4R PLANT NUTRIENT MANAGEMENT IN AFRICAN AGRICULTURE

An extension handbook for fertilizer management in smallholder farming systems

IPNI
INTERNATIONAL
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4R nutrient stewardship

4R Plant Nutrient Management in African Agriculture

An extension handbook for fertilizer management in smallholder farming systems

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4R Plant Nutrient Management in African Agriculture:
An extension handbook for fertilizer management in smallholder farming systems.

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FOREWORD

There is urgent need to increase crop production in sub-Saharan Africa (SSA) to overcome food shortage problems and meet growing food demands. Given the poor fertility of soils in the region and the low levels of fertilizer use, fertilizer use must increase if the region is to reverse the problems of low crop productivity, malnutrition and land degradation. However, the benefits of increased fertilizer use will be limited unless farmers have the knowledge to use fertilizer in the correct way.

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 fertilizer source, 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.

Effective fertilizer use, as guided by 4R Nutrient Stewardship, is important to develop sustainable smallholder cropping systems that support improved food production, increased income and maintain the soil resource base. Fertilizers supply nutrients needed by crops. With fertilizers more and better quality food and cash crops can be produced. With fertilizers the fertility of soils, which have been over-exploited, can also be restored. Correct management of fertilizer will have far-reaching social, economic and environmental benefits for farms, villages, communities and entire countries in Africa.

The majority of farmers in SSA are smallholder rural poor, cultivating land units of less than 2 ha. The issue of improved fertilizer management has direct effects on their food security situation. Growing urban populations in Africa depend largely on food produced by smallholder farmers. Extension agents play an important role in providing farmers with information on good agronomic practices. There is also need to build the capacity of agrodealers to provide extension service. Farmers depend on them for knowledge on how they can improve their farming practices. It is therefore important for extension agents and agrodealers to have the right understanding of fertilizers and their correct management to ensure that they give accurate advice to farmers.

This handbook was developed as a resource for extension agents, agrodealers and other stakeholders working with smallholder farmers in sub-Saharan Africa. Its purpose is to ensure these advisors have adequate information required to demonstrate and communicate to farmers the best ways to use fertilizers and other nutrient resources. To be effective, fertilizer use should be part of an integrated program of farming systems and should be supported by good agricultural practices including good land preparation, use of improved crop varieties, organic resources, planting population, and weed, pest and disease management.

This handbook provides practical guidelines for best nutrient management based on the principles of 4R nutrient Stewardship. As smallholder farming systems are highly variable, 4R nutrient management practices appropriate for various farms and farming systems will be site-specific and determined by the goals of the farmer, available resources, the cropping system, soil conditions, climatic conditions, and other factors that influence crop and nutrient management decisions.

Shamie Zingore, Adrian Johnston, Terry Roberts

1. INTRODUCTION TO 4R NUTRIENT MANAGEMENT PRACTICES

The nutrients needed by plants are mostly taken from the soil. If the supply of nutrients in the soil is ample, crops will be more likely to grow well and produce high yields. If, however, even only one of the nutrients needed is in short supply, plant growth is limited and crop yields are reduced. Therefore, in order to obtain high yields, fertilizers and organic nutrient resources, such as manure, are needed to supply the soil with the nutrients needed for crop growth. Achieving the best yields from fertilizer use requires good management of nutrients. The 4R Nutrient Stewardship approach provides guidelines on the best way to manage fertilizers. It consists of applying the Right Source of nutrients needed by a plant, at the Right Rate to supply the quantity needed by the plant, at the Right Time to be taken by the plant, and in the Right Place to be accessible by plant roots. Farmers should get these four "Rights" for sustainable management of plant nutrition. Correct practice of the 4R management practices will result in increased crop yields and incomes, as well as prevention of soil nutrient depletion.

For nutrient management to be considered "right," it must support the goals of farmers. The farmer is the final decision-maker in selecting the practices suited to local soil, weather, cropping systems, as well as socio-economic conditions. Because these local conditions affect the decision on the practice selected, approaches for implementing 4R management practices should improve the capacity of farmers to adapt the right practices to their local conditions.

The guidelines for the right management practices of fertilizers have been developed from research conducted over many years. The guidelines are the same globally, but how they are put into practice locally varies depending on specific soil, crop, climate, economic, and social conditions. Farmers make decisions on the practices that they select and apply locally. Examples of the 4R guidelines that will be presented in detail in this handbook are presented in Table 1.

Photo 1-1: Applying 4R knowledge ensures that farmers increase crop productivity, get more income and maintain soil fertility.

Table 1-1: Examples of 4R guidelines

The Four Rights (4Rs)				
	Source	**Rate**	**Time**	**Place**
Examples of key guidelines	• Ensure balanced supply of nutrients • Suit soil properties	• Assess nutrient supply from the soil and from the nutrient sources (organic resources, fertilizer) • Assess crop nutrient requirements	• Assess the critical time when the crop need nutrients and soil supply • Determine timing of low loss risk	• Recognize crop rooting patterns • Manage spatial variability
Examples of options for practical choices	• Commercial fertilizer • Livestock manure • Compost • Crop residues	• Test soils for nutrients • Calculate economics • Balance crop removal	• At pre-plant • At planting • At flowering	• Broadcast • Band application • Spot application

Notes

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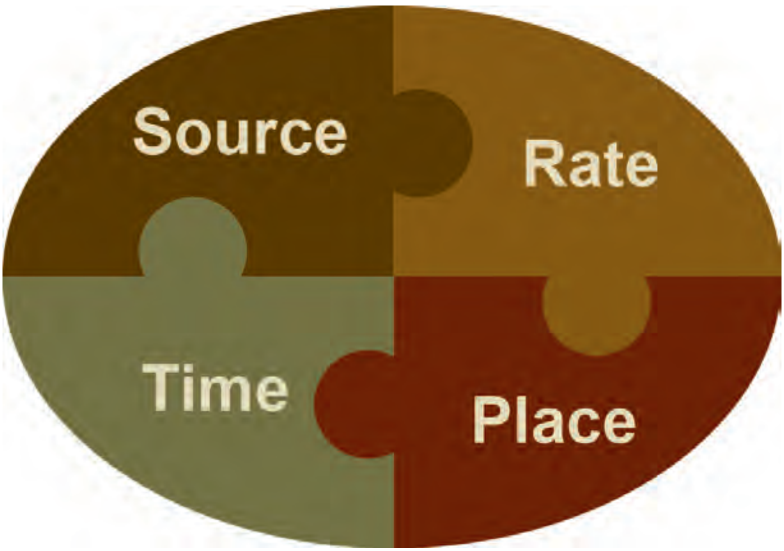
The four "rights" provide a simple checklist to assess whether a crop has been fertilized properly. The overall question "Was the crop given the right source of nutrients at the right rate, time, and place?" helps farmers to identify opportunities for improvement in fertilizing each specific crop in each specific field. There should be a balance of effort among the four rights.

The correct balance between the 4Rs is necessary to avoid too much emphasis on one at the expense of overlooking the others. The four "rights" must work together. Fertilizer use will not be right if any of the 4Rs is not implemented correctly.

To apply 4R knowledge correctly, understanding of soil fertility status is required. The next chapter provides background information on the properties of soils that are important for determining the best 4R practices under variable soil fertility conditions.



2. SOIL AND SOIL FERTILITY

2.1 Understanding the soil

Soil is a loose material, which forms a thin layer covering the earth's surface. The word "soil" means different things to different people. In crop production, soil is a medium for plant growth, which supplies nutrients, water, air for roots and support for plants. It forms on the earth's surface as a result of weathering rocks and minerals.

When fully formed, the soil has distinct layers called horizons as seen from vertical cuts when digging a pit (Photo 2-1). The cross-section of these horizons is called a soil profile. In cultivated soils, the top most layer usually has the highest amount of organic matter and nutrients. This layer is shown in Photo 2-1 as horizon O. In cultivated fields the top layer is known as the plough 'P' layer.

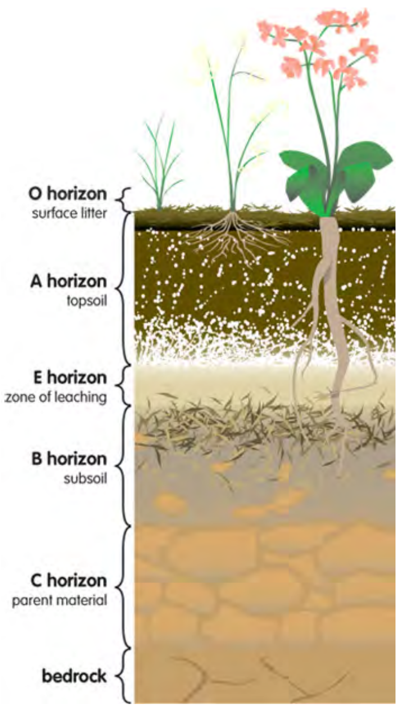


Photo 2-1: Soil profile showing different soil horizons.

Examining soil profiles is one of the useful steps towards using soils appropriately. Profiles show differences between soils and can reveal problems affecting crop growth. For a given soil profile, a soil horizon can restrict plant growth because of:

- Inadequate thickness
- Occurrence of a layer that cannot be penetrated by plant roots, known as hard pans or compact layers

Soil is made up of solids, pores and living organisms. The solid component is made up of minerals and organic matter. The pore space provides passage for water and air movement. A healthy soil should have sufficient solids, pores and living microorganisms for supply of nutrients, water and air required for plant growth.

2.2 What is soil fertility?

Soil fertility refers to the capacity of soil to supply essential plant nutrients in the amount and form that a plant can take them up. For this to be achieved, a fertile soil must have good chemical, physical and biological conditions. Soil fertility is the ability of the soil to supply all the nutrients required by the crop. A fertile soil also has a good structure that enables the flow and storage of air and water into the soil, permit best root and plant growth, and helps to anchor the plants.

A fertile soil must:

- Be deep enough to enable roots to explore a sufficient soil volume without any obstructing layer.
- Have good structure (based on the distribution and aggregation of particles) to ensure proper air and water circulation, hence growth and development of roots.
- Have a favorable soil pH range to ensure availability of nutrients (pH range 5.8 to 7.0 is suitable for most crops).
- Have a good supply of nutrients required by plants.
- Be able to store nutrients supplied from fertilizers.
- Contain sufficient organic matter.

2.2.1 Soil pH

Soil pH is an indicator of the degree of acidity and alkalinity. It is expressed by a range of pH units from 0 to 14. A pH of 7 is neutral, below 7 acidic and above 7 is alkaline pH. Soil acidity is a common problem that affects crop productivity in Africa. Agricultural soils become acidic when harvested crops remove positively charged nutrients (known as bases) and soil organic matter declines. Soil acidity can be corrected by application of agricultural lime.

2.2.2 Soil organic matter

Soil organic matter consists of roots, plant residues and soil organisms in various stages of decomposition. It has great impact upon the fertility of the soil. Organic matter in the soil gives the soil good structure, and enables the soil to absorb water and to retain and supply nutrients. It also supports the survival of soil organisms. Some of the nutrients like nitrogen, phosphorus and sulphur are held in the soil organic matter. Thus, the amounts of these nutrients in the soil will correspond to organic matter types and levels in soil. Organic matter also affects the colour of the soil and populations of soil organisms.

Addition of organic inputs (including crop residues and animal manures) is required to maintain soil organic matter at good levels. Organic inputs are an important source of nutrients, which are mostly released following decomposition. Before thinking of fertilizer application, farmers should consider utilization of available organic resources. It is also important to consider the quality of organic resources available as this has an impact on the nutrients that will be available for the crop to take up.

For example, with the decomposition of fresh lower quality organic material such as maize residues, nutrients from the soil, particularly nitrogen, will be fixed temporarily; thus not being available for the subsequent crop.

Often, the amount of nutrients contained in organic resources produced by smallholder farmers is usually insufficient to sustain required levels of crop productivity and realize the full economic potential of a farmer’s land and labour resources.

In addition to supplying nutrients, organic inputs also contribute to crop growth in other ways by:

- Improving the soil's capacity to store moisture.
- Regulating soil chemical and physical properties that affect nutrient storage and availability, as well as root growth.
- Adding nutrients not contained in mineral fertilizers.
- Creating a better rooting environment.
- Improving the availability of phosphorus for plant uptake.
- Replenishing soil organic matter.

Organic resources are available to smallholder farmers in very limited amounts and are often not sufficient for the level of crop production required for farmers to produce enough crops for food and surplus for income. Mineral fertilizers have to be applied in addition to organic inputs. Integrated Soil Fertility Management (ISFM) emphasizes the importance of increasing crop yields and building soil fertility by combining the use of fertilizers with organic resources.

2.2.3 Soil texture

Soil texture refers to the proportion of sand, silt and clay in the soil. It is responsible for how much soil organic matter a soil can hold, nutrient supply, water drainage and aeration, and effective depth of soils. The percentage of clay decreases from around 45% in clay soils to 10% or less in sandy soils.

A soil with a high percentage of sand particles (a light or sandy soil) will absorb and release water very easily. It also has less capacity to supply plant nutrients. On the other hand, a soil with a high proportion of clay particles (a heavy or clay soil) retains water and nutrients longer, but is susceptible to water logging hence can be poorly aerated. Soils with a good mix of sand and clay such as loamy soils usually have good texture with good capacity to retain water and nutrients. Soil texture is a condition that cannot be easily changed by management.

2.2.4 Soil structure

Soil structure refers to the arrangement of primary soil particles into aggregates. Important processes (e.g., water intake, drainage, aeration, root development) largely depend on soil structure. Soil structure can be modified by practices such as ploughing and cultivation, particularly in the topsoil. Organic matter is important for good soil structure.

Soil fertility is a basic need for plants to grow productively. Although soil fertility is vital to productivity, not all fertile soils are productive soils. Poor drainage, drought, insects, diseases, and other factors can limit productivity, even when fertility levels of all plant nutrients are adequate. Section 3 presents an overview of other factors that support or limit crop productivity.

Notes

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3. 4R STEWARDSHIP AS PART OF THE CROPPING SYSTEM

To maximize the benefits of fertilizer use, good agronomic practices should be employed. Crop production systems consist of several practices that determine the actual yield and profit achieved by the farmer. The practices can be placed into two groups (Figure 3-1): (i) yield-building practices: those that contribute to yield increases and yield, and (ii) yield protection practices: those that prevent yield or income losses.

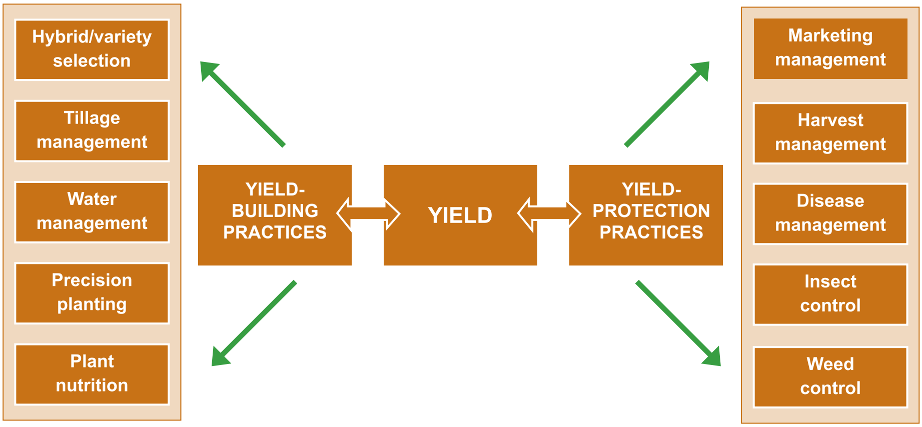

Figure 3-1: Practices that determine the yields and profits achieved by farmers.

3.1 Yield-building

To get the best yields, farmers need to invest in yield-building practices. In addition to 4R nutrient management practices, other yield-building practices are:

- **Improved crop varieties:** It is important that the farmer uses high yielding varieties or seedlings that are best suited to local growing conditions. Crop varieties should also be resistance to particular pests and diseases. Improved crop varieties usually have a higher harvest index (HI) (the ratio of harvested product to total biomass production) because more of the total biomass production is converted into the harvested product than in unimproved varieties. However, improved legume varieties with a lower HI are sometimes selected because they can be treated as 'dual-function' crop plants. For example, multi–purpose soybean varieties used for food, feed and soil fertility improvement provide a large biomass that benefits the next crop in the rotation in addition to an acceptable grain yield.

Photo 3-1. Improved seed varieties should be used to attain the best yields.

- **Good tillage practices:** Tillage is important to prepare the soil for planting. Tillage helps to level the field, control weeds, incorporate crop residues and manure and reduce soil compaction. Tillage should be done in a timely manner, at least a week before the expected planting date. Different tillage practices using mechanical, animal or manual power should be done to a depth of 20-30 cm, and should be implemented to avoid soil compaction. Minimum tillage practices using special planting tools can be used in conservation agricultural systems.

Photo 3-2: Conventional tillage using ox-drawn plough is a common tillage practice.

Photo 3-3: Reduced tillage options combined with surface retention of crop residues is an option for soil and water conservation.

- **Water and land management practices:** Water and land management practices are important to improve water available in the soil and reduce runoff and erosion. This is particularly important for fields on steep slopes, where terracing and ridging across the slope are important practices. In drought-prone areas, tied ridging is an important option to conserve water.

- **Liming:** Application of lime is necessary for acidic soils. The amount of lime required depends on the pH, crop to be grown and soil type.

- **Correct planting practices:** Crop growth is optimal when planting is done at the right time (e.g., at the beginning of the rainy season), and plant spacing is done correctly. Standard spacing practices depend on crop and growing environment. Spacing plants too close results in competition for water, nutrient and light which reduces productivity, and can also increase incidence of pests and diseases. Spacing plants too far apart reduces the yields than can be achieved. Examples of recommended spacing for major crops in Africa are shown in Table 3-1. Plant spacing should be adjusted when farmers practice intercropping.

Photo 3-4: Beans planted at the right spacing of 45 cm x 5 cm.

Photo 3-5: Maize planted at the right spacing of 75 cm x 25 cm.

Photo 3-6: Avoid planting many maize seeds on the same place as this severely reduces yields.

Table 3-1: Recommended crop spacing for major crops in SSA.

Crop	Growing environment	Inter-row spacing	Intra-row spacing	Plant population, plants/ha
Maize	High/low potential	60 – 90 cm 75 – 90 cm	20 – 30 cm 30 – 45 cm	44,000 – 60,000 30,000 – 40,000
Sorghum	High/low potential	90 cm	15 cm	75,000
Millet	High/low potential	90 cm	10 cm	112,000
Beans	High/low potential	45 cm	10 cm	225,000
Soybean	High/low potential	45 cm	10 cm	225,000
Groundnut	High/low potential	45 cm	10 cm	225,000

Note: The table provides general guidelines, actual spacing should adapted to local conditions.

3.2 Yield protection

Crops are susceptible to weeds, pest and diseases. Losses can occur at various stages of growth including seedling establishment, crop growth and development, harvesting and storage. Integrated weed, pest and disease management practices are required to minimize crop yield losses. Strategies for effective management of weeds, pests and diseases include:

- Use crop varieties resistant to major diseases.
- Ensure timely and effective weeding.
- Practice suitable crop sequences, such as cereal-legume crop rotations.
- Regular monitoring of crops to ensure timely intervention.
- Pay attention to pest and disease forecasting techniques where available.
- Use non-chemical pest and disease management practices.
- Use agrochemicals in a precise manner and according to legal requirements.
- Ensure that only specially trained knowledgeable persons apply agrochemicals

- Ensure that equipment used for the handling and application of agrochemicals complies with established safety and maintenance standards.
- Avoid impact on non-target areas of any pest and disease management activity.
- Timely harvest is important to reduce yield losses.
- Drying and storage management.

Photo 3-7: Effective weeding ensures good crop growth.

Photo 3-8: Poor weeding severely limits yields.

Examples of benefits of good agronomic practices

Example AP-1: Effects of fertilizer application on yields of hybrid and open pollinated maize seed varieties

To get the best results from using fertilizer following the 4R strategies, other good agronomic practices must be used. The use of appropriate hybrid seed varieties is an important part of the agronomic practices that should be used. When high rates of fertilizer are used, improved seed varieties (hybrids) give better response to fertilizer than open pollinated varieties, as they are developed to achieve high yields with good management.

In 2008, experiments were conducted at 5 locations in Zimbabwe to determine the response of maize hybrid and OPV varieties to fertilizer application. The experiments included (i) fresh hybrid seed varieties; (ii) hybrid seed varieties that had been recycled from the previous year; (iii) OPV seed varieties; (iv) OPV seed varieties that had been recycled from the previous year. Maize was planted at a density of 53,000 plants per ha. Fertilizer was applied at a rate of 100 kg N; 30 kg P and 40 kg K per ha.

Experimental results showed that fresh hybrid seed varieties gave a yield of about 6 t/ha, which was greater than the 4.5 t/ha achieved with open pollinated varieties with the similar amount of fertilizer. The added benefits of using hybrid seed when farmers use fertilizer was about 1.5 t/ha. Hybrid seed should be used for one season only, as hybrid seeds lose their vigor when recycled. Experimental results showed that recycled hybrid seed gave only 4 t/ha in the second year of use, compared with the 4.4 t/ha that was produced with recycled open pollinated varieties.

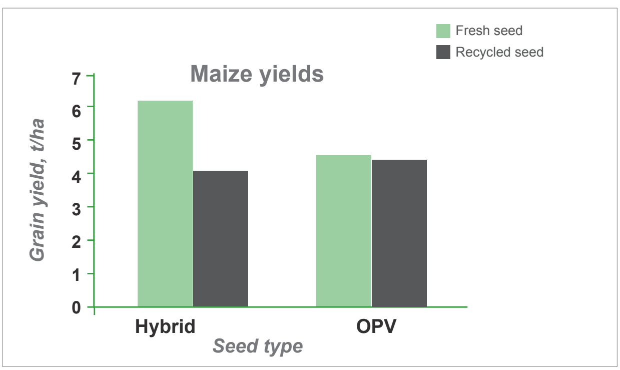

Figure 3-2. Response of hybrid and open pollinated maize varieties to fertilizer for two seasons.

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Example AP-2: The effects of plant population on cowpea yield under semi arid conditions soils.

Using the appropriate plant population density is important to achieve good yields. Correct plant population ensures that crops take advantage of soil water, nutrients and light to achieve optimum economic yield. Plant population to use depends on the crop, variety, soil type, agro-ecological potential and amount of fertilizer and manure to be used.

Low plant population reduces yield potential, delays development of full canopy and therefore encourages more weed growth as more light reaches the soil surface. However, too high plant population is a waste of seed, causes competition for water, nutrients and light, may cause lodging, and may encourage disease development under the plant canopy thereby reducing yield.

To get the best yield, use the correct/recommended plant population for the agro-ecological area you are located in.

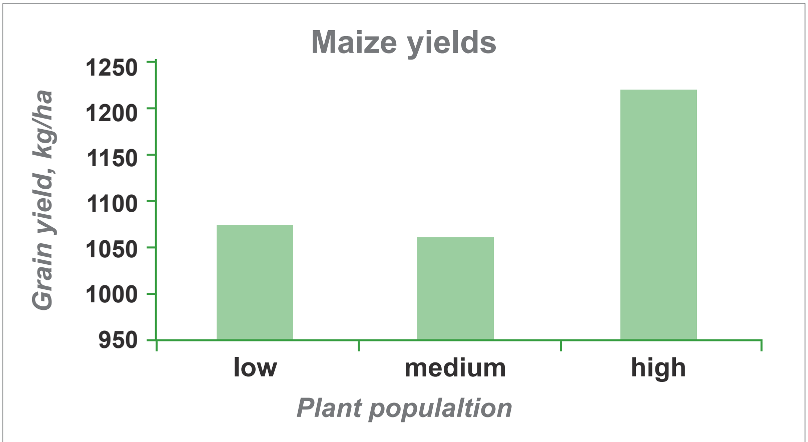
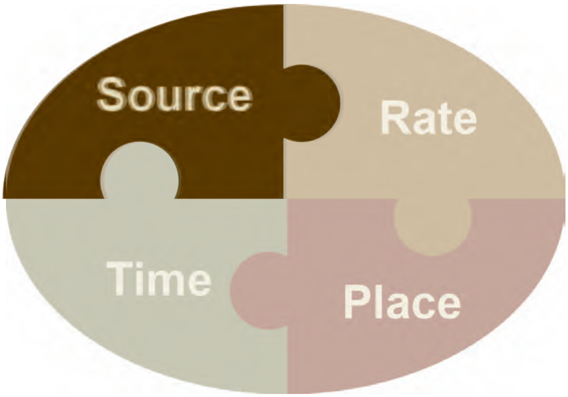


Figure 3-3. Effect of low, medium and high cowpea plant population on yield. Low -111,000, medium – 148,000, and high – 185,000 plants/ha).

4. DETERMINING THE RIGHT SOURCE



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

- Consider rate, time, and place of application.
- Understand the nutrients that limit specific crops in the area.
- The fertilizer must supply the required nutrients in plant-available forms or in forms that convert timely into a plant-available form in the soil.
- Suit soil physical and chemical properties to ensure efficiency (e.g. avoiding nitrate application to flooded soils, surface applications of urea on high pH soils, etc.).
- Recognize how application of one nutrient affects the availability or uptake of another. For example, application of nitrogen can increase phosphorus availability. The complementing effects between manure and mineral fertilizer should also be considered.
- Recognize compatibility when mixing fertilizers - certain combinations of sources attract moisture when mixed, limiting uniformity of application of the blended material; fertilizer particle sizes should be similar to enable uniform application of fertilizer in the field.

- Recognize benefits and harmful effects of nutrients that may be supplied together by one fertilizer to the crop of interest. For example, muriate of potash (potassium chloride, KCl) fertilizer supplies the nutrients chloride (Cl^-) and potassium (K) that are both good for maize, but chloride can be harmful to the quality of tobacco and some fruits.
- Know the composition of the fertilizers and their effect on plants. Some sources of phosphorus fertilizer, such as single super phosphate, contain plant-available calcium and sulphur, and small amounts of magnesium and micronutrients.

There is no one single right source of nutrient for all conditions. The need for specific nutrients should be established in advance of application whenever possible. Factors such as fertilizer product availability, the type of soil, fertilizer application equipment, and labour requirement all need to be considered.

4.1 Nutrients needed for plant growth

There are many essential nutrients required for the growth of plants and these are derived from both the air and soil. Carbon (C), hydrogen (H) and oxygen (O) are derived from the air and water.

The nutrients presented in Table 4-1 are taken from the soil, and are known as mineral nutrients. They are divided into macronutrients (needed by plants in large quantities) and micronutrients (needed by plants in small quantities).

Many cropped soils are not able to supply all nutrients in the amounts required for crops to achieve high yields. Therefore, additional nutrients are usually needed in the form of fertilizers or manure.

Table 4-1: Essential plant nutrients.

Nutrients	Chemical symbols	Primary uptake form	Main form in soil reserves
Macronutrients			
Nitrogen	N	Nitrate or Ammonium	Organic matter
Phosphorus	P	Phosphate	Organic matter, minerals
Potassium	K	Potassium	Minerals
Sulphur	S	Sulphate	Organic matter, minerals
Magnesium	Mg	Magnesium	Minerals
Calcium	Ca	Calcium	Minerals
Micronutrients			
Chlorine	Cl	Chloride	Minerals
Iron	Fe	Iron	Minerals
Manganese	Mn	Manganese	Minerals
Zinc	Zn	Zinc	Minerals
Copper	Cu	Copper	Organic matter, minerals
Boron	B	Boron	Organic matter
Nickel	Ni	Nickel	Minerals
Molybdenum	Mo	Molybdate	Organic matter, minerals

4.2 What are the sources of nutrients?

Since the nutrients required by crops are supplied by the soil in small quantities, farmers commonly add more nutrients through fertilizers bought from stores or through manures from livestock or compost. Nutrient sources that are available on-farm include compost manure, animal manure, green manure and crop residues.

Fertilizers: Nutrients are brought to the farm mainly in the form of fertilizers. Except for nitrogen, all other nutrients are derived from naturally occurring earth minerals that can be mined and processed in industries into forms that are easy to transport and available to crops.

Photo 4-1: Fertilizers are an important source of nutrients for many cropping systems.

Legumes: Air contains 79% nitrogen gas, which cannot be used directly by plants. However, grain legume crops (such as soybean, groundnut, pigeon peas, cowpeas, Bambara, groundnuts and beans) and green manure legume plants (such as mucuna and crotalaria) are capable of converting this nitrogen gas from the air to a form usable by the plants. These legume plants have nodules on the roots (Photo 4-2), which act as 'small factories' that manufacture the nitrogen that they use for their growth. When legume residues are added back to the soil, they decay and release the nitrogen that can be used by crops in rotation, and also contribute to building organic matter.

Photo 4-2: Nodules 'fertilizer N factories' on roots of a legume crop.

On the other hand, maize and other cereal crops cannot manufacture their own nitrogen, as they do not have these special 'factories' on their roots. These crops will therefore require external nitrogen fertilization to achieve high yields or benefit from nitrogen fixed by the rotated legume.

Other organic materials:

- Organic material release nutrients that they contain during their decay.
- Organic material will contain a wide range of nutrients, although the nutrients will mainly be in small amounts.
- The quality of organic materials determined by the nutrients it contains.

- Most organic material found in smallholder farms are of poor quality, and have low content of major nutrients.

- Despite the low nutrient quality, the organic material are valuable as a source of soil organic mater.

Animal manures and composts are good sources of plant nutrients when used correctly. Manures contain all nutrients needed by plants, though quantities are usually small compared to the amounts required by plants for high yields. The amount of nutrients in manure, particularly nitrogen, can be increased by feeding livestock on good quality pastures and reducing losses of nutrients during storage and handling.

Photo 4-3: Cattle manure heap on a farm in Eastern Zimbabwe. Manure use in large amounts is mostly limited to few farms that own cattle.

Almost all mineral nutrients enter plants through the roots. The primary form in which the nutrients are absorbed by roots is shown in Table 4-1.

4.3 Choosing the Right Source of fertilizer

Any natural or manufactured material, which contains at least 5% of one or more of the three primary nutrients (nitrogen, phosphorus and potassium), can be called a fertilizer. Industrially manufactured fertilizers are called mineral fertilizers and have different colours and forms (granules or powder). There are many factors that need to be considered when choosing the right source of fertilizer. In addition to guidelines mentioned earlier, factors such as fertilizer availability, delivery price, and economic constraints can all be important. Decisions may be influenced by the availability of different types of fertilizer within reasonable distance.

Selecting the right fertilizer source begins with determining which nutrients are actually required to achieve target yields. Nutrients that are limiting can be determined through soil and plant analysis, nutrient omission experiments, or visual deficiency symptoms in the field (see Sections 8 and 9). As soil testing is not readily available for most smallholder farmers, local indicators of soil fertility and observation of nutrient deficiency symptoms provide a simple option to determine nutrient requirements.

Assessment of actual nutrient requirements needs to be done in advance of the fertilizer application decision. Merely guessing at the needed nutrients can lead to problems associated with under- or over-fertilization and can result in poor crop response to applied nutrients or toxicity, and loss of money.

It is common to focus on a single nutrient that is in short supply and not take into account other nutrients. For example, a lack of adequate nitrogen is easy to detect by observing stunted growth and yellowing leaves. However, the maximum benefit from applied nitrogen fertilizer will not be obtained if other shortages (such as for phosphorus or potassium) are not also corrected. Although focus is often placed on individual nutrients, all the nutrients function together to support healthy plant growth.

Knowledge of fertilizers is also important to determine the Right Source. Fertilizers are normally sold with a grade, or guaranteed minimum nutrient contents. The primary nutrients (N, P and K) are expressed as percent N-P_2O_5-K_2O. They are always given in this sequence - the first number represents N content; the second available P as P_2O_5, and the third, soluble K as K_2O equivalent. For example, for a compound fertilizer labeled 7-14-7, this means nutrient content of the fertilizer is 7% N, 14 % P_2O_5, and 7% K_2O, which translates to 7%N, 6%P and 6%K respectively.

For fertilizers containing other nutrients, additional numbers can be added with the chemical symbol of the nutrient; for example, a 21-0-0-24S fertilizer contains 21% N and 24% S only.

Photo 4-4: Ammonium sulphate fertilizer containing 21% N and 24% S.

Photo 4-5: A compound fertilizer for maize containing 7% N, 14% P_2O_5, 7% K_2O and 8.5% S.

On fertilizer label, P is expressed in its oxide form P_2O_5, and K in the oxide form K_2O.

To convert from the oxide form to the elemental form, use the following conversion factors:

For phosphorus,
$\%P = \%P_2O_5 \times 0.44$
or $P \times 2.29 = P_2O_5$

For potassium,
$\%K = \%K_2O \times 0.83$
or $K \times 1.20 = K_2O$

This means that there is only 44% P in the weight of P_2O_5, the rest of the weight is oxygen, whereas there is 83% K in the weight of K_2O. For example, if a farmer applies two 50 kg bags/ha (100 kg total) of a 17-17-17 grade fertilizer, the total amount of nutrients applied will be 17 kg N, 17 kg P_2O_5 and 17 kg K_2O.

In terms of N, P and K applied, this is equivalent to:

- 17 kg N,
- 17 x 0.44 =7.5 kg P
- 17 x 0.83 =14 kg K

The label on the fertilizer packaging also indicates the weight of the bag, sometimes recommendations for correct handling and storage, and the name of the producer or distributer of the fertilizer. Most fertilizers also have a brand name printed on the fertilizer bag.

4.4 Forms and types of fertilizer

Most fertilizer is supplied in solid form. Depending on the process of manufacture, the particles of mineral fertilizers can be of many different sizes and shapes: from granules, pellets to fine powder (dust). Fertilizer is also available in larger compacted granules that release nutrients slowly. The urea super granules are the most common fertilizer in this form, and are mostly used in low land rice production to reduce N losses through volatalization. Liquid fertilizers are widely used for horticulture and in irrigated systems.

Photo 4-6: *Most fertilizers are available in the form of small granules.*

Photo 4-7: Urea super granules.

The main forms of fertilizer used by smallholder farmers in Africa are as follows:

1. Straight fertilizers which supply only single nutrients. Good examples are urea and ammonium nitrate that supply only nitrogen.
2. Compound fertilizers which are a mixture of multiple nutrients within a single solid fertilizer particle. This approach differs from a blend of individual fertilizers mixed together to achieve an average nutrient composition. Each particle of compound fertilizer delivers a mixture of nutrients as it dissolves in the soil and avoids the problem of any separation of particles during transport and handling or application. There are certain ratios of nutrients that are commonly available and recommended for particular crops, making it easy for farmers to choose the right source.
3. Bulk blends fertilizers which consist of a mix of various granular fertilizers in a batch that will meet the specific nutrient combinations. Blends are adjusted with differing ratios of nutrients for individual crop and soil conditions. They are popular because they are made from the cheapest components and mixed with relatively simple and inexpensive equipment. The individual fertilizer components must be chemically and physically compatible for mixing and storing. Attention needs to be given to possible separation of the individual components that may occur during transportation and handling.

The 50 kg bag is the main packaging unit for fertilizer distribution to small-scale farmers. Smaller bags targeted to resource-constrained farmers are also available in some areas.

Governments have established strict regulations on the type of fertilizer bags (or containers) in which mineral fertilizers are delivered to farmers and how they have to be labeled. The information on the label must always include the quantities of nutrients contained and their forms.

4.5 Properties of different types of fertilizer

4.5.1 Straight fertilizers

- They are economical for addressing the deficiency of a single macronutrient which is considered as most limiting.

- They can be easily blended to meet the nutrient demands of a particular field or crop.

Photo 4-8: Examples of straight fertilizers

Table 4-2: Some of the most important straight fertilizers used in SSA.

Fertilizer	Properties	Agricultural uses	Management
Urea	• Contains nitrogen only at 46% N • Most concentrated solid nitrogen supplying fertilizer • White in colour with round granules • Usually has lower cost per unit than other N-fertilizers • Highly water soluble	Good for top-dressing	• Must be covered by soil at application to avoid volatile losses of ammonia to the air • Should only be applied when it is possible either to incorporate it into the soil immediately after spreading or when rain is expected within a few hours following the application • Should be packed in moisture proof bags and well stored
Ammonium sulphate	• Contains 21% nitrogen and 23% sulphur • Usually white in colour with small sugar like granules	• Very useful where there is need for both nitrogen and sulphur • Preferred for use in irrigation systems such as rice systems where nitrate based N fertilizers are not suitable due to denitrification losses under water logged conditions • Useful in increasing the effectiveness of post-emergence herbicide sprays in weed control • 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 • Should be incorporated into soils upon application to avoid losses

Table 4-2: -continued

Fertilizer	Properties	Agricultural uses	Management
Calcium ammonium nitrate (CAN)	• Contains 27% nitrogen; also supplies small amounts of calcium • Grey or light brown in colour depending on the coating used	• Can be used as a basal source of nitrogen but mainly used as a top dressing fertilizer • Most suitable nitrogen fertilizer for semi-arid regions • Suitable for application in acidic soils as it is about neutral when applied to soil	• Should be stored in a closed dry room • Must be covered by soil at application
Single super-phosphate (SSP)	• Contains 16 to 20% of P_2O_5, 12% of sulphur and more than 20% calcium (CaO) • Is grey ash in appearance with good storage qualities	Good source of phosphorus, sulphur and calcium	• Requires no special handling procedures • Phosphorus does not move fast with water in soil, and so should be applied near root zone of plants
Triple super-phosphate (TSP)	• Contains 46% P_2O_5 and 15% calcium • Is the most concentrated form of straight phosphorus fertilizer • Dissolves in water • Is usually grey in colour with large granules	Is suitable on most soil types In addition to phosphorus, also supplies calcium	• It contains traces of free phosphoric acid hence must be properly packed • Should be applied at the right rate, time and well covered to minimize losses to water bodies through surface runoff • Does not move fast in soil hence should be applied near root zone of plants

Table 4-2: -continued

Fertilizer	Properties	Agricultural uses	Management
Muriate of potash (MOP)	• Only supplies potassium at a rate of 60% K_2O • Is the leading straight potassium fertilizer used on most crops • Is free flowing without handling and storage problems • Is completely soluble in water	Suitable for most soils	• The entire requirement of MOP may be applied as basal dose but split application is recommended in sandy soils and high rainfall areas • Requires no special handling procedures

4.5.2 Multi-nutrient fertilizers

Multi-nutrient fertilizers contain more than one macronutrient. A large number of multi-nutrient fertilizers (also known as Compound Fertilizers) are offered in different countries. Table 4-3 gives the examples of multi-nutrient fertilizers that are available in Kenya and their nutrient contents.

Table 4-3: Common multi-nutrient fertilizers SSA.

Fertilizer type		%N	%P_2O_5	%K_2O
NPK fertilizers		5-26	5-35	5-26
Diammonium phosphate	DAP	18	46	-
Monoammonium phosphate	MAP	11	52	-
Nitrophosphate	NP	20-26	6-34	-
PK fertilizers	PK	-	6-30	6-30

The main advantages of multi-nutrient fertilizers to the farmer are:

- Ease of handling, transport and storage.
- Ease of application.
- Even distribution of nutrients in the field.
- Balanced fertilization, (i.e., nitrogen, phosphorus and potassium).
- Available together from the start and in accordance with plant requirements.
- Lower cost of application due to labour saving.

4.5.3 Secondary and Micronutrients

Secondary and micronutrients are needed in small amounts, usually less 40 kg/ha for secondary, and less than 5 kg/ha for micronutrients. Micronutrients require special attention and care because there is a narrow margin between too much and too little in the needs of plants. If too much of a given micronutrient (e.g., boron) is applied, it may have a harmful effect on the crop. Special compound fertilizers can be prepared containing micronutrients along with the NPK grades for soils and crops where deficiencies are known to exist.

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

Examples of benefits of using the right fertilizer source (RS)

Example RS-1: Effects of mineral fertilizers and organic resources on crop productivity.

Fertilizers contain nutrients that are immediately available for use by crops, while nutrients in organic resources are available slowly, as they are released during decomposition. Organic resources supply multiple nutrients, as well as organic carbon that improves soil organic matter, soil structure and soil pH. However, the effects of organic resources are highly variable, just as the quality of organic resources varies widely in nutrient and carbon contents.

Studies in many countries have shown that the use of mineral fertilizers and organic resources in combination is required to achieve the best yield results (Figure 4-1). The practice of using mineral and organic resources in combination, together with practicing good agronomic practices is known as Integrated Soil Fertility Management (ISFM). ISFM is based on combining the use of mineral and organic nutrient sources of nutrients. ISFM ensures that crop productivity is enhanced, without depleting soil nutrients and soil organic matter. ISFM works well for smallholder farmers because:

- Both mineral and organic resources are available to farmers in limited quantities. Combing them helps to increase the overall amounts of nutrient used in crop production.
- Mineral fertilizers and organic resources work differently and compliment each other. This results in higher yields when they are used together than when used separately, even when the same amount of N is applied.
- Combining mineral resources and organic resources helps to improve availability of nutrients throughout the growing season. It also ensures that soil fertility is maintained to support good crop productivity for many years.

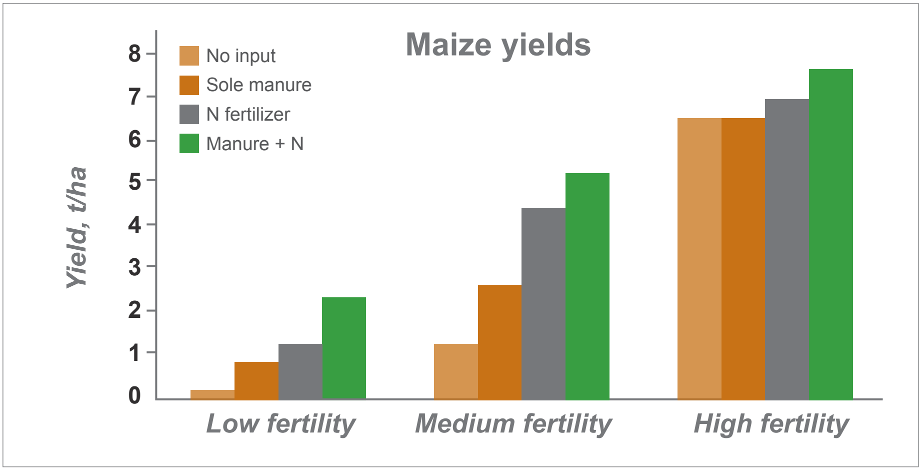
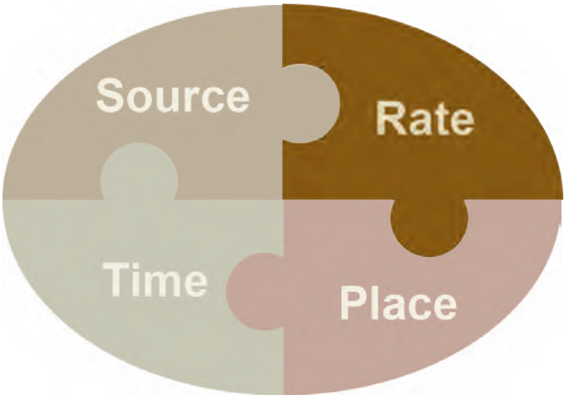


Figure 4-1: Effect of N applied as mineral fertilizer and cattle manure and their combination on maize grain yields in soils of varying fertility in SSA.

5. DETERMINING THE RIGHT RATE



Once the right source of nutrients is determined, it should provide the required plant nutrients in sufficient quantities, in balanced proportions, in available form, and at the time when the plants require them. The guidelines for determining the Right Rate of fertilizer are as follows:

- Consider source, time, and place of application.
- Assess the amount of nutrients required by the crop. Yield is directly related to the quantity of nutrients taken up by the crop until maturity.
- Select a yield target that the farmer feels capable of attaining. This must be realistic, based on soil and rainfall conditions. A yield target provides an important guide on the estimation of the total amount of nutrients required by the crop.
- Assess the capacity of soil to supply nutrients. Methods used include soil and plant analysis, and fertilizer response experiments. Where these are not available, simple methods such as crop production history and knowledge of soil types can also be used.
- Consider all available nutrient resources. For most farms, this assessment includes quantity of manure, composts, crop residues, as well as mineral fertilizers that are available.

- Consider the fertilizer requirements for the crop to be grown.
- Consider how management affects soil nutrients. If the output of nutrients from a cropping system exceeds inputs, soil fertility declines in the long term.
- Consider economics of the rate of fertilizer use. The additional application of fertilizer when fertilizer rates are already very high results in small yield increases and lowers economic benefits.
- For nutrients retained in the soil after harvesting, such as phosphorus and potassium their availability to future crops should be considered.

Ensuring the right rate of fertilizer application is important as under- or over-application of a particular nutrient may affect crop production, incomes, and the health of the soil. The yield of a crop will be mainly determined by the nutrient present in the most limiting quantity. In other words, the deficiency of one nutrient cannot be overcome by the excess of another. Therefore, all essential nutrients must be present in quantities sufficient to meet the requirements of the growing crop.

The right rate is conditional on source, time, and place. The nutrient source needs to release the right amount of available forms at the right time and in the right place to meet the needs of the growing plants.

5.1 How to determine the amount of nutrients required by crops

Different crops require different amounts of nutrients for healthy growth and maturity. The quantity of nutrients required also depends largely on the crop yield targeted. Matching nutrient supply with plant nutrient demand is required to select the right fertilizer rate. Some of the nutrients taken up by the crop will be removed from the field in the harvested portion of the crop, while the remainder will be recycled back into the system as crop residue. In situations where crop residues are removed to feed livestock, for fuel, or burnt, almost all nutrients taken up by the crop are removed from the field.

The total amount of nutrients required by a specific crop and yield level can be estimated by multiplying the expected yield for that crop by the amounts of nutrients taken for each tonne of yield. Estimates of nutrients removed for low, medium and high yield level for major cereal and grain legume crops in Africa are shown in Table 5-1. Different varieties of a crop will also differ in their nutrient requirements and their response to fertilizer. A local crop variety may not respond as well to fertilizers as an improved variety; for example, hybrid maize will often give a much better response to fertilizers and produce much higher yields than local varieties.

Table 5-1: Nutrients removed by crops at different yield levels

		Nutrient Removed (kg per hectare)		
	Grain yield t/ha	N	P_2O_5	K_2O
	1	24	12	18
Maize	2	48	24	36
	4	96	48	72
	8	192	96	144
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
Sorghum/Millet	1	20	12	30
	2	40	24	60
	4	80	48	120
Soybean	1	80	18	40
	2	160	36	80
	3	240	54	120
Beans	1	65	15	35
	2	130	30	70
Groundnuts	1	70	12	28
	2	140	24	56
	3	210	36	84

Although the figures given in Table 5-1 are a good first indication of the plant nutrient needs at the respective yield level, other factors have to be taken into account in order to determine the actual fertilizer requirement. For example, soil nutrient reserves as well as a possible unavailability of the applied nutrients to the plant roots due to different types of losses. Therefore, the nutrient requirements are generally higher than the nutrient removal by crops.

5.2 How to assess nutrients supplied by the soil

A portion of the nutrients required for plant growth is met by what can be supplied by the soil. The soil's capacity to supply these nutrients depends on several factors which include:

- **Soil organic matter levels:** the higher the soil organic matter level the higher the nutrient supply potential of the soil.
- **Soil texture:** clay soils have a greater capacity to retain nutrients and soil organic matter than sandy soils. Therefore, clay soils tend to have a greater nutrient supply potential than sandy soils.
- **The capacity of the soil to bind nutrients:** This applies mainly to phosphorus. Soils that bind phosphorus cover wide areas in SSA. These soils have low supply potential of phosphorus although their total soil P may be high.

Soil organic matter contains most nutrients required for plant growth. However, many of these nutrients exist in very small quantities, and will need to be complemented by fertilizers. In cropping systems where farmers have significant amount of organic matter, such as animal manure, the organic matter can be a dominant source of nutrients, particularly nitrogen and sulphur, and be complemented by some fertilizers.

One of the methods for determining soil contributions to plant nutrient supply is a soil test. Detailed information on soil sampling and testing can be found in Section 8. To be effective in providing recommendations for the Right Rate, soil testing should be combined with information from fertilizer experiments.

Soil testing is not readily available or affordable for most smallholder farmers. Other alternative approaches, such as farmer criteria for soil fertility assessment (including soil texture, colour and management history) and analysis of nutrient deficiency symptoms in crops can provide alternative approaches for general prediction of the capacity of the soil to supply nutrients.

5.3 How to assess nutrient contribution from local resources

When selecting the right fertilizer rate, the contribution toward meeting crop nutrient requirements coming from all available nutrient sources needs to be considered. Some of these sources include crop residues and green manures, animal manures and composts. In irrigated systems, irrigation water can also contribute substantial amounts of nutrients.

Potential nitrogen contribution from legume crops and green manures should also be considered. Part of the nitrogen in grain legume residues is manufactured by the roots of the legume crops, and is not removed from the soil. Therefore, when grain legume residues are retained in the field they provide nitrogen for the crop planted in the following season. Where cereal crops are grown in rotation with a legume, adjustments for the nitrogen application rate can be made.

However, the amount of nitrogen manufactured by different legumes crops varies widely. Some legumes with low nitrogen manufacturing potential, or which concentrate nitrogen in grain, may only have a small nitrogen contribution to the soil.

Some of the factors that influence potential soil nitrogen contribution by grain legumes include:

- The nitrogen-fixing capacity of the legume. Examples include:
    - Low nitrogen-fixing capacity: beans;
    - Medium nitrogen-fixing capacity: groundnut;
    - High nitrogen-fixing capacity: soybean; cowpea, pigeon pea.
- Some legumes require inoculation with specific rhizobia. If such legumes are not inoculated, the amount of nitrogen manufactured will be poor.

The yield and nitrogen manufacturing capacity of the legume crop are influenced by soil fertility and nutrient management. Legumes particularly require phosphorus and potassium, and where deficient, secondary and micronutrients.

Crop residues contain substantial quantities of plant nutrients. Recycling of such residues back to the soil increases the nutrient content of the soil. On the other hand, harvesting crop residues leads to increased removal of nutrients from the field, particularly potassium.

Photo 5-1: Farmers commonly remove crop residues from the field after harvesting to use as fodder or as a source of fuel.

The quantity of nutrients in organic materials varies widely. Average nutrient contents for some organic resources in smallholder systems are listed in Table 5-2; these vary widely across regions and farms. Other local guidelines for estimating nutrient contents of organic material can be used whenever available to adjust fertilizer rate recommendations accordingly.

Table 5-2: NPK contents of major organic resources in SSA. Average values are presented and nutrient contents for each source may vary substantially.

Plant material					
Type	***Name***	***Plant part***	***%N***	***%P***	***%K***
Legume tree	Acacia angustissima	Leaves	3.2	0.17	-
Legume tree	Calliandra calothyrsus	Leaves	3.3	0.17	0.8
Legume tree	Leucaena leucocephala	Leaves	3.9	0.19	2.1
Legume tree	Tephrosia vogelii	Leaves	2.9	0.18	1.1
			3.5	0.19	1.7
Herbaceous legume	Crotalaria Grahamiana	Leaves	3.0	0.13	0.8
Herbaceous legume	Crotalaria Juncea	Leaves	3.8	0.16	1.3
	Mucuna pruriens	Leaves	4.4	0.3	1.6
Shrub	Flemingia macrophylla		2.7	0.16	0.7
Shrub	Pigeon pea	Leaves	3.3	0.19	1.3
		Stems	1.3	0.06	0.6
Tree	Coffee	Husks	1.7	0.13	2.9
Grain legume	Groundnut	Leaves	3.0	0.17	2.4
Grain legume	Soybean	Leaves	3.6	0.15	2.4
Grain legume	Beans	Leaves	2.9	0.3	2.8
Grain legume	Cowpea	Leaves	2.9	0.11	2.1
Cereal crop	Rice	Leaves/stems	1.0	0.06	1.4
Cereal crop	Maize	Leaves/stems	0.9	0.07	0.7
Grass	Hyparrhenia	Whole plant	2.0	0.2	1.7
Manures					
Type			***%N***	***%P***	***%K***
Cattle			1.2	0.23	0.9
Goat			1.3	0.39	0.8
Sheep			1.3	0.50	-
Chicken			2.5	1.58	3.3

In many smallholder farming systems, crop residues are an important source of fodder. Nutrients can therefore be recycled back to the field through the use of manure.

5.4 How to assess fertilizer recovered by the crop

Determining how much of the fertilizer applied is recovered by the crop is a major factor in determining the fertilizer rate needed. Even with best management practices based on 4R Nutrient Stewardship, the amount of the applied fertilizer utilized by the crop will be less than 100%. Application of the 4R practices helps to improve the amount of fertilizers utilized by crops. Local area conditions also influence how crops utilize fertilizers. These include, weather, soil type, and cropping system. The effectiveness of fertilizer use by crops is termed as fertilizer use efficiency (FUE).

One method of calculating FUE that is useful in determining the right fertilizer rate is agronomic efficiency (AE). Agronomic efficiency is the amount of yield increase per unit of fertilizer applied, which can be calculated, in a simple way, as the number of bags of grain that are produced for each bag of the same fertilizer type applied. AE is calculated as follows:

AE = (Y-Y0)/F

Where:

i. Y is crop yield with fertilizer applied;
ii. Y0 is the crop yield with no fertilizer applied;
iii. F is the amount of fertilizer nutrient applied.

For example, application of 1 (50 kg) bag of urea applied per ha is expected to give the farmer between 5 and 20 (50 kg) bags of maize grain. High returns are obtained when other nutrients are applied with the nitrogen in urea.

Agronomic Efficiency can be used to estimate the rate of fertilizer required to achieve a certain yield target. If current yield and expected yield are known, the amount of fertilizer required is calculated as:

AF = (Y-Y0)/AE

5.5 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. The greater carbon contribution helps to maintain or build organic matter, which is a key factor in maintaining soil fertility.

Second, many nutrients are retained in soils, and the rate of their addition influences the levels of their availability in the soil over time. Nutrients retained in soils include phosphorus and potassium. When soils are very low in these nutrients, amounts considerably greater than the amount removed by the crop may be required to provide good crop yields.

When soils have high levels of these nutrients, amounts less than crop removal will be adequate. When soils are at a desired level of these nutrients, it is important to maintain this level by ensuring that the total amount of nutrients applied each year equals the amount of nutrients in the harvested crop.

5.6 Assessing the most economic rate of application

In situations where farmers aim to maximize income from crop production, they should apply the nutrient rate that will result in the greatest monetary return to the applied nutrient from the current crop. This rate will usually be less than the minimum rate that results in maximum crop yield, and will decline if input costs increase and crop price remains stable.

Aiming to achieve the nutrient rate that results in the greatest monetary return to the applied nutrient from the current crop is the approach typically used for nutrients like nitrogen and sulphur, which are mobile in the soil and not retained year to year. For nutrients that are retained in the soil, including phosphorus and potassium, the benefits of nutrient application are long-term in nature; therefore, their costs, and the returns from their application, are usually taken into account over several years. Applying fertilizer at rates to build soil fertility may not usually give the highest monetary return for just one crop, but may become economical over a longer time period when the responses in the following years are considered.

It should be noted, however, that most smallholder farmers produce staple crops for subsistence, with excess produce sold for household income. Fertilizer application rates that are higher than the economically optimal may be required to produce enough food for household consumption. In such cases, the major factor determining the Right Rate is the targeted yield that meets the household food requirement.

Practical example: Calculating fertilizer requirement from fertilizer recommendations

The amount of fertilizer to be applied per hectare or on a given field is determined through the amount of nutrients needed and the types and grades of fertilizers available. Usually mineral fertilizers are delivered in 50 kg bags. Therefore, the farmer has to know the quantity of nutrients contained in a 50 kg bag.

Nitrogen fertilizers

A farmer is advised to apply 40 kg nitrogen per ha to his crop as basal fertilizer at the time of planting. How much calcium ammonium nitrate (CAN) fertilizer should he apply? How many bags of CAN should he buy from a fertilizer dealer?

Solution

- According to the fertilizer recommendation the farmer would apply 40 kg nitrogen per ha.
- However, the CAN contains only 21% nitrogen, meaning that the amount of CAN required is: 40.0/0.21 = 190 kg CAN.
- Now, one bag of CAN fertilizer weighs 50 kg. Therefore, 190 kg CAN/50 kg/bag = 4 bags.
- 4 bags are therefore required

Phosphorus fertilizers

A farmer is advised to apply 20 kg phosphorus per ha on his 5-acre field. How many bags of triple super phosphate (TSP) or single super phosphate (SSP) should he buy?

- *For the same phosphorus fertilizer recommendation, which type of phosphorus fertilizer (and how much) should he apply to: ground nuts; maize?*

Solution

Caution: For phosphorus fertilizers, the % indicated on the bag refers to % available P_2O_5; to convert % phosphorus to %P_2O_5, multiply by 2.3.

- 1 ha is equivalent to 2.47 acres; 5 acres are equivalent to 5.0/2.47 = 2 ha.
- A recommendation of 20 kg phosphorus per ha translates into 20 kg phosphorus per ha x 2.3 = 46 kg P_2O_5/ha.

- Amount of P_2O_5 required for 2 ha is equal to 46 kg P_2O_5/ha x 2.02 ha = 93 kg.
    - For TSP containing 45% P_2O_5, amount of TSP required is 100/45 x 93 = 206 kg TSP, or 206 kg/50 kg/bag = 4 bags.
    - SSP is preferred for legumes due its sulphur content. SSP contains 20% P_2O_5, therefore amount of SSP required for 2.02 ha is 100/20 x 92.5 kg = 462.5 kg, or 462.5 kg/50 kg/bag = 9 bags.

- For maize the farmer can apply TSP or diammonium phosphate (DAP), the latter is preferred to TSP because of its added N content. If he were to apply DAP, the following computations hold:
    - DAP contains 46% P_2O_5,
    - Therefore amount of DAP required for 2.02 ha is 100/46 x 92.5 kg = 201 kg, or 201 kg/50 kg/bag = 4 bags.

Potassium fertilizers

For potassium fertilizers, the percentages indicated on the bag refers to % water-soluble K_2O; to convert % potassium to % K_2O, multiply by 1.21.

After soil testing, a farmer is advised to apply 60 kg potassium per ha to his banana crop. How much muriate of potash (KCl) should he apply?

Solution

- KCl is 60% K_2O.
- Therefore, amount of KCl to apply is 60/0.5 = 120 kg/ha.

Examples of benefits of using the right fertilizer rate (RR)

Example RR-1: Effect of phosphorus fertilizer application rate on maize yields

Phosphorus deficiency is a major factor limiting maize yields in Western Kenya. Applying the right rate of P ensures that farmers achieve the largest monetary gains from phosphorus fertilizer application while at the same time reducing yield losses due to under application.

A study in Western Kenya evaluated the effects of spot application of different rates of phosphorus fertilizer at a fixed nitrogen application rate of 60 kg nitrogen per hectare. Maize grain yield increased with increasing phosphorus application rates, with the highest maize yield achieved at a phosphorus application rate of 131 kg of phosphorus per hectare.

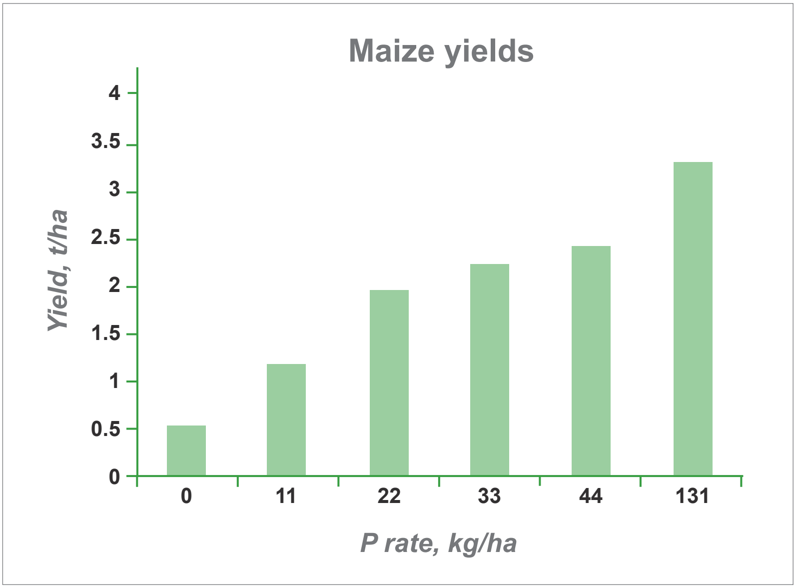


Figure 5-1: The effect of P fertilizer application on maize yields in western Kenya.

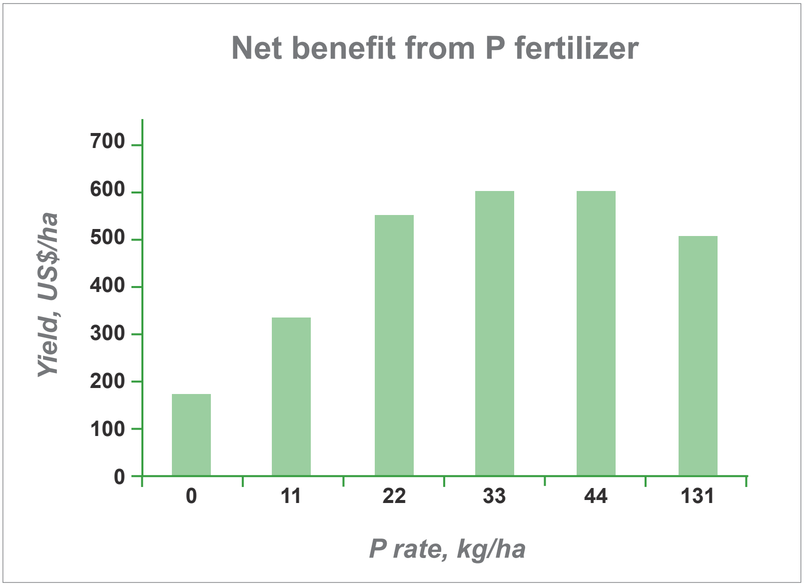


Figure 5-2: The effect of P fertilizer application on maize profits in western Kenya.

A cost benefit analysis of the different phosphorus rates however revealed that the maximum benefits from the application of phosphorus was achieved on the application of 44 kg of phosphorus per hectare. This illustrates that the fertilizer application rates that result in the highest yields are not necessarily the most economically viable.

When farmers have little cash to invest in fertilizer, applying P at rates that give the highest returns per each $ invested would be the best option (Figure 5-2).

The right fertilizer application rates should consider the yields and economic increases from each additional unit of fertilizer applied. For nutrients that are immobile, such as P, the P applied in one season will be available to the following crop; hence right rates should also consider residual P effects as well as P remaining in the soil for the following crop.

Notes

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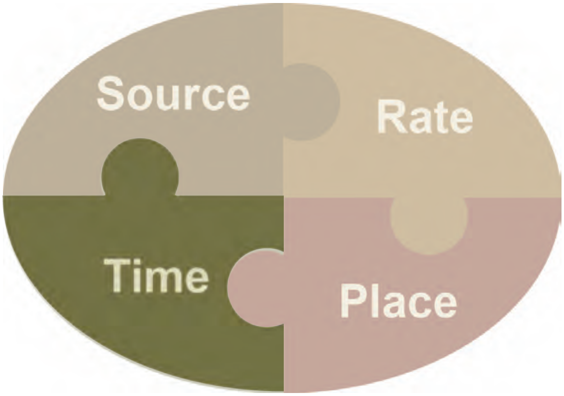
6. DETERMINING THE RIGHT TIME



The guidelines for right time for a nutrient application are as follows:

- Consider source and rate.
- Consider the dynamic of nutrient uptake by the plant of interest. Nutrients should be applied to match the seasonal crop nutrient demand, which depends on planting date and crop growth characteristics.
- Assess dynamics of soil nutrient supply. Mineralization of soil organic matter supplies some nutrients, but if the crop's uptake needs are not matched by the release of nutrient, crop yields will be limited.
- Recognize dynamics of soil nutrient loss. For example, nitrogen is easily lost especially in sandy soils and should be applied in 2-3 splits during season when growing cereal crops.
- Consider labour availability. Timing of nutrient application should not delay time-sensitive operations such as planting. For example, manure application demands a lot of labour, and should be applied before the first rains to avoid delaying of planting.

6.1 Assessing timing of plant uptake

Assessing crop uptake dynamics and patterns can be an important component in determining appropriate timing of nutrient application. Most crops take up nutrients slowly at the early stages of growth, and nutrient uptake increases to a maximum during the rapid growth phase, and declines as the crop matures. Rate of plant nutrient uptake is thus not consistent throughout the season.

Applications timed correctly at specific growth stages are beneficial to crop yield and the quality of the grain produced. Well-timed applications are also important to reduce nutrient losses.

Key examples for good nutrient application timing include:

- Nitrogen application to cereal crops such as maize should be done two or three times during the growing season (split application). When applying nitrogen at three stages, one-third of the nitrogen should be applied at planting together with other nutrients. Additional application of nitrogen at 4 weeks (one-third) and 8 weeks (one-third) after planting is recommended. This split application is very important to match the periods when plant needs most N. Nitrogen not taken by the plants moves rapidly out of the rooting zone, and cannot be used by the plant.

- As grain legumes use the nitrogen from the air, all fertilizer is applied at the time of planting, with no additional nitrogen required as the crop is growing.

- When growing groundnuts in soils deficient in calcium, addition of calcium fertilizers, such as gypsum, are needed at the time when groundnut pods are developing. Application of calcium fertilizer is sometimes required just before flowering.

6.2 Assessing availability of soil nutrients during the cropping season

Soils supply some of the nutrients required by a crop. Generally, the more sandy the soil, the lower the nutrients that a soil can supply. Also, soils that have been cultivated for long periods with little additions of mineral fertilizer or organic resources can only supply small amounts of nutrients. Soil nutrients supplied by the soil are relevant to the rate component of the 4Rs, but it can impact timing options and requirements as well. Factors (including weather) that influence the rate of mineralization may influence the specific times optimum for fertilizer application.

In general terms, the greater the soil's capacity to retain and supply nutrients and provide it throughout the growing season, the less need there will be for adding that nutrient.

Two contrasting examples:

- For many agricultural soils, P and K fertilizers can be applied once to supply the needs for one or more crops grown in the same field. The applied phosphorus and potassium are held by the soil, but remain available to crops grown the next season.

- Acidic soils common in high rainfall areas in Africa bind phosphorus fertilizer and make it unavailable to growing plants. In such soils annual application of phosphorus fertilizer must be done in a concentrated band at planting to enhance uptake by the roots.

6.3 Assessing the risk of soil nutrient losses

Nitrogen requires good management because it is easily lost from sandy soils. Nitrogen can be lost though several ways such as washing through the soil by rain (or irrigation), dissolved in runoff water, or lost into the air as gas. Phosphorus is much less likely to be washed through soil in rain or irrigation water, but losses are mainly from surface water runoff. Placement of phosphorus fertilizer below the surface can greatly reduce the risk of loss by runoff water.

In situations where there is significant potential for loss of nutrients, the fertilizer should be applied at the correct time. For example, application of nitrogen fertilizer in sandy soils in high rainfall areas requires several applications at low rates to reduce risk of losses, or sometimes supplemental late applications may be needed should a late heavy rain leach the earlier-applied nitrogen from the soil.

6.4 Evaluating timing of field operations

- The labor availability for fertilizer application and other field and household operations affect timing decisions.

- Timing of fertilizer applications should also take into account weather conditions. For example top dressing nitrogen 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.

- The availability of fertilizer can be a problem in many smallholder farming areas in Africa. Therefore, fertilizer should be purchased well in advance to ensure that correct fertilizer types are available for use at the right time.

- Fertilizers that release nitrogen slowly can be applied as a single application early in the season. However, the slow release fertilizers are more expensive than standard fertilizer, and they are mainly used in commercial farming.

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Examples of benefits of applying fertilizer at the right time (RT)

Example RT-1: Effect of fertilizer split application on yield.

Nutrients such as nitrogen quickly move down the profile (leaching) when it rains resulting in plant roots failing to absorb them. These nutrients can join water resources and reduce water quality. To reduce the losses, which are costly to the farmer, it is necessary to apply the fertilizer at difference growth stages of plant growth. This is called split application of fertilizer. Split application allows the fertilizer to be applied in amounts required by crops during growth.

Typically, one third of nitrogen fertilizer is applied at planting in the form of compound fertilizer together with all the plant requirements of phosphorus, potassium and sulphur. Two-thirds of the nitrogen is applied as topdressing at 4-8 weeks after planting in one or two split applications. The number of split applications depends on soil type and rainfall distribution, among other factors. Nitrogen moves down sandy soils much faster and therefore more split applications are required compared to clay soils. High rainfall amount and intensity causes more nitrogen to be washed out of the soil and therefore more split applications are required such conditions compared to low amount and intensity rainfall.

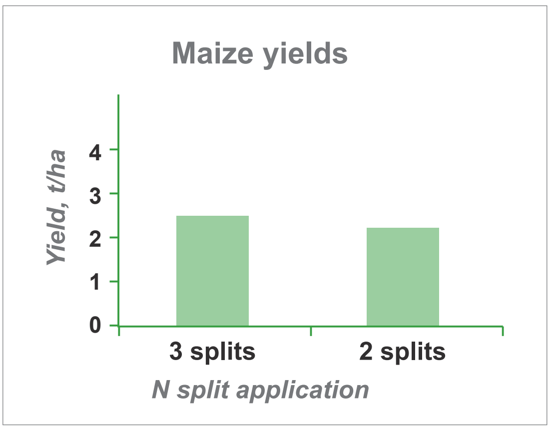
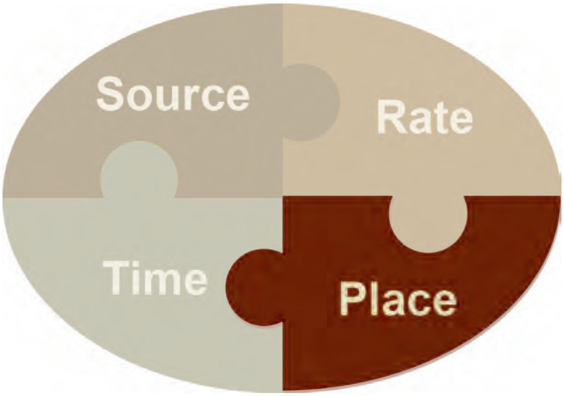


Figure 6-1: Effect of N split application on maize yields in high rainfall areas in eastern Zimbabwe.

7. DETERMINING THE RIGHT PLACE



Applying nutrients at the right place means adding nutrients to the soil at a place where the crops can easily access them. Right place depends on many factors that include the type of crop, tillage practices, plant spacing, crop growth stage, crop rotation or intercropping, and weather variability.

The main guidelines for right placement of nutrients are the following:

- Consider source, rate, and time of application.
- Consider where plant roots are growing. Nutrients need to be placed where they can be taken up by growing roots when needed.
- Consider mobility of nutrients in the soil. Nutrients that move little in the soil, such as phosphorus, should be concentrated in bands or holes close to the plants to improve availability.
- Suit the tillage system under practice. For example, special equipment is used to apply fertilizer under the soil while maintaining crop residue cover in conservation tillage systems can help to conserve nutrients and water.
- Manage differences in soil fertility within a field or between different fields in a farm. Assess soil differences within a field and between different fields in a farm and decide on fertilizer application based on soil fertility differences.

7.1 Fertilizer placement method

There are four main different methods for placement of fertilizer or organic resources that include:

7.1.1 Broadcasting

- Fertilizers are applied uniformly to the surface of a field and incorporated.
- Broadcasting is suitable for crops with a dense planting population, such as rice.

Photo 7-1
Step 1: Fertilizer weighed into container.

Photo 7-2
Step 2: Spreading fertilizer by broadcasting.

- It 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.
- Whether the fertilizer is broadcast by hand or with fertilizer spreading equipment, the spreading should be as uniform as possible.
- The method is easy to implement and has low labour requirements.

7.1.2 Banding

- Used when fertilizer placement near the plant rows is required.
- Fertilizers are placed in bands or strips at a depth of 5-8 cm below the soil surface.
- The fertilizer applied in the band should be placed under, or beside the seed, and covered with soil. Direct contact between the seed or the germinating plant should be avoided, especially when fertilizers containing ammonium are used, as they affect germination.
- It is preferably used for crops planted in rows, when there are relatively large spaces between rows, but relatively small spaces between plants (beans, soybean, and millet).
- It is effective on phosphorus fixing soils.
- It is also effective when the amounts of fertilizer available are too small to be broadcast on soils with a low fertility level.
- To ensure uniform distribution, the amount of fertilizer to be placed in each row should be determined and measured out in an appropriate container.

Photo 7-3: Basal fertilizers applied by banding

7.1.3 Spot application/Hill placement

- Fertilizers are applied in small amounts close to each planting hole at planting or close to the each plant during the crop growing season.
- Spot application is the most effective method when very low rates of fertilizer are used.
- To ensure uniform distribution of fertilizer, small dollop cups of different sizes that are calibrated to achieve various application rates should be used. Where dollop cups are not available, farmers can also use small containers (such as bottle tops), but should confirm the level of fertilizer that is required to achieve a desired application rate.
- Spot application is also preferred when crops are widely spaced and when the risk for nutrient losses through leaching are high.

Right method for spot application: Basal fertilizer application

Photo 7-4
Step 1: The right size of dollop cup or soft drink bottle-top is used for desired fertilizer application rate

Photo 7-5
Step 2: Basal fertilizer is applied at the time of planting by placing fertilizer at one side of the planting hole to avoid direct contact with seed

Right method for spot application: Basal fertilizer application

Photo 7-6

Step 3: Covering fertilizer after basal spot application

Right method for spot application: Top dressing fertilizer application

Photo 7-7

Step 1: Top dressing fertilizer applied using a dollop cup.

Photo 7-8

Step 2: Top dressing fertilizer placement by spot application.

Photo 7-9

Step 3: Covering fertilizer after top dressing application.

7.1.4 Deep placement

- Urea fertilizer can be compressed into large granules ranging from 1-4 g, that are larger than normal fertilizer granules. The granules are placed 5-10 cm into the soil by hand or specially designed applicators.
- Deep placement is an effective method for nitrogen application to paddy rice.
- The disadvantages of the deep placement method are that (i) the compressed fertilizer granules are more expensive than standard fertilizers, and (ii) deep placement is a high labour demanding operation.

Photo 7-10: Mechanical urea deep placement.

NOTE:

For any fertilizer placement method, basal nutrients should be incorporated immediately after application, to avoid losses due to runoff and erosion. Incorporation of urea and ammonium-based fertilizers also reduces losses that may occur through emission of ammonia to the air. When fertilizer is applied by hand, care should be taken to distribute nutrients uniformly and at the exact rates.

Where fertilizer application equipment is used, it should be adjusted to ensure uniform spreading and correct rates. The equipment should be well maintained.

7.2 Applying fertilizer to variable fields

In addition to placement within the soil or on the plant, right place also considers where to apply nutrients within the farm. Most smallholder farms consist of field units that are managed differently and vary in soil fertility status. On many farms, more fertilizers and manure are used on fields closest to homesteads, than on fields further away. This results in differences in soil fertility on fields within the same farm.

Differences in management also contribute to differences in soil fertility on fields between farms. Such differences should be considered when farmers make decisions on where to apply limited fertilizers within the farm. Farm- and field-specific fertilizer application recommendations should consider:

1. Prioritizing nutrient application to the fields that give the greatest yield response to fertilizer or organic resource application.
2. Applying moderate amounts of nutrient resources in very fertile fields to maintain soil fertility and avoid nutrient depletion.
3. Use various soil organic matter and land management practices to restore soil fertility and improve crop productivity in degraded fields.

Examples of benefits of applying fertilizer at the right place (RP)

4R Example RP-1: Variability in fertilizer response on fields of different soil fertility status.

Soil fertility varies from field to field on smallholder farms. This can be on different fields on the same farm or on different farms. Part of the soil fertility variability is caused by different management practices. Farmers in many regions in SSA use very limited amounts of fertilizer and organic resources such as livestock manure. The limited resources are mostly concentrated in fields closest to homesteads 'homefields' with little added to fields further away 'outfields'. This results in fields with high soil fertility status in small areas around the homestead and infertile of degraded fields further away. These differences in soil fertility should be taken into account when deciding on how farmers can efficiently use limited nutrient resources.

In many cases, homefields tend to give better yield responses than outfields that are very poor in soil fertility. This is because many factors including poor soil conditions due to low soil organic matter contents limit crop response to fertilizer application. Precision placement of nutrients on smallholder farms should first consider soil fertility variability on the farm. Farmers should prioritize applying fertilizer to fields that give the highest fertilizer response.

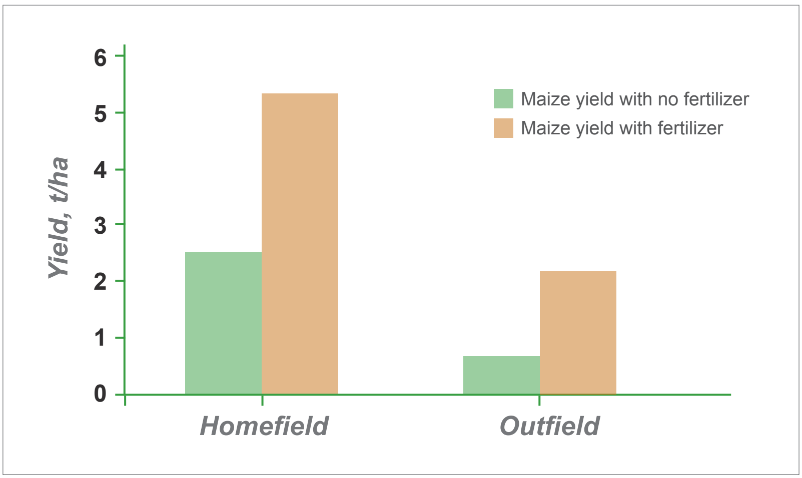


Figure 7-1: Typical maize yield with and without fertilizer application on homefields and outfields on smallholder farms.

4R Example RP-2: Effect of P fertilizer placement on maize yields.

Phosphorus has low mobility in the soil and identifying the most suitable phosphorus application method is therefore important to maximize the yield and economic benefits achieved from phosphorus fertilizer application.

Results from a study in Western Kenya showed that spot application of phosphorus at a rate of 131 kg of phosphorus (P) per hectare (P131) produced higher yields compared to the broadcasting (B131) and incorporation of a similar amount of phosphorus fertilizer in different soil types. The P was applied as TSP at the time of planting. As phosphorus is immobile in the soil, concentrating phosphorus close to the plant by spot application allows the plant roots to take up the phosphorus more effectively. However, spot application is more labour demanding, the choice of application method will need to take into account labour availability.

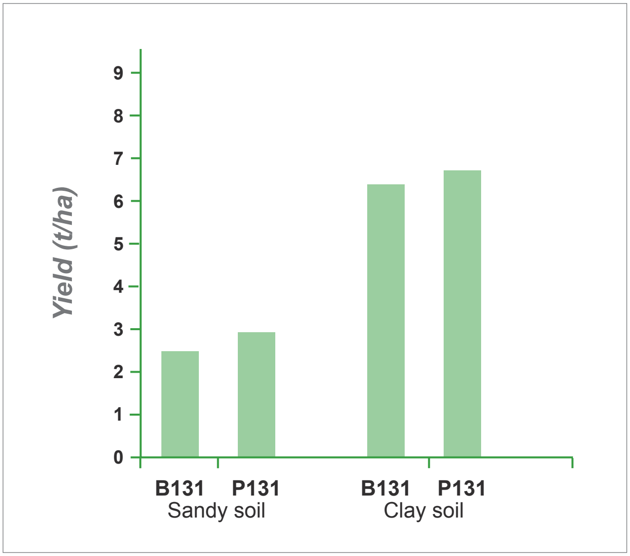


Figure 7-2: Effect of P fertilizer broadcasting (B) versus spot application (P) on maize yields.

8. SIMPLE APPROACHES TO DETERMINE FERTILIZER NEEDS

8.1 Nutrient deficiency signs in plants

If plants do not get enough of a particular nutrient they need, there are signs that show that a particular nutrient is in short supply that can be seen in the general appearance as well as in the colour of the plant.

The observation of the deficiency signs is easy in some cases, but difficult in others. The reasons are:

- Deficiency signs of two different nutrients can look similar.
- When more than one nutrient is in short supply, the deficiency sign of one nutrient can hide signs of other nutrients.
- Some hunger signs are not caused directly by shortage of nutrients, but by poor soil conditions such as too much water in the soil.
- Some deficiency signs can easily be confused with viral or fungal disease symptoms or damage caused by insect pests, toxic effects of agrochemicals such as herbicides.

Because of these possible difficulties, there may be need to verify hunger signs by soil tests and field experiments.

Though hunger signs are useful as an indicator that a particular nutrient is in short supply, applying adequate nutrients to feed the crop after the hunger signs have already appeared will still result in lower yield as compared to that from crops which receive adequate fertilizer from planting to harvesting.

Nitrogen shortage in crops can be corrected if nitrogen is applied after observing deficiency symptoms. However, adding phosphorus and potassium after the hunger signs have already appeared is less effective for the current crop. Therefore, good fertilizer management should avoid serious nutrient deficiencies for a crop throughout the growing season.

General hunger signs for some crops are specified below:

Nutrient	***Sign***	
Nitrogen	• Plants grow poorly and appear very small • Yellow leaves, starting from the older leaves • Lower leaves die early while the top of the plant remains green (this can sometimes be mistaken for lack of soil water)	
Phosphorus	• Plants look very short • Leaves appear purple • Grain is poorly filled	
Potassium	• Poor plant growth • Leaves dry up along the outer edges • Plants easily fall	

Magnesium	• Yellow colouring between green leaf veins.	
Sulphur	• Plant leaves are yellow and this can be mistaken as nitrogen deficiency. • The main difference with nitrogen deficiency is that sulphur shortage causes yellowing of upper leaves, even on newest growth.	
Calcium	• Young leaves show yellowish colour • Plants appear to wilt • Roots are poorly developed.	

Zinc	• Short growth of leaves • Yellow lines between the leaf veins in lower part of leaf	
Iron	Young leaves show yellow lines between green veins. The lines cover the whole length of the leaves	

8.2 Soil testing

Soil testing is used to find out how much of a nutrient will be available for the plants from the soil, and how much should be additionally applied in the form of a mineral fertilizer to reach an expected crop yield. The higher the level of a soil test in plant nutrient, the less is the amount needed from fertilizers.

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. A soil test cannot be better than the sample that is tested. Therefore, careful sampling is a must. Where soil testing is an option, extension workers can help farmers to collect, package and send samples for analysis.

The following steps should be followed to collect soil samples:

1. Identify the fields to be sampled and sample them separately.
2. Do not mix soils from different fields.
3. If soil in any area of a field appears different, or if crop growth is significantly different from the rest, the area should be sampled separately.
4. The tools for taking a sample are a spade and a knife. If available a can be used soil borer (auger) is more appropriate because of standard depth and diameter.
5. A clean bucket and container should be used to place soils (care should be taken to thoroughly clean the bucket or container which has previously been used for fertilizer spreading).
6. If a spade is used, a V-shape should be cut to a depth of 20 cm.
7. A knife is then used to trim off both edges of the slice leaving a strip (core) of soil on the spade 2 cm wide.
8. About 3-5 spade cores should be randomly taken over a quarter- acre field. The number of samples should be adjusted for a small or larger field.
9. The samples should be placed in a clean bucket and mixed thoroughly.
10. A composite sample of 0.5 kg of the mixed soil (usually after air-drying it on a clean sheet of paper) should be taken and placed in a sample bag.
11. The sample bag should be clearly labeled. Label information should include name of farm, field location and date of sampling.

12. A diagram of the area for a particular sample can also be drawn in the farmer's notebook, so that the soil test results can be related correctly to the field.

The major challenges for soil testing in SSA are:

- The high costs of soil analysis
- The testing laboratories are often in towns far from major smallholder farming areas.

8.3 Plant sample analysis

Analysis of nutrient amounts in the plant can also provide a good way to show which nutrients are deficient in the plants. Collection and analysis of plant samples is more difficult than soil sampling and testing, and should be done with the support of researchers.

8.4 Fertilizer trials

Fertilizer field trials are important to determine the nutrient needs of crops in relation to the final yield obtained. In such trials, fertilizers are applied at known nutrient rates (often done in line with the data found with soil or plant testing), crop responses are observed, and final yields are measured.

Field trials have the following advantages:

1. They are the best way to determine the nutrient needs of crops and soils for advising farmers on their fertilizer needs.
2. They will show you how accurate recommendations based on soil and plant testing are in relation to the yield obtained.
3. They permit an economic evaluation of the profits that farmers can get from the use fertilizers.
4. The growing crops can be photographed. The pictures can be used in publicity and demonstrations for many years.
5. Demonstrations or simple trials show the benefits of fertilizers to farmers and agricultural workers. The way to conduct demonstration (or a simple trial) is discussed in Chapter 9.

General recommendations for a region are available when enough fertilizer trials have been carried out. However, nutrient needs for a crop on a given soil cannot be determined once and for all, because conditions change over time. When only one nutrient is applied (unbalanced fertilization), another may become limiting.

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9. FERTILIZER EXTENSION WORK

Extension agents and agrodealers play an important role to help farmers make good decision on purchase and use of fertilizer. Demonstrating 4R practices to farmers through conversation, articles, fieldwork and meetings will help farmers understand how good fertilizer management will lead to higher crop yields and income.

When communicating to the local farmers about fertilizers, extension workers should know the fertilizer types available. Information include what grades of fertilizers are available in stock and what is the time required to order them. Secondly, extension workers should contact researchers in their area for any up-to-date information available on fertilizer recommendations.

Field demonstrations should be implemented on the basis of these recommendations, which should be adapted to the results for a particular area. Field demonstration should be conducted with the participation of farmer groups starting with the design stage to implementation and evaluation. This helps farmers understand the process of developing and practicing good 4R practices. Fertilizer demonstrations should be integrated in a program of good agricultural practices.

9.1 Conducting a fertilizer demonstration

Before starting a fertilizer demonstration good planning is required based on the following questions:

1. What do I want to demonstrate to the farmer?
2. With which crop will the demonstration be most convincing (most valuable or most grown in your area or most needed for food)?
3. With which farmers will I cooperate? What will be the best-situated place or field for the demonstration?
4. What fertilizer do I have available for use on the selected crop?
5. When and how do I have to apply the fertilizer? What other measures do I need to take into account?

Therefore, in order to carry out a fertilizer demonstration you need to prepare and have ready the following:

- A plan for the demonstration (two or more plots, where and with which crop, size of each plot, demonstration on one field only or on several fields).
- A notebook for the demonstration plan, for plot records (amount of nutrients applied, date of application), location of plots, growth observations, weed and pest control during crop growth and the final yields.
- One or more interested farmers who will work with you and help you to conduct the demonstration in his/their fields.
- Fertilizer of the right grade or grades at the right time and a dry place to store the fertilizers before use.
- A scale or balance to weigh out the fertilizer quantity for each plot.
- Paper bags, preferably multi-layered, in which you put the fertilizer for the different treatments clearly marked.
- A measuring tape or device to determine the plot size/length and shape; stakes and strings to mark the plot boundaries, particularly the corners.
- Harvesting equipment, including cutting tools, and scale or balance for measuring crop yields.
- Information on actual fertilizer and agricultural produce prices, and possibly a pocket calculator to calculate the economic outcome of the demonstration (value/cost-ratio VCR and/or the net profit).

As a general rule: Keep your fertilizer demonstrations simple.

9.1.1 Design

Various designs can be used to demonstrate different aspects of fertilizer management.

1. To demonstrate the need for fertilizer application. The simple design would be: no fertilizer versus recommended fertilizer.

2. If you want to convince farmers to use a higher rate of nitrogen and/or phosphorus and/or potassium you have to adapt the design to compare two rates of nutrients. The design then would be:

No fertilizer; lower rate of nutrient; (e.g. 30 kg N/ha); higher rate of nutrient (e.g. 60 kg N/ha).

The same design is used for phosphorus and potassium. The demonstration while testing a higher rate of one nutrient, should always be done in the presence of the other two nutrients (balanced fertilization).

3. If you want to demonstrate to the farmers the importance of balanced fertilization you will have to use three or four plots with the following treatments:

- *No fertilizer versus plot with only nitrogen (N)*
- *Plot with nitrogen and phosphate (NP)*
- *Plot with nitrogen, phosphate and potassium (NPK)*

Variations of this design with four plots are:

- *No fertilizer N – just PK*
- *or no fertilizer P – just NK*
- *or no fertilizer K – just NP*
- *Fertilized with NPK*

4. In addition to proving the benefits of fertilizer use you may also want to demonstrate the benefits of improved agricultural practices, particularly the system of integrated plant nutrition. Then you need a four plot design:

- *Plot: no fertilizer with farmer's practice*
- *Plot: recommended fertilizer with farmer's practice*
- *Plot: no fertilizer with recommended improved practices*
- *Plot: recommended fertilizer with recommended improved practices*

9.1.2 Determination of plot size

The size of demonstration plots will depend on the field size of farms. In regions where farms and fields are small, the demonstration plots also have to be small.

However, they should be large enough to make convincing demonstrations and to get accurate yield data to determine the effect of the treatments. Thus, the size of plots used for each treatment may vary between 50 to 400 square meters (5 m x 10 m up to 10 m x 40 m).

In general, the plots used in the demonstration should be rectangular and laid out side-by-side. Paths of 0.5 to 1 m in width should be left between the plots and around the site of the demonstration. To avoid movement of water between plots during periods of intense rainfall, sufficiently high bunds must be placed around the plots. Keep in mind the topography of the field: plots should be protected to avoid movement of water from one plot to the other. In addition, planting rows must be perpendicularly to the slope direction.

9.1.3 Calculation of fertilizer rates per plot

If you wish to apply straight fertilizers to the demonstration plot (i.e., urea, triple superphosphate and muriate of potash), calculate the quantities for the different treatments according to the formula below:

Amount of fertilizer needed per plot =
[Nutrient rate (kg/ha) x plot area] / [Percentage nutrient in fertilizer x 100]

Table 9: An example of a treatment structure for a demonstration.

Plot	N	P_2O_5	K_2O
1	0	0	0
2	30	30	30
3	60	60	60

With a nutrient rate of 30 kg N/ha, a plot area of 50 square meters and urea with 46% N as nitrogen fertilizer the calculation is as follows:

Amount of urea needed per plot:
[30 x 50] / [46 x 100] = 0.33 kg of urea needed per plot.

Therefore, you would have to weigh out 0.33 kg of urea per plot for treatment b) and 0.66 kg for treatment c). For a plot size of 400 square meters the necessary quantity of urea would be 2.64 kg and 5.28 kg, respectively. Rates in pounds and acres can be calculated in a similar way.

9.1.4 Evaluation of fertilizer demonstrations

The demonstration sites must be regularly visited throughout the season, wherever possible with the owner of the field. Data on growth development as well as on rainfall/irrigation, weed and disease control, etc. should be written down in your notebook.

The harvesting and weighing of the yield can be done in the course of a field day. It will be important to have information on fertilizer costs and agricultural produce prices at hand, so that you can calculate the value/cost-ratio or the net profit and prepare diagrams and posters to be shown at the field day. When calculating the value/cost-ratio you divide the value of the increase in crop yield by the cost of fertilizer applied to obtain that yield:

[Value of yield increase (in terms of money)] / [Fertilizer costs (in terms of money)]
= Value/cost-ratio (VCR)

Annex: Conversion factors for various units for area, distance, weight and fertilizer.

Area				
1 hectare	=	2.471 acres		
1 acre	=	0.4047 hectare		
Distance				
1 metre	=	1.0936 yards	=	3.2808 feet
1 yard	=	3 feet	=	0.9144 metre
1 centimeter	=	0.3937 inch		
1 inch	=	2.54 centimeters		
Weight				
1 kilogram	=	2.2046 pounds		
1 pound	=	0.4536 kilogram		
1 kg/ha	=	0.8922 lb/acre		
1 lb/acre	=	1.1208 kg/ha		
1 metric ton	=	2 204.6 pounds		
Fertilizers				
Phosphorus				
P_2O_5	=	P x 2.2914		
P	=	P_2O_5 x 0.4364		
Potassium				
K_2O	=	K x 1.2046		
K	=	K_2O x 0.8302		

Glossary

4R Nutrient Stewardship	Is a way to increase crop yields, profits and environmental benefits by ensuring the Right fertilizer source, is used at the Right rate, at the Right time and in the Right place.
Acidic soils	Soils with a pH below 7.
Alkaline soils	Soils with a pH above 7.
Agro-dealer	Small-scale independent stockists or input distributors of fertilizer, seeds and agro-chemicals.
Agronomic efficiency	The difference between yield in a control plot and in a plot supplied with a particular nutrient divided by the amount of the given nutrient applied.
Agronomy	The use of science to manage soils and crops to produce food, fuel and fibre.
Biological nitrogen fixation	A process by which nitrogen (N_2) in the atmosphere is converted into ammonium (NH_4+) by nitrogenase - a biological catalyst found naturally in the symbiotic *Rhizobium.*
Blanket fertilizer recommendations	Generally applicable fertilizer use rates that do not consider variability in soils, farm management and climate.
Commercial farming	A large-scale production of crops and animals for sale
Crop residues	The part of the crop biomass that is left when the grain or tuber has been removed.
Crop rotation	A practice of growing different crops in the same area in different seasons.
Fertilizer	Any natural or manufactured material, which contains at least 5% of one or more of nitrogen, phosphorus and potassium.
Green manure	A green manure crop is grown for a specific period, and then ploughed under and incorporated into the soil when still green.
Harvest index	The ratio of grain/tuber to total biomass production.
Hybrid seed	Is seed produced by cross-pollinated plants created to breed a desired trait or characteristic, the crosses are specific and controlled.

Integrated plant nutrition	Combined use of mineral and organic fertilizers to address site-and soil specific deficiencies for improved crop productivity.
Legume	A plant in the family *Fabaceae*, or the fruit or seed of such a plant.
Limiting nutrient	Single nutrient that is in short supply that limits crop growth.
Macronutrient	A chemical element (nitrogen, phosphorus, or potassium) of which relatively large quantities are essential to the growth and health of a plant.
Micronutrient	Nutrients required in small quantities (i.e., less than 0.1% of plant dry matter) by the crop, often sufficient in most soils.
Nitrogen fixation	A process by which nitrogen (N_2) in the atmosphere is converted into ammonium (NH_4+).
Nitrogen mineralization	The process by which organic N is converted to plant-available inorganic or mineral N form.
Nutrient deficiencies	Demand for nutrients is less than the soil supply resulting in reduced or impaired plant growth.
Open pollinated variety (OPV)	Seed produced when pollination occurs by insect, bird, wind, humans, or other natural mechanisms. Due to lack of restrictions on the flow of pollen between individuals, open-pollinated plants are more genetically diverse.
Plant root nodules	A swelling on the root of a leguminous plant, such as the soybean, that contains bacteria of the genus *Rhizobium*, capable of nitrogen fixation.
Rhizobia	Bacteria present in the soil that form root nodules with compatible legume plants and are able to fix atmospheric nitrogen (N_2) within the nodules.
Rhizobia inoculation	The process of applying commercially produced Rhizobia to legume seed or to the soil where legume seed will be planted to introduce compatible and effective symbiotic bacteria and improve nodulation and biological nitrogen fixation.
Soil fertility gradients	Differences in soil fertility caused by differences in crop management (e.g., application of organic and mineral fertilizers) within a farm over the long term.

Soil pH	Soil pH is a measure of the acidity or alkalinity in soils.
Soil texture	The amount of sand, silt and clay in the soil.
Soil type	Usually refers to the different sizes of mineral particles in a particular sample, the three basic soil types are clayey, loamy and sandy soils.
Split application	Is the application of the desired amount of fertilizer two or three times during the growing season as opposed to a single application.
Spot application	When fertilizer is applied to each planting hill.
Subsistence farming	The farmer only grows or produces enough to feed his or her family, often suffer food deficits.
Symbiosis	An interaction between two different organisms living in close physical association, to the advantage of both organisms.
Topography	Is the arrangement of the natural and artificial physical features of an area.

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