apply equal quantities of fertilizer per planting hole or planting station.

Fertilizer applied through spot application should be immediately covered with some soil to avoid losses of nutrients.

*__Spot application__ of basal fertilizer using a dollop cup.*

*__Spot application of top dressed__ fertilizer in a maize field using a dollop cup.*

## 2.4 Deep placement

Deep placement involves application of large fertilizer granules 5 to 10 cm into the soil by hand or using specially designed applicators.

Urea fertilizers can be compressed into large granules that are suitable for application through deep placement.

Deep placement is an effective method for N fertilizer application in paddy rice. Fertilizer application through deep placement is relatively expensive compared to other placement methods due to the higher cost of compressed fertilizer granules, and the high labour demand, plus specialized equipment required.

***Farmer holding compressed urea granules*** *and a urea granules applicator in a paddy rice field.*

***Deep placement*** *application of compressed urea granules in a paddy rice field.*

# Notes

# Notes

# Module 4: Right Place Quiz

1. Which of the following is among the core scientific principles that define right place for nutrients application?
   a) Bury nutrients deeply in the soil
   b) Mix nutrients throughout the whole soil volume
   c) Consider where plant roots are growing
   d) Incorporate nutrients using primary tillage

2. The nutrient placement method that most uniformly distributes nutrients throughout the soil volume is
   a) Spot application
   b) Banding
   c) Broadcasting
   d) Deep placement

3. Which fertilizer placement method is best suited for legume crops such as beans and groundnut?
   a) Deep placement
   b) Broadcasting
   c) Spot application
   d) Banding

4. Which of the following fertilizer placement options is best suited for application of fertilizer P to a maize crop?
   a) 5 cm beside and 5 cm below the seed
   b) In direct contact with the seed
   c) Directly below the seed
   d) Broadcast and thoroughly incorporated

5. Which of the following crops is not suited for fertilizer application through banding?
   a) Lentils
   b) Wheat
   c) Soybean
   d) Groundnut

6. Which fertilizer placement method is best suited for maize?
   a) Deep placement
   b) Broadcasting
   c) Spot application
   d) Banding

7. Which of the following is incorrect about fertilizer application by spot application?
   a) Most effective method when low very low rates of fertilizer are used
   b) Suitable for crops grown at wide spacing
   c) Most labour efficient method
   d) Spot applied fertilizer should be covered with some soil

8. Which of the following is not a key consideration when deciding on right placement of fertilizer?
   a) Suit the tillage system
   b) Consider the target yield
   c) Manage spatial variability
   d) Consider mobility of nutrients in the soil

9. For low fertility soils, low rates of band applied nutrients can help to
   a) Increase the use efficiency of the applied fertilizer nutrient
   b) Increase the fertilized soil volume as nutrients diffuse outwards
   c) Meet the total nutritional demands of the crop
   d) Fertilize a large volume of soil to attain maximum yield

10. What is the right order of the 4R rights of fertilizer management?
   a) Right rate, right source, right time, right place
   b) Right source, right rate, right place, right time
   c) Right source, right time, right place, right rate
   d) Right source, right rate, right time, right place

**For the answers, take the on-line quiz at:**

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# ABOUT **The 4R Solutions Project**

4R Solution

www.4rsolutions.org

The 4R Solutions Project is funded by Global Affairs Canada to improve the livelihoods of 80,000 smallholder farmers in Ethiopia, Ghana and Senegal by improving agricultural productivity and farm income through incorporation of 4R Nutrient Stewardship into local farming practices. 4R Nutrient Stewardship supports best management of plant nutrients based on four key practices: Right Source, Right Rate, Right Time, and Right Place.

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