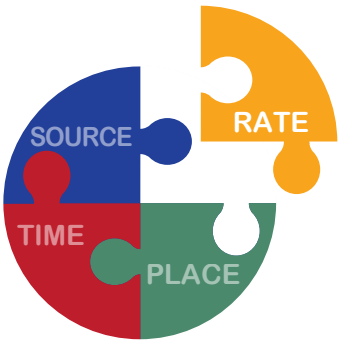
4R NUTRIENT STEWARDSHIP GUIDEBOOK

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.

AFRICAN PLANT NUTRITION INSTITUTE

4 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.

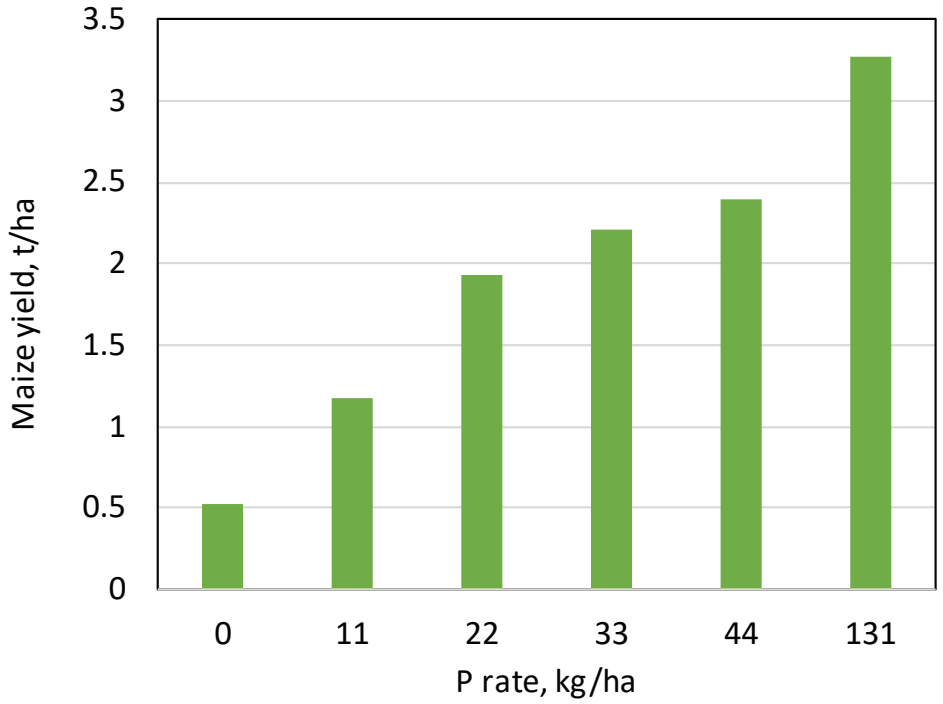
- If soils have high levels of these nutrients (good soil fertility), nutrient application rates can be **less** that crop removal.
- Conversely, if soils have low levels of these nutrients (low soil fertility), nutrient application should supply **more** nutrients than crop removal. When soils have 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.



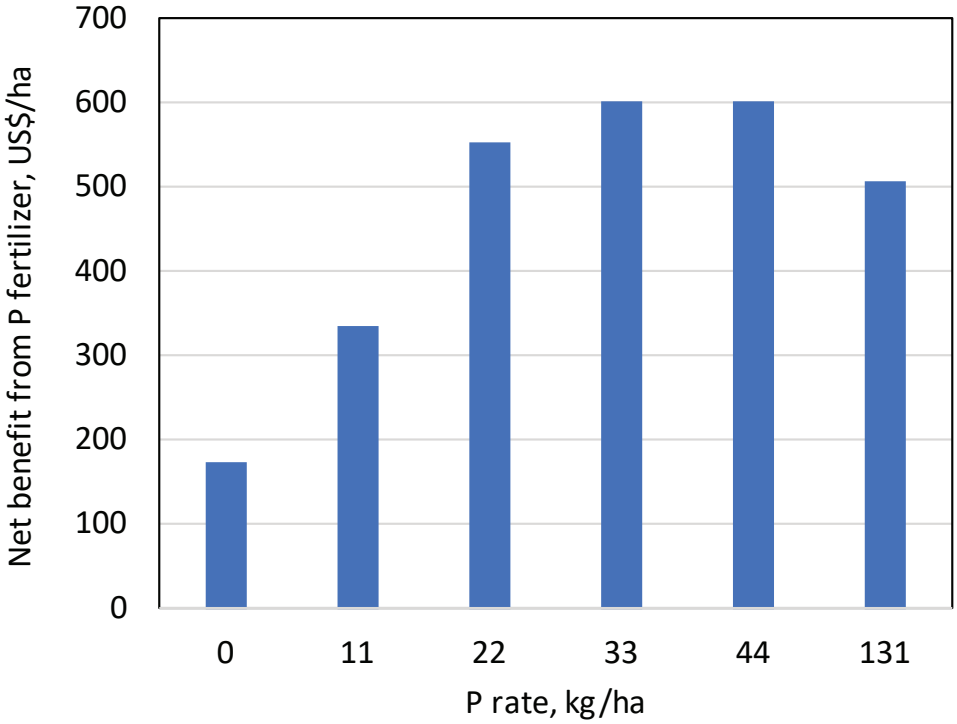


Figure 1. Crop yield response data in the top chart demonstrates that a P application rate of 131 kg/ha resulted in the largest maize yield; however, the bottom chart indicates that application of 33 kg/ha was most profitable.

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

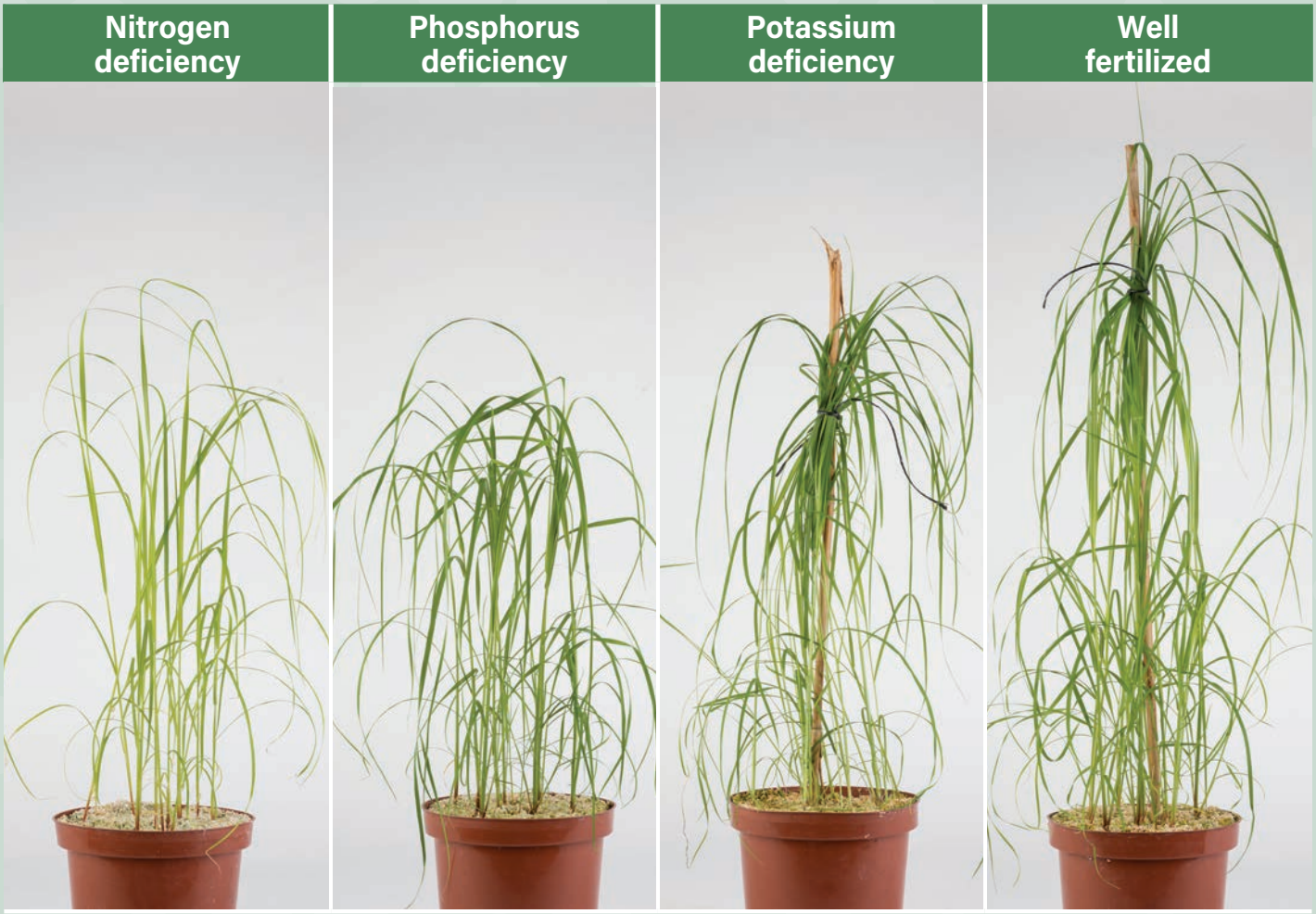
- Since MOP is 60% K_2O, the amount required to supply 30.3 kg K_2O is:

  = 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

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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/

ABOUT **The 4R Solutions Project**

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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