CURRENT INNOVATIONS IN MAKING SITE SPECIFIC NUTRIENT MANAGEMENT

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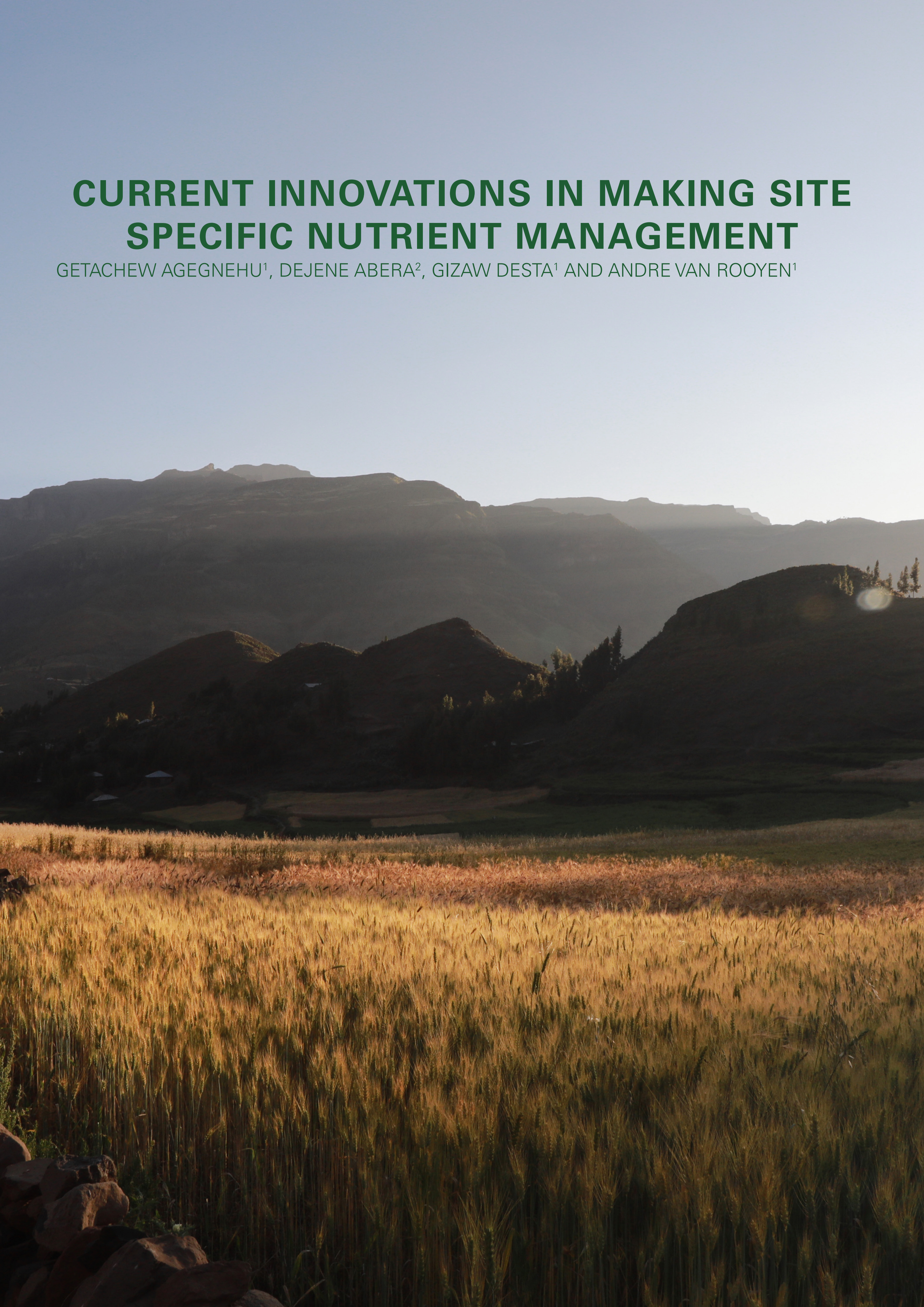

The Africa Research In Sustainable Intensification for the Next Generation (Africa RISING) program comprises three research-in-development projects supported by the United States Agency for International Development (USAID) as part of the US Government's Feed the Future initiative.

Through action research and development partnerships, Africa RISING is creating opportunities for smallholder farm households to move out of hunger and poverty through sustainably intensified farming systems that improve food, nutrition and income security, particularly for women and children and conserve or enhance the natural resource base.

The three regional projects are led by the International Institute of Tropical Agriculture (in West Africa and East and Southern Africa) and the International Livestock Research Institute (in the Ethiopian Highlands). The International Food Policy Research Institute leads the program's monitoring, evaluation and impact assessment.

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FOREWORD

A CALL FOR SITE SPECIFIC NUTRIENT MANAGEMENT IN ETHIOPIA

This manual is produced to provide a way out of constraints associated with blanket fertilizer recommendations in Ethiopia. There is a general trend of soil fertility decline in the farmlands of Ethiopia. Furthermore, the soil fertility status and response to fertilizer application varied between different farms and along the different landscape positions. When compared to the foot slope and backyard areas, the decline in soil fertility is very high in the hillslope areas due to erosion and no/or limited replenishment of organic inputs to the farmlands. Despite the increasing level of fertilizer import in the country, the soil degradation problem has limited crop response to fertilizer application which resulted in low productivity of soils. In recent years, soil degradation and decreasing crop productivity in slope areas and varying responses across different landscape positions, agro-ecology, farming system, soil type and production seasons to fertilizer application have received considerable attention to opting for site specific nutrient and other management practices.

Site specific nutrient management approach is a dynamic, plant based, field and season specific nutrient management approach. It aims to synchronize nutrient supply and demand according to differences in crop requirements, indigenous nutrient supply and nutrient recovery from fertilizer and other sources. It is an approach of feeding crops with the right nutrient source, at the right rate, when required (right time) at the right place. The use of Decision Support Tools (DST) that can provide guidelines for fertilizer use and expected yield levels at various spatial and temporal scales is vital for smallholder farmers who have limited resources to get laboratory analysis for their soils. Several studies reported increased fertilizer use efficiency and reduced crop production risks with the use of decision support tools. The overall objective of this training module is to ensure effective fertilizer use to increase grain yields of smallholder farmers in Ethiopia. This manual will also enhance knowledge among the agricultural extension staff as a way of boosting their capacity to disseminate site specific nutrient management innovations appropriately.

ACKNOWLEDGEMENTS

We acknowledge the funding from the USAID in Washington to the Africa RISING project in the Ethiopian Highlands and funders for the Mixed Farming Systems hrough their contributions to the CGIAR Trust Fund. .

HOW TO USE THE MODULE

With fertilizer representing a major cost input, applying fertilizers and/or soil amendments following proven scientific principles is vital to ensure optimized economic return without adding to environmental concerns. This module is designed to provide basic principles on site specific nutrient management (SSNM), the benefits of SSNM over the blanket fertilizer recommendation and its application to the Ethiopian farming condition. The module is prepared to help the woreda level extension experts and subject matter specialists (SMS) to give training to development agents and farmers on SSNM to enable efficient fertilizer use. To make the learning process more active, pre and postassessment of the readers' knowledge of SSNM is included in each module section. This could also be done in group discussions. The module mainly contains and describes:

- Site specific nutrient management principles
- The need for SSNM over the blanket fertilizer recommendation in Ethiopian agriculture
- The 4R (Right Source, Right Rate, Right Time, Right Place) in site specific nutrient management

Considering the varying nutrient supply of different soils and uptake by different crops in different agro-ecological zones and growing seasons, the recommendations presented in this module are general guidelines. Hence, mainstreaming the principles of SSNM with location context, indigenous knowledge and continued monitoring, evaluation and learning is highly encouraged to achieve the objectives of SSNM and hence improve response to fertilizer applications. Internalizing acquired knowledge and skills through discussions and practical application is also vital.

Additional relevant evidence and information sources are listed for those seeking more indepth information about site specific nutrient management.

PREASSESSMENT: RESPOND TO THE FOLLOWING ASSESSMENT QUESTIONS BEFORE PROCEEDING TO THE NEXT SECTION

1. Awareness of the 4Rs (Right Type, Right Amount, Right Time, Right Place) principles in site specific fertilizer recommendation
   A. Fully aware of it
   B. Partly aware of it
   C. Not aware of it at all
2. Do you know what dictates/influences crop response to fertilizer application [respond 'Yes' or 'No' for the listed below]
   A. Landscape position
   B. Soil type
   C. Agro-ecology
   D. Production season
   E. Fertilizer/nutrient source
   F. Fertilizer/nutrient rate

G. Fertilizer application time
H. Fertilizer application place

3. Why selecting the right time for fertilizer application is vital to get better crop response? Encircle the right answer.
   A. It provides an opportunity to synchronize with crop maximum demand and better uptake
   B. It enables to escape nutrient loss agents such as torrential rainfall after fertilizer application
   C. It enables to avoid crop damage that can be caused due to fertilizers such as urea application when soils are dry
4. Why using the right nutrient source is important to improve grain yield in crop production? [Respond 'Yes' or 'No' for the listed below]
   A. Different nutrients have an unequal contribution to yield improvement
   B. Yields can be improved by applying nutrients that are not yield limiting nutrient in that location
   C. Identifying the yield limiting nutrient and applying that nutrient in sufficient amounts is the solution to improve the yield
5. How does the right place for fertilizer application influences crop yield?
   A. Different nutrients have a different level of mobility in the soil
   B. Different fertilizers have different effects when applied in contact with the seed, plant roots or leaves
   C. Different fertilizers have different effects when applied in contact with seeds, plant roots or leaves
   D. Different fertilizer placement methods have a different level of fertilizer use efficiency and environmental risks
6. How different is site specific nutrient management (SSNM) from what is already in use?

If you missed one or more questions from the above, then this module is for you. We encourage you to read further and get the answers.

MODULE LEARNING OBJECTIVES

The learning objectives of the module are to enable the learners:

- describe major factors dictating crop response to fertilizer applications
- list the principles governing SSNM
- justify the need for SSNM to the agricultural production system in Ethiopia
- list important steps to start using SSNM

MODULE OVERVIEW

Fertilizer recommendations in Ethiopia are often based on crop response data averaged over large areas, though farmers' fields show large variability in terms of nutrient supplying capacity and crop response to nutrient applications. Blanket fertilizer recommendation over large areas of smallholder farming systems fails to meet the spatially varying nutrient requirement of crops and hence the yield increment. In Ethiopia, landscape position is among the other factors governing soil variability and hence crop response to fertilizer applications in different landscape positions. For instance, varying crop response to applied fertilizer (ranging from 50 to 300% higher in foot slopes than in hillslope landscape positions) is reported. In addition, field cropping history or management practices can also cause farmland variability and hence crop response to fertilizer applications. Due to such variability, the possibility of over or under application of nutrients is very high with its economic and environmental consequences with the existing blanket fertilizer recommendations. This leads to inefficient use of added nutrients, as the current fertilizer recommendation rates do not well address the spatial variability in nutrient supply and response variability among the fields.

Making an informed decision or recommendation on the nutrient application in terms of the "right" type, amount, time and placement of fertilizer, also known as the site specific nutrient management (SSNM) approach, is vital for better use efficiencies of the applied fertilizers. The SSNM approach is a dynamic, plant based, field and season specific nutrient management approach. It aims to synchronize nutrient supply and demand according to the differences in crop requirements, nutrient supply capacity of soils and nutrient recovery from fertilizer and other sources. The SSNM approach was first developed by researchers of the International Rice Research Institute and their national partners in Asia in the 1990s to address spatial variability in soil fertility and response to fertilizer application in smallholder rice farming systems. The amount (rate) of fertilizer application seems mostly a more emphasized component probably due to its direct relation to cost. On the other hand, the right nutrient source, time and place of application are frequently overlooked and may hold more opportunities for improving performance. SSNM provides an approach to "feeding" crops with nutrients as and when required. Hence, it ensures that the required nutrient types are applied at the proper rate, time and place based on the soil nutrient supply potential, crops' nutrient needs, soil related properties and the status of the cropping season. With good crop management, SSNM increased yield by about 45 to 200% over farmers' fertilizer practice. Decision support tools (DSTs), software was developed based on multiple parameters known to affect the response of crops to fertilizer/nutrient application, are vital for nutrient management planning. It can give support to SSNM by estimating the amount of fertilizer or nutrient to be applied for different crops in the specific production area and season. In general, applying fertilizers following proven scientific principles is essential to ensure an increase in the productivity of crops without adding a negative impact on the environment. Hence, there is an urgent need to create awareness and capacitate the extension officers and development agents for the necessary advice and capacities to be delivered to farmers to adopt the SSNM approach using DSTs.

MODULE LEARNING CONTENTS:

- Right source
- Right rate
- Right time
- Right placement
- Right management
- Decision support tools for site specific nutrient management

SESSION 1. RIGHT SOURCE

LEARNING OBJECTIVES

The learning objectives of this session are to enable the learners to:

- describe the major process that occurs in the soil after applying Urea and DAP fertilizers and/or other soil amendments
- recognize how soil and climate properties affect nutrient availability in soil
- describe major factors influencing the decision for different fertilizer types/nutrient sources

MODULE OVERVIEW

Selecting which nutrient source or fertilizer type to use begins with evaluating which nutrients are required for optimal plant growth and which form of nutrients to apply. Climate, topography, parent material, organisms and time as soil forming factors determine the dominant soil forming processes and consequently the type of soils in a given area. The physicochemical properties of soils including landscape position, soil pH, Soil Organic Matter (SOM), salinity or sodicity can limit crop response to fertilizer application unless the necessary amendments are in place. Understanding the major process that occurs in the soil after applying fertilizers and/or other soil amendments would help to decide which nutrient source of fertilizer type to apply depending on the location specific soil physicochemical properties.

Nitrogen and phosphorus, in that order, are the most limiting nutrients for cereal crop yield in the soils of Ethiopia. Other nutrients can be important in some specific locations and crop types. This must be identified in a specific location for specific crops. Advice on such information and what form and rate of these nutrients to use can be obtained from the local level agricultural extension office provided that is already included in the extension package. The nearby agricultural research centres can also provide such advice. Visual observation of deficiency symptoms during the crop vegetative growth stage can also help to identify which nutrients also limiting and are required to apply.

MODULE LEARNING CONTENTS

- Primary macronutrients forms for plant uptake
- Secondary macronutrient forms for plant uptake
- Micronutrients for plant uptake

PREASSESSMENT: Respond to the following assessment questions before proceeding to the next section

Categorize the listed nutrient elements (N, P, S, Fe, Mo, Ca, Mn, Mg, Cu, K, Zn, B, Cl) into the following nutrient categories

A. Primary macronutrients
B. Secondary macronutrients
C. Micronutrients

Which nutrient group is required in larger quantities by plants?

A. Micronutrients
B. Macronutrients
C. Primary macronutrients
D. Secondary macronutrients

What soil problems require amendments for better crop response to fertilizer application?

A. Soil acidity
B. Organic matter depleted soils
C. Low moisture stressed soils
D. Waterlogged heavy soils

What are the benefits of knowing and using the right source of nutrients for crop production?

A. Gives solution to the yield limiting nutrient first
B. Avoids unnecessary application of the nonlimiting nutrients
C. Gives the opportunity to consider the suitable source that can be applied to the soil properties
D. A and B
E. All

List major factors you need to consider while determining the right nutrient source/fertilizer type

Write down your opinion on the combined use of organic fertilizers with inorganic fertilizers for sustainable production and the challenges for farmers to apply it

If you missed one or more questions from the above, then this module is for you. We encourage you to read further and get the answers.

PLANT NUTRIENT AND THEIR SOURCES: WHAT DOES PLANT NUTRIENT SOURCE MEAN?

A plant nutrient is a chemical element that is essential for plant growth and reproduction. An essential element is a term often used to identify a plant nutrient. Normally, for an element to be a nutrient, it must fit certain criteria; the first main criterion is that the element must be required for a plant to complete its life cycle. The second criterion is that no other element substitutes fully for the element being considered a nutrient. The third criterion is that all plants require the element.

Plants require about 17 essential elements. Based on the amount required by plants, they can be grouped into three: namely, primary macronutrients, secondary macronutrients and micronutrients. The right nutrient source must supply the required nutrients in plant available forms or in forms that convert timely into a plant available form in the soil.

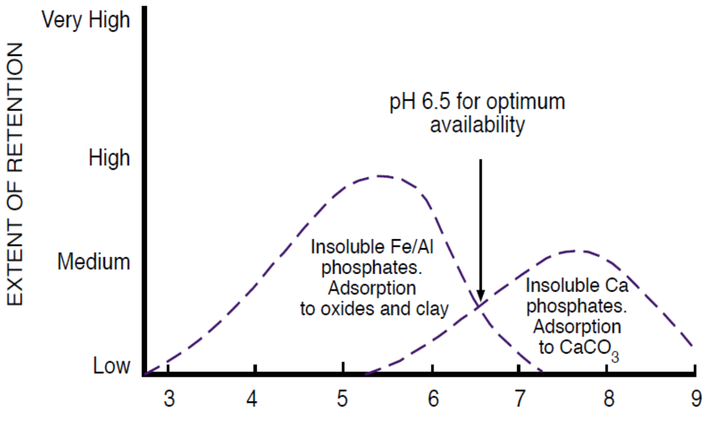
Essential Nutrients			
Basic elements	**Primary macronutrients**	**Secondary macronutrients**	**Micronutrients**
Carbon (C)	Nitrogen (N)	Sulfur (S)	Manganese (Mn)
Hydrogen (H)	Phosphorus (P)	Magnesium (Mg)	Iron (Fe)
Oxygen (O)	Potassium (K)	Calcium (Ca)	Copper (Cu)
			Zinc (Zn)
			Boron (B)
			Chloride (Cl)
			Molybdenum (Mo)
			Nickel (Ni)
	Plants require primary macronutrients in larger quantity than secondary macronutrients		Plants require micronutrients only in smaller quantity

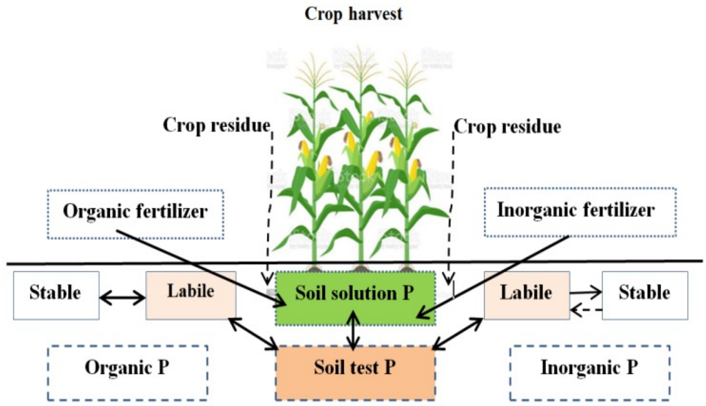
PRIMARY MACRONUTRIENTS (N, P AND K) FORM FOR PLANT UPTAKE

Urea fertilizer as a source of N is the most used fertilizer in Ethiopia. Nitrate (NO_3^-) and ammonium (NH_4) are the most plant available forms of N. Urea applied to soil in the presence of moisture, gets converted into ammonium bicarbonate by the commonly occurring urease enzyme through hydrolysis. Urease enzyme is abundant in most soils, plants and residues. Nitrate, formed by nitrification of ammonium in the presence of oxygen by nitrifying bacteria, is very mobile (susceptible to leaching) and repelled from the negative charges of the clay surface. Ammonium is attracted to exchange sites on clay surfaces.

Diammonium phosphate [$(NH_4)_2HPO_4$] and NPS compound fertilizers are commonly used P-source fertilizers in Ethiopia. Orthophosphate ions ($H_2PO_4^-$ and HPO_4^{2-}) are the most readily accessed phosphorus form by plants. Phosphorus containing fertilizer such as DAP applied to soil reacts with water and gets converted into HPO_4^- and NH_4^+. Ammonium (NH_4^+) follows the same routes as in the case of urea and it improves P uptake by the plant. Depending upon the soil reaction (pH), phosphorus availability to plant roots and its retention can be affected (Figure 1).

Figure 1. Soil pH affects P retention and availability for plant uptake (a) and the fate of P-fertilizer after addition to soil (b).

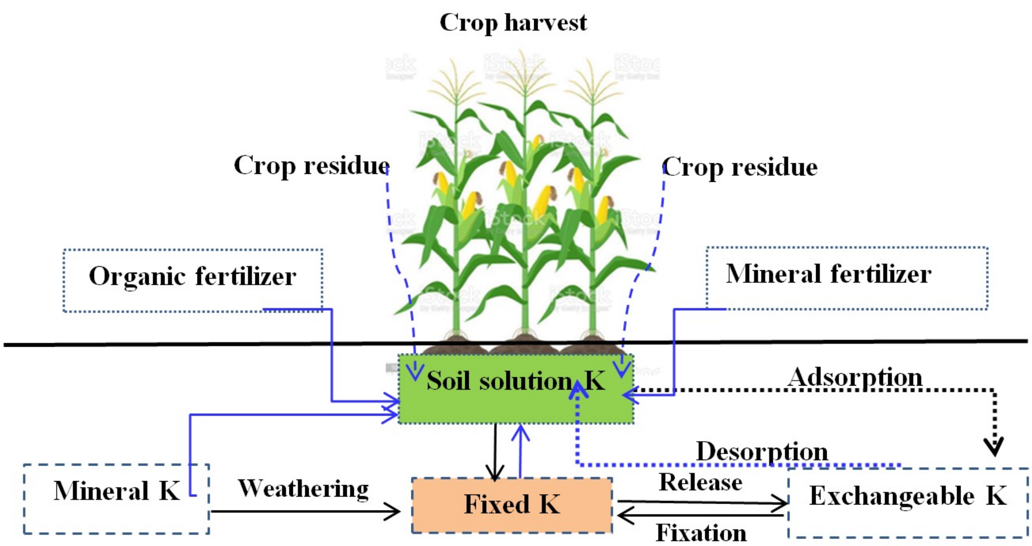




Solution P is a very small part of the total soil P. It is the P fraction taken up by plants. Labile soil P is more plentiful than soluble P but it is still only a small fraction of total soil P. Labile P is not strongly adsorbed in the soil and may enter the soluble phase quickly. Soil test P encompasses both the labile and the soil solution P. Lastly, stable/non labile P is unavailable to plants and constitutes the largest fraction of total soil P. With time, a small amount of non labile P converts to labile P and solution P.

Plant available K includes solution K and exchangeable K (Figure 2). The common potassium fertilizers are Muriate of potash (MOP) and Sulfate of potash (SOP), which combines K+ with chloride (Cl–) or with sulfate (SO42–), respectively. The two fertilizer types have advantages and disadvantages determined by their chemical behaviour in soils and the nutrients supplied in addition to potassium. Potassium chloride (KCl) supplies chloride (Cl–), which is an essential micronutrient. Potassium sulfate (K2SO4) supplies plant available sulfate sulfur (SO4–S). The potassium in both fertilizers is in the same form and these salts are water soluble, though the water solubility of SOP is about one-third that of MOP. The biggest disadvantage of MOP is its high salt index (116 for MOP 0–0–60 vs. 42 for SOP 0–0–50) and chloride content.

Figure 2. Fate of K fertilizer after addition to soil.



The ‘fertilizer salt index’ is a measure of salt concentration that induces salinity in the soil solution. The salt index is a numeric ratio of the increase in osmotic pressure produced by a selected fertilizer product compared to that produced by the same weight of sodium nitrate (NaNO3), where sodium nitrate is assigned a relative value of 100. Sodium nitrate is used for comparison as it was widely available when the salt index was developed and it is 100% soluble in water. The salt index of some common fertilizer products is presented in Table 1.

Table 1. Salt index of various common fertilizer materials available in Ethiopia

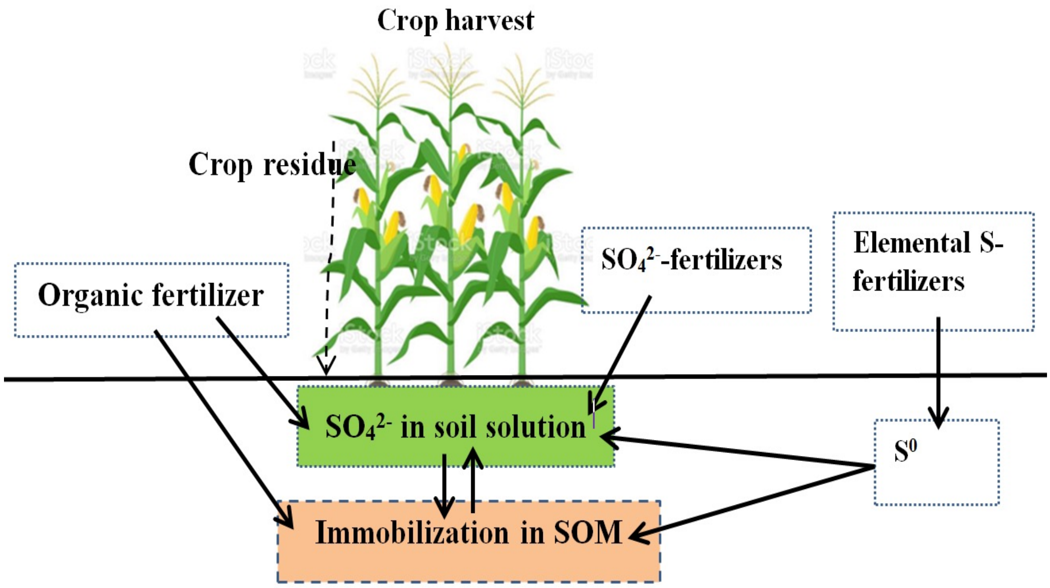
Fertilizers and nutrient analysis	Salt index per equal weights of NaNO3
Nitrogen	
• Ammonium Nitrate (34% N)	104
• Ammonium Sulfate (21% N and 24% S)	88.3
• Urea (46% N)	74.4
Phosphorus	
• Diammonium Phosphate, DAP (46% P_2O_5, 18% N)	29.2
• Monoammonium Phosphate, MAP (50–52% P_2O_5 and 10–12% N)	24.3–26.7
• Triple superphosphate, TSP (46% P_2O_5)	10.1
Potassium	
• Potassium Chloride/Muriate of Potash, MOP (60% K_2O)	116.2
• Potassium Nitrate (44 K_2O, 13 N)	69.5
• Potassium Sulfate/Sulfate of potash, SOP (50% K_2O, 18% S)	42.6

Source: Mortvedt (2001).

SECONDARY MACRONUTRIENTS (S, CA AND MG) FORM FOR PLANT UPTAKE

Secondary macronutrients are just as important as any of the other 14 essential plant nutrients for plant nutrition, except for their amount. Plants require S in the form of sulfate (SO4–2) that exists primarily in soil solution. The sulfate in soil solution is replenished by mineralization of organic matter, weathering of mineral S, oxidation of reduced S and desorption. Sulfate fertilizers are immediately available to crops but are prone to leaching below the root zone especially in sandy soils in high rainfall areas. Elemental S fertilizers must first be oxidized by soil microorganisms to sulfate for crop uptake but are not leached from soil (Figure 3).

Figure 3. The fate of fertilizer S added as either elemental S (S0) or sulfate (SO42–) in soil.



Both Ca and Mg in soils occur as soluble divalent cations (Ca2+ and Mg2+), on cation exchange sites and in carbonate minerals. Calcium and magnesium dynamics in the soil are quite like potassium. As for potassium, when plants absorb soluble ionic forms from the soil solution, it is then replenished from exchangeable and mineral calcium and magnesium. The absence of clay fixation with calcium and magnesium cycle is the major difference as compared to that of potassium nutrient cycle.

Low exchangeable calcium content in the soil often causes acidity problems due to low base saturation before actual calcium nutrient deficiency becomes an issue. Unlike calcium, magnesium is mobile within the plant and easily translocate from older to younger tissues. Hence, Ca deficiencies affect the growing points and younger tissues while Mg deficiency affects first the older leaves. Applying Ca and Mg occurs most commonly through liming practice. Therefore, if acidic pH problems are corrected through liming, calcium and magnesium supply will be maintained and at amounts more than removed with crop harvest, except when the form used is pure calcitic lime. Plants require less magnesium than calcium, but deficiencies are more common because less magnesium exists in the soil solution and on the soil exchange complex.

MICRONUTRIENTS FOR PLANT UPTAKE

Micronutrients [boron (B), chloride (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), zinc (Zn) and nickel (Ni)] are essential to plant growth, yet they are required in much smaller amounts than macronutrients. Metal micronutrients (Cu, Fe, Mn, Zn, Ni) are positively charged and held strongly by the soil, especially at pH levels above 7. Chelation process, a process where dissolved organic substance or 'chelate' binds with a metal cation to form a soluble metal–organic complex, results in increased desorption or dissolution of the metal micronutrients for plant uptake. Hence, management practices, which increase soil organic matter, can increase the degree of chelation, thereby increasing their availability to plants.

The anion micronutrients (B, Cl, Mo) exist either as neutral or negatively charged molecules in soil water and are held less strongly, except for Mo. Soils high in Fe/Al oxides will absorb Mo strongly, reducing Mo availability. Higher levels of phosphate increase Mo availability because P and Mo are so similar that P will compete for the same absorption sites as Mo, resulting in Mo desorption.

The soil reaction characteristics are important parameters to consider as they affect nutrient availability to the crops. The soil pH generally suitable for plant root growth is close to neutral ranging from a slightly acidic pH of 6.5 to a slightly alkaline pH of 7.5. Nitrogen (N), Potassium (K) and Sulfur (S) are major plant nutrients that appear to be less affected directly by soil pH than most others do. Phosphorus (P), however, is directly affected (Figure 1). Most other nutrients (micronutrients especially) tend to be less available when soil pH is above 7.5. The exception is molybdenum (Mo), which appears to be less available under acidic pH and more available at moderately alkaline pH values.

WHY IS IT IMPORTANT TO KNOW ABOUT NUTRIENT SOURCES?

Selecting the right fertilizer product/nutrient or other amendments for the nutrient needs of the crop or soil properties ensures:

- better resource use efficiency
- better yield and quality targeted
- identify which fertilizer types have a high salt index
- understand the relative tendency of fertilizer to raise the salt content of the soil and
- select the right fertilizer source based on the soil properties

Fertilizers with a high salt index can damage seedlings and weaken plants by reversing natural osmotic pressure and oversaturating crops with insoluble element forms.

Crop response to fertilizer application can be influenced by soil physicochemical properties, agricultural land management practices and landscape position differences which are also a function of the soil forming processes.

A. For acidic soils, incorporating liming material to raise the pH from the strongly acidic range to near neutrality (depending on the sensitivity of the crop to be grown) is a prerequisite. Such amendments are important to improve P and Mo availability, reduce Ca and Mg deficiency and improve yield and resource use efficiency in general. The yield increment of 30–40% with liming alone and 50–100% increment when liming is combined with ISFM was reported in Ethiopia.
B. Landscape variability also creates soil fertility variability between farms in terms of soil nutrient status. Considerable differences in the nutrient supply capacity of soils (e.g. Zn, Cl, P) in different landscapes were confirmed from field studies. Different studies including that of ICRISAT and Africa RISING project have confirmed the soil physicochemical properties including the nutrient levels, SOM content and soil texture are considerably varying in the undulating landscape of the agricultural land in Ethiopia. The studies further demonstrated significant differences in crop

responses to the same nutrient source fertilizer applications: 50 to 300% higher in foot slopes than in hillslopes. The decision as to what is the right source to satisfy crop needs is hence vital by considering the soil supply capacity. In some soils and landscape positions, amendments and/or supplements with the right source is a prerequisite to get optimum agronomic and economic returns to fertilizer/nutrient applications.

C. Applying organic sources (compost/vermicompost/manure/biochar), cereal–legume crop rotation and/or intercropping are vital for sustainable production. These practices replenish soils with some macro and micronutrients, improve soil physiochemical properties, soil water and nutrient retention capacity and hence improve the applied fertilizer use efficiencies in general. It then contributes towards the development of a resilient agricultural production system to the climate variability impacts and ensures the environmental integrity of the production system.

D. Soil organic carbon is a promising indicator for guiding N fertilizer use that leads to better water and nutrient use efficacies (Figure 4). Studies at hillslopes and/or other land areas with low soil organic matter, demonstrated that application of organic fertilizers improved soil water content, water use efficiency, agronomic N use efficiency and grain yield (Figures 4 and 5). This could imply that critical/minimum SOC amounts need to be maintained to realize improved nitrogen use efficiencies and optimal yields.

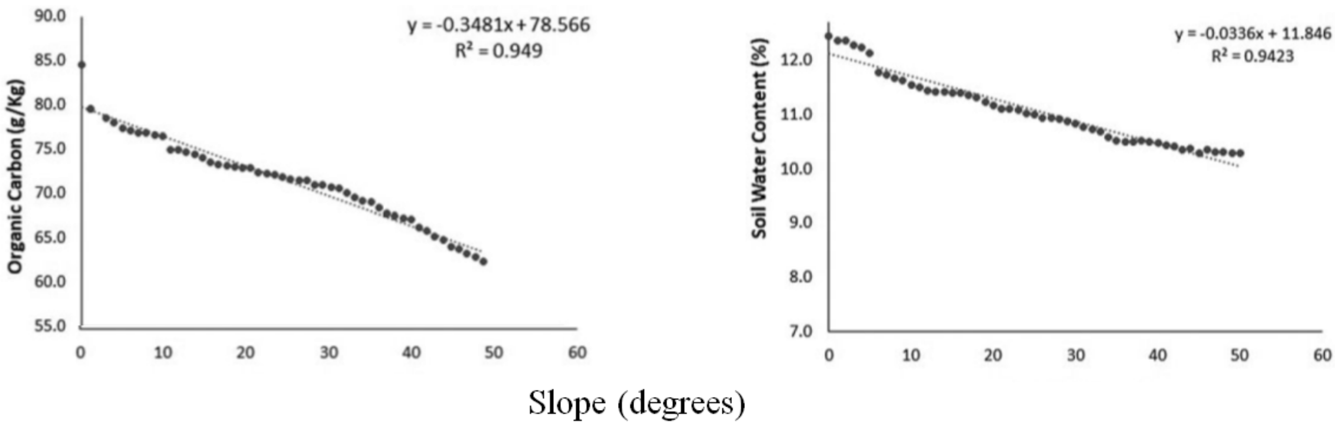
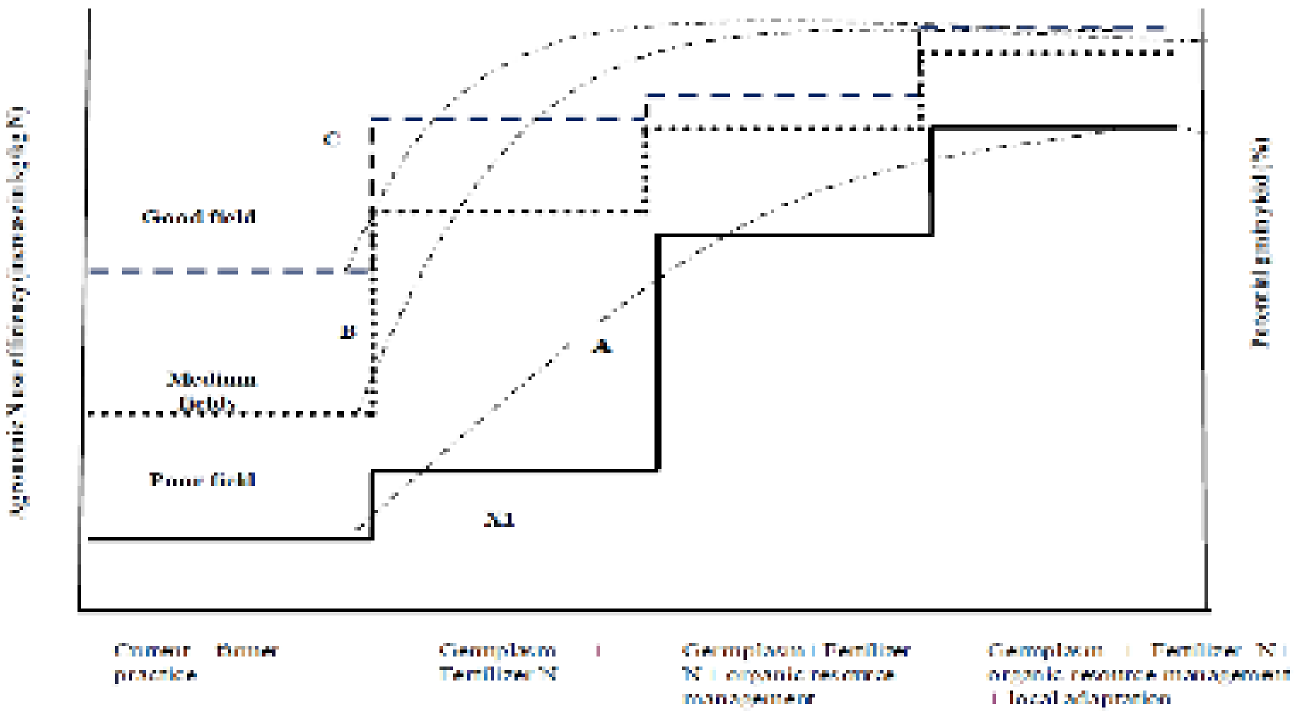


Figure 4. Relationships between slope and soil organic matter; and between slope and soil water content at woreda scales, Ethiopia.

Source: Amede et al. (2020).

Combined use of organic fertilizers with inorganic fertilizers can increase the total nitrogen, organic matter and available phosphorus content in the topsoil by 11.9, 18.7 and 97.8%, respectively, compared to the equal chemical NPK input. Adopting practices that increase organic matter can help produce more mineralized P and hence increase soil test P and its availability for plant uptake. Replenishing soils with organic inputs improve the availability of some micronutrients in soils to the level, it could satisfy plant requirements.

Figure 5. Conceptual relationship between the Agronomic Efficiency (AE) of added N fertilizers and organic resources, potential grain yield and implementing various components of ISFM under tropical farming heterogeneity.



HOW TO DECIDE ON THE RIGHT NUTRIENT SOURCE?

Selecting the right fertilizer source begins with determining which nutrients are limiting yield and required to achieve target yields. Visual deficiency symptoms in the field can provide a simple option to determine nutrient requirements in their specific locations. Furthermore, the existing soil conditions, landscape, position and farming practices of a given area dictate the need for different nutrients and amendments required for the best results. Hence, considering the following factors is vital to identify adequate fertilizer type and/or other amendments.

Identify the nutrients that are yield limiting for the target crops in the area. Nitrogen and phosphorus in this order are the most yield limiting nutrients in the farmlands of Ethiopia. The recently conducted nutrient omission experiments throughout the country confirmed the same. Fertilizer type recommendation maps are a source of this type of information that can be tailored to location context using practical experiences of visual deficiency symptoms observed in the field (Figures 6 and 7).

Figure 6. Visual leaf assessment.

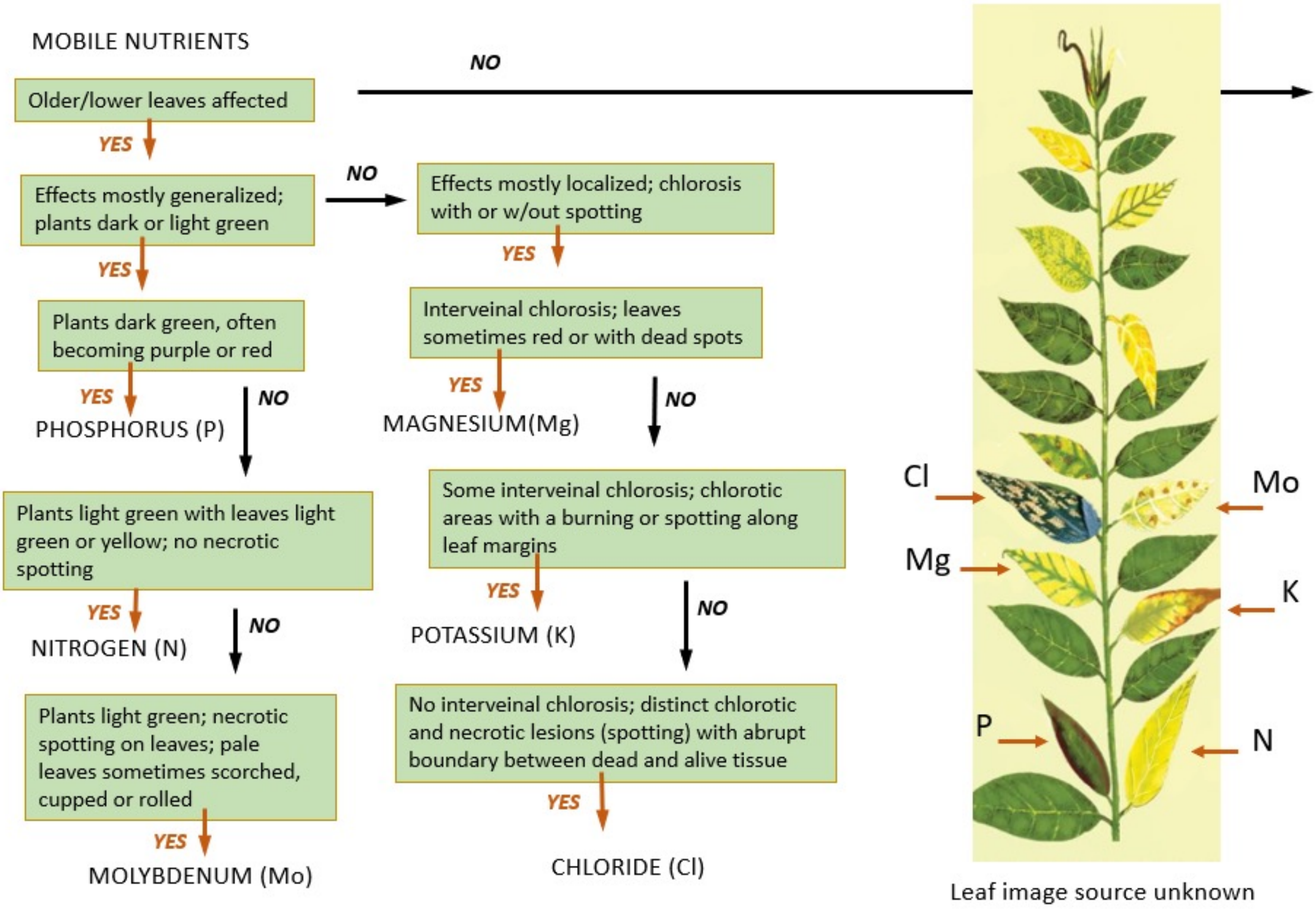
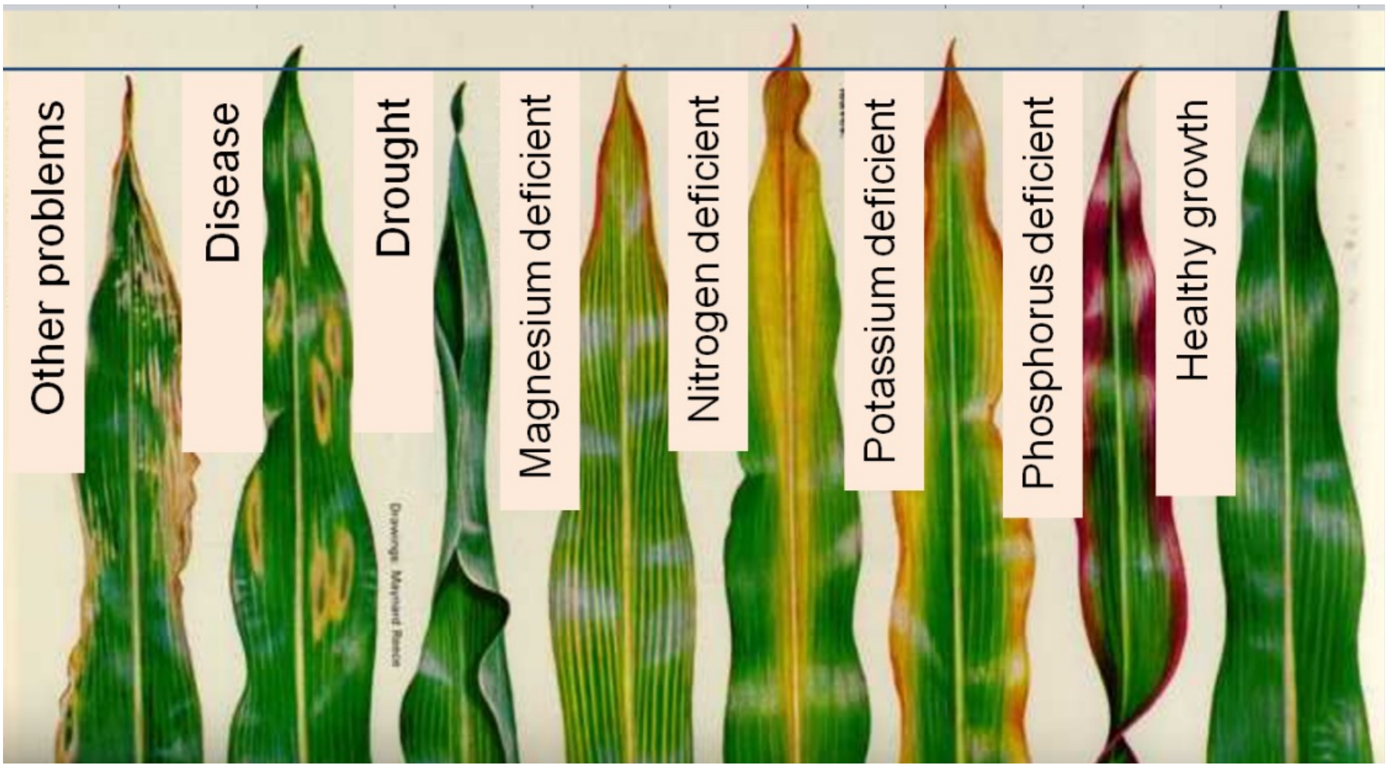


Figure 7. Nutrient deficiency symptoms on maize leaf.



High salt index fertilizers, such as potassium chloride, are not recommended for in-furrow placement. Potassium sulfate is often preferred over potassium chloride for some chloride sensitive crops such as potatoes, tobacco, some vegetables and fruits including citrus although these sensitivities are highly dependent on growing conditions, soil salinity and the salinity and chloride in irrigation water. Most studies showed little if any difference in the field performance of these two potassium sources provided that sulfur or chloride is not deficient and the total chloride from soil salinity or irrigation water is within the tolerance of the specific crop. Potato growers often use the sulfate of potash as the potassium source because of concerns about chloride sensitivity. Chloride is reported to affect plants primarily by increasing the soil salinity (osmotic potential of soil water). It interferes with a plant's ability to take up water. knowing the total salt loads by the Muriate of potash to be applied, the potassium rate and growing conditions are important for deciding the application.

Consider the other 3Rs (required rate, time and place) of fertilizer application as it can impact which source is the most acceptable (as indicated in their respective section).

Know the composition of fertilizers and their effect on plants. For example, Muriate of potash (KCl) fertilizer supplies chloride (Cl^-) and potassium (K^+) nutrients. Both nutrients may be good for certain crops whereas Cl^- may not be good for some specific crops such as potatoes in saline soils and when fields are irrigated with water containing high amounts of chloride salts. Potassium sulfate is primarily used where Cl toxicity or sulfur (S) deficiency is a problem.

Amending options for soil related identified problems before fertilizer applications are important to get the expected response to the applied fertilizer:

- Organic source addition is vital for soils depleted of organic matter; this includes available organic sources such as farmyard manure, compost and vermicompost.
- Liming is important in acidic soils; calculating lime requirement should be done in close consultation with regional soil laboratories and research institutes.
- In situ moisture conservation for low moisture constrained areas such as tied ridge is important in farmlands in flat areas.
- In areas where farms are sloppy and erosion is a major problem, soil and water conservation measures are important to protect soil and nutrient from loss by erosion water. Soil and water conservation structures suitable to the specific areas can be used by referring to "A guidelines for development agents on soil and water conservation in Ethiopia". https://www.wocat.net/library/media/54/
- Drainage for waterlogged areas particularly in Vertisols is also important. There is a guideline on how to implement it. Refer to "**የኮትቻ አፈርን ለማልማት ተሻሽሎ የተዘጋጀ የአተገባበር መመሪያ**" for further details on how to implement.
- Consider exploiting the complementing benefits between organic and inorganic fertilizers (up to 50% substitution of inorganic fertilizer N by application from organic sources) depending on the quality of the organic source. Organic sources with C: N ratio of less

than 30:1 result in net mineralization to release N for plant uptake. Refer to "**የተፈጥሮ ማዳበሪያን ከሰዉ ሰራሽ ማዳበሪያ ጋር አቀናጅቶ መጠቀም የምርምር ዉጤቶች**"

Regular monitoring of the SSNM applied fields, evaluation and learning of its performance and feedback on what went well and what do not are important for further improving the SSNM technology.

POSTASSESSMENT: TO BE COMPLETED ONCE THE MODULE IS COVERED

- Describe the major scientific principles that influence the right source for nutrient application. Discuss the characteristics of farm in your location.
- Describe the right source of nutrients that best suits for wheat/other dominant cereal crop production in your specific environment. Consider your area farm characteristics and available nutrient sources from commercial production and locally produced organic and other amendments as required.
- Evaluate the farmers' experience in your area in this regard and indicate what went right and what needs improvement.

SESSION 2. THE RIGHT RATE

LEARNING OBJECTIVES

The learning objectives of this session are to enable the learners to:

- describe factors that are responsible to determine the right nutrient rate and/or other amendments rate.
- apply location specific (landscape position, soil physicochemical properties, moisture condition, …) based right nutrient and other amendment rates to achieve the desired yield target.

MODULE OVERVIEW

Farmers' fertilizer use in Ethiopia is at a lower level in terms of area coverage as well as the amount applied per unit area. Ensuring the right rate of fertilizer application is important as under or over application of a nutrient may affect crop production, the returns to fertilizer application and the health of the soil.

The right rate depends on the source, time of application and application place. Hence, the nutrient source used must release the right amount in an available form in sufficient quantities at the right time when the plants require them and in the right place to meet the needs of the growing plants.

Yield response to fertilization varies with crop type and variety, soil type and other limiting factors. Fertilizer application results in increased yield but with diminishing returns until maximum yield is reached: thereafter, excessive fertilizer application can reduce yield.

LEARNING CONTENTS

- the fertilizer source (granule, organic, liquid, …), time and placement used to determine fertilizer rate
- the right fertilizer rate is a function of crop type and yield target
- the innate nutrient supply capacity of different soils
- the locally available nutrient resources of the specific area
- nutrient mobility in soils influences the rate
- contribution from the precursor crops
- salt index of the fertilizer influences the rate

PREASSESSMENT: RESPOND TO THE FOLLOWING ASSESSMENT QUESTIONS BEFORE PROCEEDING TO THE NEXT SECTION

The right rate refers to the application at:

A. sowing/planting
B. side dressing during the vegetative growth period
C. fertigation application or leaf spray (if any)
D. all are important

How do you rate the response potential of soils located in different landscape position to fertilizer applications?

A. Foot slope has higher response potential than hill or midslopes
B. Hill or midslopes have higher response potential than foot slope
C. Soils with low soil organic carbon have better response potential than soils with higher soil organic carbon

The right rate for fertilizer application is vital in SSNM. Why? Because it varies with the:

A. Soil fertility status
B. Crop type and crop variety
C. Landscape position (foot slope, hill slope, …)
D. A and B
E. All
F. None

Applying the right rate contributes towards the following.

A. Improve agronomic use efficiency (kg of grain produced per kg of fertilizer applied) in different locations
B. Reduce the probability of over or under application of nutrient vis-à-vis the crop requirement
C. Reduce nutrient loss to the environment
D. All are possible
E. None

If you missed one or more questions from the above, then this module is for you. We encourage you to read further and get the answers.

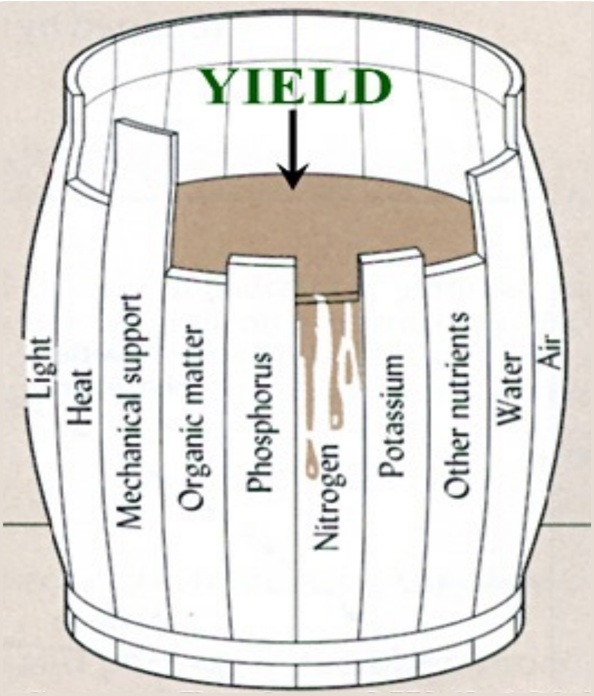
WHAT DOES THE RIGHT RATE MEAN?

The right rate refers to the amount of fertilizer needed for the crop production season to achieve the desired yield target and it is based on extensive research over locations, crop types, varieties and years. The right rate considers the amount of fertilizer applied at all the desired times in the growing season. Depending on the cropping system used, soil's supply and response potential variability, crop requirement and the cropping season status, the farmer needs to know the right rate of fertilizer:

- applied at planting/sowing
- side dressing during the growing season
- fertigation through the irrigation system
- leaf spray during the adequate growing season

The Liebig-Sprengel Law of the Minimum states that growth is limited by the limiting nutrient. It means that the yield of a crop is mainly determined by the nutrient present in the most limiting quantity (Figure 8). Deficiency of one nutrient cannot be overcome by the excess of another nutrient implying that the most limiting nutrient must be applied in sufficient rate to meet the requirements of the growing crop.

Figure 8. Yield is dictated not by total resources available, but most by the scarcest resource, N in this case.



In recent years, soil degradation and decreasing crop productivity in sloppy areas have received considerable attention to opting for site specific nutrient management and other management practices. It is also widely recognized that having a single recommendation rate for a given crop or even for a variety is unrealistic and unpractical because of the nature of the soils and production practices across different locations, soils, seasons, cultivars, fertilization practices and production techniques differ. Despite this, most fertilizer study results and hence the rate of recommendations in Ethiopia are derived from trials executed on flat (levelled) lands.

Considerable evidence has been documented from different studies indicating that crop response to fertilizer application is a function of inherent soil fertility (varying supply capacity), variation in soil properties across a toposequence and previous crop and their management effects. At hillslopes, crop response to fertilizer rate was found considerably low as compared to the response obtained at foot or mid slopes. For instance, crop response to applied fertilizer is reported to be 50 to 300% higher in foot slopes than in hillslope landscape positions. Low soil organic carbon content, coarse soil texture, shallow soil depth, soil erosion related constraints and limited plant available water are identified as attributing factors limiting crop response to fertilizer application in the hillslopes. The varied yield response to fertilizer treatments across soils and landscapes signifies the need for adopting a site specific fertilization approach. Hence, it is likely that advising the fertilizer rate recommended for the flatlands to the mid and hillslopes decreases fertilizer use efficiencies and can also be a potential risk in the surrounding water bodies due to higher erosion in the hillslopes. Hence, it is important to consider a landscape based fertilizer management approach to respond to the varying response potential of the farmers' fields.

Soil acidity and associated low nutrient availability are key constraints to crop production mainly in Nitisols of Ethiopian highlands. The right soil amendments and consequently the increasing availability of nutrients are hence important to get the benefits from applying the right fertilizer rate. Applying agricultural lime showed yield increments ranging from 34–252% in wheat, barley and teff, 29–53% in faba bean and soybean and 42–332% in potato in Ethiopia. The combined applications of lime and P revealed up to 133% more grain yields of barley as compared to the control (without P and lime).

HOW TO DETERMINE AND APPLY THE RIGHT RATE?

The guiding principles to determine the right rate of fertilizer include:

THE SOURCE, TIME AND PLACE OF APPLICATION

Different fertilizer types (organic, inorganic, liquid, granule etc.) have different levels of nutrient content which is important to determine the right rate. The amount of fertilizer product is calculated based on the amount of nutrients recommended for the crop variety in the production location and the nutrient content of the fertilizer product.

The nutrient requirement of a crop along its development stages varies considerably. Application times (before planting, at planting and during the growth period) are also important to determine the right rate. Placement (broadcasting, banding, foliar, fertigation etc.) is also an important factor to be considered for the right rate determination. These are described in the following section of this module.

THE CROP TYPES, VARIETIES AND YIELD TARGETS

Different varieties of a crop can differ in their nutrient requirements and their response to fertilizer. Improved varieties respond well to fertilizer application. For example, hybrid varieties give a much better response to fertilizers and produce much higher yields than local varieties and requires a higher fertilizer rate.

The yield target can be approached by considering the yield that model farmers attained in good seasons using better management. This must be realistic and tailored to the soil and rainfall conditions of the production area. A yield target provides an important guide on estimating the total amount of nutrients required by the crop.

The portion of the nutrients required for plant growth is supplied by the soil. The capacity of soils to supply these nutrients depends on several factors which include:

A. Soil organic matter levels: The higher the soil organic matter levels, the higher the nutrient supply potential of the soil.
B. 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.
C. Cation exchange capacity soils: Soils with considerable organic matter and clay content are known to have higher cation exchange capacity. Such soils tend to be richer, acting as nutrient reservoirs than highly weathered and degraded soils.
D. The capacity of the soil to bind nutrients: This applies mainly to phosphorus. Soils that bind phosphorus (acidic soils) cover wide areas in the country. These soils have a low supply potential of phosphorus although their total soil P may be high unless adequate amendments are made.

The locally available nutrient resources of the specific area

- While deciding the right fertilizer rate, identifying locally available nutrient sources and their contribution towards meeting crop nutrient requirements is essential to consider. Some of these sources include farmyard manures and vermicompost/composts. These organic sources are mainly good sources of nitrogen and sulfur and micronutrients. However, the primary macronutrients that exist in most organic sources cannot satisfy the crop nutrient requirement. Hence, the combined use of organic and inorganic fertilizers adds a synergetic effect towards improved nutrient use efficiency.
- For most organic fertilizers including farmyard manures and compost/vermicompost, the right amount to be applied is mostly calculated based on the N equivalence of the recommended N rate for that specific crop variety. It means that the N content of the organic source will be determined and then the required amount of the product is calculated towards satisfying a maximum of up to 50% of the nitrogen recommended for the crop in the production area. Studies revealed up to 50% of the crop nitrogen requirement can be satisfied from organic sources while the other 50% N can be applied from inorganic sources without yield penalty. For further information and application of the practice refer to “**የተፈጥሮ ማዳበሪያን ከሰዉ ሰራሽ ማዳበሪያ ጋር አቀናጅቶ መጠቀም- የምርምር ዉጤቶች**”. This information source is in press and will be uploaded to the EIAR website (
- http://www.eiar.gov.et). A guideline on “**የቀልዘ-ተሳቦ ትል አመራረትና አጠቃቀም**“ is also available for good understanding and application of the practice in their production system.
- Nutrient mobility in soils influences the rate
- The mobile nutrient such as N from urea is applied in split: 50% or mostly lower amount at sowing, while over 50% at about maximum growth stage of the crop.

CONTRIBUTION FROM THE PRECURSOR CROPS

Potential nitrogen contribution from legume crops and green manures is also important. Retaining legume crop residues in the field can contribute some amount of nitrogen to the crop planted in the following season. Hence, where cereal crops are grown in rotation with legumes, yield improvements are likely depending on the amount of nitrogen fixed by different legume crops.

The need for biological fertilizer usage for some legume crops is also important that can influence potential soil nitrogen contribution by grain legumes. For further understanding and application of the practice, refer to **"Application guideline for rhizobial biofertilizer technologies".**

SALT INDEX OF THE FERTILIZER INFLUENCES THE RATE

When fertilizers of high salt index are added to the soil, it can often create an imbalance in osmotic pressure that can result in the plant being unable to take up water and nutrients, therefore leading to the eventual loss of the plant's natural metabolic processes. Hence, the application rate for such fertilizers, particularly when the total rate is high, may need to be split into two to reduce its side effect.

For inorganic fertilizer products, existing fertilizer recommendation rates as indicated in the extension packages (available at woreda level agricultural extension office) are in use. For SSNM, there is location specific refined rate for different fertilizer sources which is developed based on the environment (soil and rainfall) and fertilizer response of crops research data. These rates are calculated by the Decision Support Tool (DST) from the input data to be provided by the farmer or by the support of the development agent about the farm location. In the past recent years, studies have demonstrated that landscape position is one of the major factors influencing the SOM, texture, cation exchange capacity and others. Hence landscape position is important factor to be considered for deciding the right rate in site specific nutrient management. In this regard, the landscape based fertilizer recommendation decision support tool (DST), developed by ICRISAT, is under validation. The decision support tool considers the above listed important factors to give site specific nutrient recommendations for different crops in different locations. This DST will have its own guideline on what information about the farmland is to be used as input and who will do what to support farmers to apply the right rate.

For the combined use of locally available organic fertilizers with inorganic fertilizers, the promising rates are to replace up to 50% of the N requirement crops by application of organic fertilizer based on N equivalence. These rates showed soil health improvement with no yield penalty or with grain yield improvement. In the long term, the use of organic fertilizer improves crop response to fertilizer application.

The right amendments such as the lime requirement in acid soils are determined based on soil exchangeable acidity and/or soil pH. For further understanding and application, refer to

“Managing acid soils for reclaiming livelihoods in Ethiopia” http://oar.icrisat.org/11409/1/Managing%20acid%20soils_Ethiopia_02%20May%202019_low.pdf

The right rate for a selected crop variety is not a fixed amount; but can vary spatially and with the status of the season.

POSTASSESSMENT: TO BE COMPLETED ONCE THE MODULE IS COVERED

- What are the major factors that need to be considered for deciding the right rate of fertilizer for a given crop? Discuss characteristics of the farmland in your area.
- Consider the experience of farmers in your area concerning the right rate and comment on what went right and what needs improvement.

SESSION 3. THE RIGHT TIME

Learning OBJECTIVES

After completing this session, the reader should be able to:

- list what you understand from the right application time
- list the benefits of the right application time on crop yield and quality
- describe factors governing the right application time

MODULE OVERVIEW

Timing the application of nutrients so that the applied nutrients are available before peak crop nutrient demand is critical. The right timing of nutrient application supports adequate crop growth during the entire growing season and improves crop yield and nutrition quality and minimizes nutrient losses. Crop development and hence nutrient uptake is generally slow during seed germination or transplanting then increases through flowering and fruiting and finally slows down at physiological maturity which is described as a sigmoidal growth pattern. Hence, matching fertilizer application time with how the plants' nutrient needs change during the growing season is essential for producers to increase uptake, yield and use efficiencies. The soil nutrient supply potential from the mineralization of soil organic matter, the soil moisture condition and the nutrient loss risk in the soils are also important factors to consider while deciding the right time for fertilizer application. The mobile nutrient such as nitrogen is easily lost especially in sandy soils and should be applied in 2–3 splits during the growing season for cereal crops. Potassium and sulfur are less mobile than nitrate but more mobile than P which makes them to some extent susceptible to loss in sandy soils and should be applied in a split during the growing season for cereal crops. The entire recommended rate of fertilizers containing relatively immobile nutrients such as phosphorus is once as basal at sowing or transplanting.

LEARNING CONTENTS

- Crop growth stage dictates the application time
- Varying soil physicochemical properties can influence the right application time
- Nutrient mobility and hence the nutrient loss risk influence the right application time
- Salt index status of the fertilizer also determines the right application time

PREASSESSMENT: Respond to the following assessment questions before proceeding to the next section

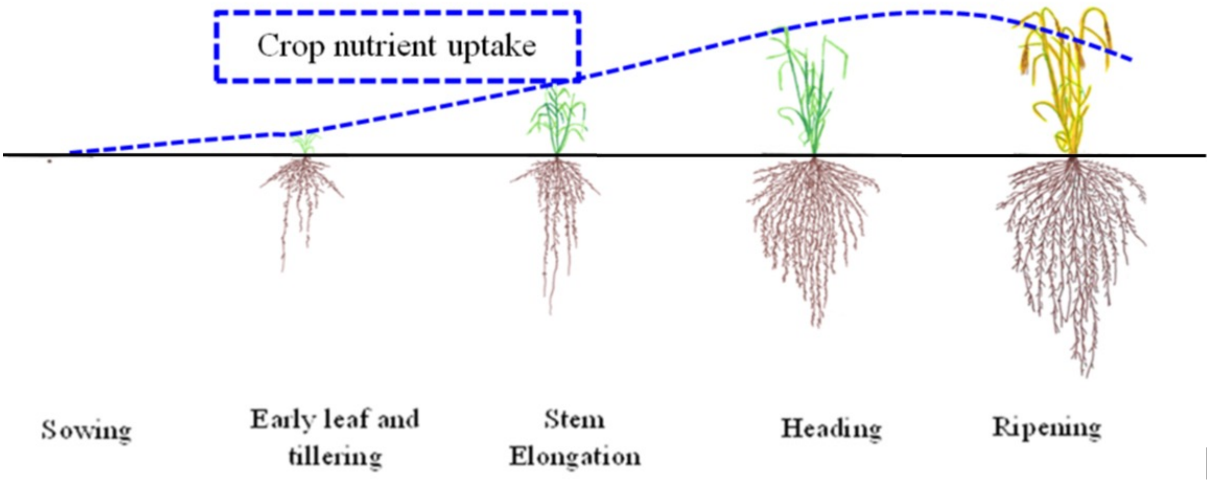
- What do you understand about the right fertilizer application time?
- List major factors you think need to be considered while deciding the right application time
- Do you think nutrient/fertilizer type is an important factor in deciding the right application time? Discuss
- Describe the right application time for the fertilizer types commonly used in your area for wheat production?

If you missed one or more questions from the above, then this module is for you. We encourage you to read further and get the answers.

WHAT DOES THE RIGHT TIME MEAN?

Timing is the process of assuring the plant with an available form of nutrients at peak crop nutrient demand. The right timing is interconnected with the right source, the right rate and the right placement. To attain optimum productivity, nutrients in plant available form (right source) must be available in sufficient amounts (right rate) where the crop can access them (the right place) to meet crop demand at all stages (right time) through the growing season. Crop nutrient uptake dynamics and patterns vary with the crop development stage during the growing season. Most crops take up nutrients slowly at the early stages of growth and increase to a maximum during the rapid growth phase (from early tilling through stem elongation) and decline as the crop matures (Figure 9). Hence, the right rate is about trying to satisfy the crop with the nutrient demand of that growth stages.

Figure 9. Different growth stages of wheat have different requirements for nutrient.



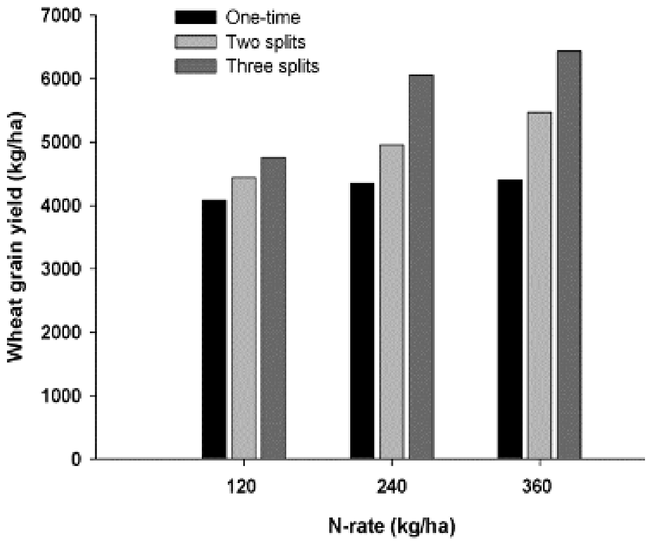
For mobile nutrients, the purpose of fertilizer application at planting is to cover the crops' nutrient needs until the first side/top dress application. For immobile nutrients, it must fulfil the crop requirement throughout the growing season.

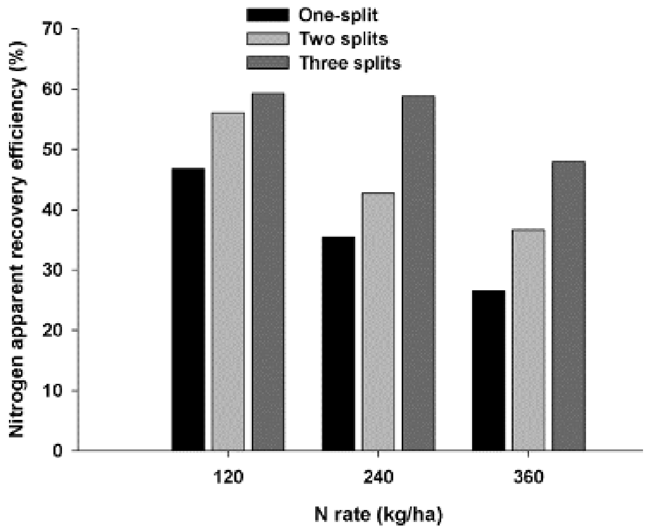
WHY IT IS IMPORTANT TO APPLY AT THE RIGHT TIME?

Synchronizing nutrient availability to crop demands leads to improved use efficiency and returns to investments in fertilizer application. When a crop's total nitrogen requirement is supplied with a single pre plant or at planting application, the crop luxury use of nitrogen results in excess vegetative growth and lodging that in turn causes yield loss. Furthermore, most of the N must wait for the crop's future needs. It means the window for its potential loss remains open longer. Postponing application of a portion of the N treatment to the growth stage when the crop is better able to use the nutrient, plants take up the nitrogen more quickly and efficiently. This enables growers to get more from their fertilizer investment and fewer losses of fertilizer to the environment. Hence, applying N fertilizer as close as possible to the time of crop uptake improves N use efficiency.

For wheat production on the highland Vertisols (Akaki and Robe research sites) of Ethiopia, two split applications of N (one-third at sowing and two-third at mid tilling) were demonstrated superior to the one time application at sowing. It enhanced wheat grain N uptake by 11.7–32.9%, total N uptake by 10.6–36.7%, apparent N recovery by 24.2–71.4% and agronomic efficiency of N by 23.2–45.6%, particularly under severe water logging stress of the study sites. In the central highlands of Ethiopia, other results of a study also revealed improvement in yield and N use efficiency due to split application. Higher rates of N applications require more splits for both grain yield and N use efficiency over the two split applications (Figure 10).

Figure 10. Wheat grain yield (kg/ha) and N apparent recovery efficiency (%).





Source: Fresew et al. (2018).

Two splits = half at planting and half at tilling; Three splits = one-quarter at sowing, half at tilling and one-quarter at booting.

The split application has also revealed a considerable reduction of N2O loss by about 30 to 50% in high N rate application production systems in the USA and China. Generally, where total N rates get higher and higher such as for hybrid varieties, more than two splits are advised for better use efficiency, to reduce losses to the environment and to reduce the possible negative impact of the salt index of urea on seed germination.

Timing the application of nutrients can affect both yield and quality. N application near anthesis consistently increased grain protein content, grain protein yield, grain volume weight and kernel size. Both split application regimes (two or three) produced higher protein than if all were applied before planting. When applications are made late in the season, foliar applications may be more likely to increase protein content than applications on the soil, as a portion of the foliar applications may be absorbed directly through the leaf.

HOW TO IMPLEMENT THE RIGHT TIME?

In addition to the crop growth stage, the following factors are important to consider applying the right application time.

A. Varying soil physicochemical properties can influence the right application time

The varying soil physicochemical properties along the landscape positions influence the right time for fertilizer application. Broadly speaking, the sandier the soil, the lower will be the nutrients that soil can supply. Clay soils and organic carbon rich soils with greater capacity for retaining nutrients have better supply potential throughout the growing season. The amount and rate of mineralization of soil organic matter may influence the best specific time for fertilizer application. Landscape position that influences the above listed soil related characteristics is therefore important to consider not only for the right rate but also for the right time of application.

When growing crops in soils deficient in calcium and magnesium (acidic soils), the addition of lime is required about one month before planting while lime microdosing is done at planting and mixed into the soil.

B. Nutrient mobility and hence the nutrient loss risk influence the right application time

For relatively mobile nutrients, the application is in two to three splits. The number of splits may depend on the rate of a particular fertilizer (higher for higher rates such as for hybrid varieties), the soil texture (higher in sandy soils) and the rainfall condition (higher for intense rainfall areas) that can cause high loss through leaching and erosion.

Applying nitrogen fertilizer in sandy soils in high rainfall areas requires several applications at low rates to reduce the risk of losses. Sometimes supplemental late applications may be needed when heavy rain leached the earlier applied nitrogen from the soil. The timing of fertilizer applications should also consider weather conditions. For example, topdressing nitrogen fertilizer should be avoided when the soils are not moist, during periods of heavy rains or when heavy rains are imminent. Nitrogen fertilizers should be applied when the soil is moist. Commonly, for wheat production, one-fourth to one-third of the right rate of N is recommended to apply at planting together with other nutrients, one-third to half at about 30–35 days and the remaining one-third at about 60 days after planting to match the periods when a plant needs most N.

The varying risk of nutrient loss in the soil also influences the right timing for application. When a mobile nutrient such as nitrogen is applied ahead of crop growth, there is a high probability that most of it is susceptible to denitrification, leaching or volatilization depending on the physicochemical properties of soils and the rainfall or irrigation water application. Hence, fertilizer application time should be planned to minimize the chance of leaching of nutrients due to heavy rainfall or irrigation in light textures sandy soils. For mobile nutrients, split applications play an important role in a nutrient management strategy to improve productivity, profitability and environmental integrity. The purpose of fertilizer application at planting is to cover the crops' nutrient needs until the first side/topdress application to properly promote early growth for higher yield. Hence, applying N fertilizer to cereal crops should be done in two or three splits during the growing season.

For fertilizer products containing immobile plant nutrients such as phosphorus and potassium, the total recommended fertilizer rate is applied one time at planting; and it can sufficiently fulfil the crop requirement throughout the growing season. A considerable proportion of the applied phosphorus and potassium can be held by the soil and can be available to crops grown the next season. Topdressing of P did not confirm to affect crop yield as P usually bounds near the soil surface and does not migrate to the actively growing root system. Soil acidity binds phosphorus nutrients and makes them unavailable to growing plants. In such soils, liming is vital to increase the pH of the soil to near neutral levels to improve nutrient availability.

C. Salt index status of the fertilizer also determines the right application time

For higher salt index fertilizers such as KCl, a lower amount of application is preferred at sowing or planting. Higher rate application affects seed germination. Hence, a split application not in contact with the seed and or root is recommended.

Foliar application for micronutrients and nitrogen fertilizers must be at the appropriate crop growth stage for maximum absorption, mostly from tilling to the flag leaf stage. The appropriate application times and concentrations are mostly provided by the producing company on the package.

For mobile nutrients such nitrogen, avoid application when high rainfall is expected immediately after its application. Similarly, avoid any split of nitrogen fertilizer application when soil is not moist enough.

POSTASSESSMENT: TO BE COMPLETED ONCE THE MODULE IS COVERED

- Describe the major scientific principles that define the right time for nutrient application for a different set of farm conditions.
- Discuss farmers' experience in your area on fertilizer application time and evaluate it from the principles influencing the right time for application. From your evaluation what went right and what needs improvement?

SESSION 4. THE RIGHT PLACEMENT

LEARNING OBJECTIVES

After completing this module, the reader should be able to:

- Describe what the right placement means
- Describe the benefits of the right placement
- list and describe fertilizer placement options
- describe the factors determining the decision for the right placement of the fertilizer or nutrient
- list the effects of fertilizer placement on emergence, fertilizer use efficiency and environmental risks

MODULE OVERVIEW

Fertilizer application, either to the soil or directly onto the plant, is common practice when nutrient deficiencies limiting crop yield or quality are known. Hence, the right placement refers to applying fertilizers in/on the soil close to a specific place with or without reference to the seed or plant to supply the nutrients in adequate amounts to the roots of growing plants. Climatic effects, nutrient interaction in relation to physical and chemical processes in the soil and the risk of nutrient toxicity on seed germination or seedlings are among the factors influencing the right placement of fertilizer. The right placement is important to take advantage of the root soil dynamics considering the nutrient movement and opt to minimize nutrient losses from the field. The right placement for most crops in general is in the root zone or just ahead of the advancing root system.

LEARNING CONTENTS

- Fertilizer placement in the soil at planting (broadcasting, in seed row, side and/or below seed row).
- Fertilizer placement in the growing season (side/topdressing, foliar spray, with irrigation water).

PREASSESSMENT: RESPOND TO THE FOLLOWING ASSESSMENT QUESTIONS BEFORE PROCEEDING TO THE NEXT SECTION

- List and describe the fertilizer application methods/placements you know
- List and discuss factors influencing the right placement of fertilizer application
- Why do fertilizer application methods/placement matter? Discuss it
- Discuss farmers' experience regarding the right placement for the major fertilizers used in your area

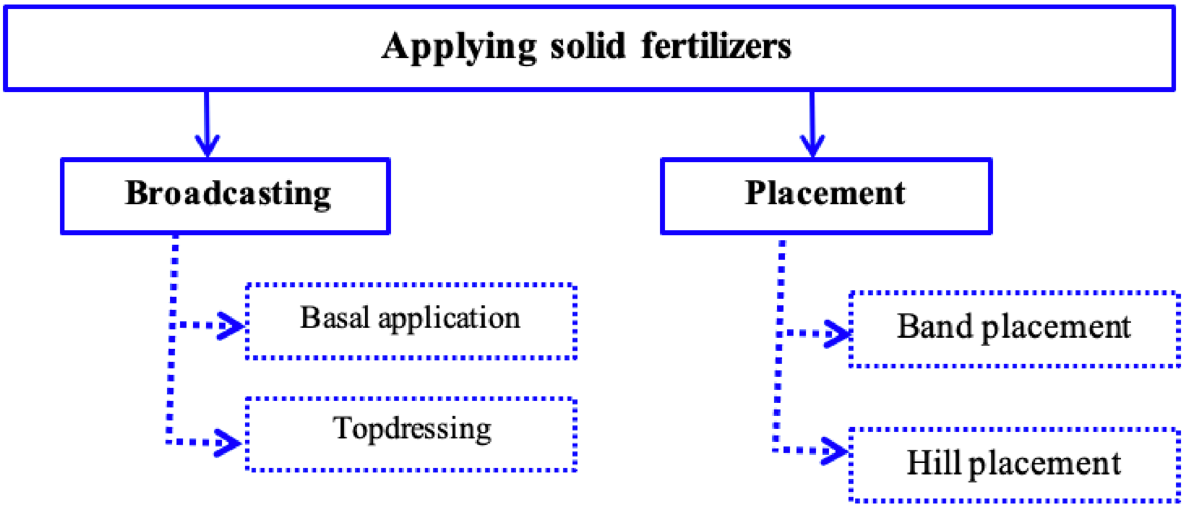
If you missed one or more questions from the above, then this module is for you. We encourage you to read further and get the answers.

WHAT DOES THE RIGHT PLACEMENT MEAN?

Placement refers to the placement of fertilizers in the soil at a specific place with or without reference to the position of the seed. It can be applied as concentrated strips/bands along the row or in a hill before or at planting to the soil, typically near the developing plant. This can be a surface or subsurface application.

SOLID FERTILIZER APPLICATIONS

Broadcasting refers to a uniform application of fertilizer across the entire soil surface (incorporated into the soil as basal or topdressing). It is suitable for crops with dense stands. Broadcasting as the basal application at sowing or planting while topdressing is applying fertilizers particularly nitrogenous fertilizers in closely sown crops like teff and wheat to supply nitrogen to the growing plants.



LIQUID FERTILIZERS APPLICATIONS

A foliar application is feeding plants by spraying liquid fertilizer directly to the leaf surface as opposed to applications into the soil.

Fertigation is the combined application of water soluble solid or liquid fertilizers with irrigation water through a pressurized irrigation system. Generally, easily water soluble fertilizers such as urea fertilizers are applied along with irrigation water. It increases yield and minimizes soil and water pollution.

The existing fertilizer placement practice commonly used by farmers in Ethiopia is either to broadcast (most smallholder farmers for most crops) or to apply in a concentrated line (few farmers for few crops). Hence, the use efficiencies are low.

WHY IS THE RIGHT PLACEMENT IMPORTANT?

The right placement of nutrients allows a plant to develop properly and attain its potential yield, based on the environmental conditions in which it is grown. Hence, the proper nutrient placement is to assure that the plant for best access to the nutrients that are generally in the root zone or just ahead of the advancing root system.

Nitrogen in urea fertilizer volatilizes when it is broadcasted on the soil surface. Hence, it requires to be incorporated into the soil to minimize the risk of volatilization. High concentrations of ammonium will then build up in the soil, to be taken up by plants. In alkaline situations, ammonium (NH4) can be converted back to ammonia (NH3) gas. The high amounts of hydroxyls (OH–) in the soil can strip hydrogen (H+) away from NH4 to make H2O and NH3. When high salt index fertilizers are added to the soil, it can often create an imbalance in osmotic pressure that can result in the plant being unable to take up water and nutrients, therefore leading to the eventual loss of the plant's natural metabolic processes. Hence, a fertilizer placement method appropriate to the fertilizer salt index is required to reduce damage to the seed or seedlings.

The fertilizer placement method also differs with the fertilizer rates to be applied to get the impact expected. When relatively large quantities of fertilizer (the recommended rate by broadcasting) are to be applied, broadcasting can be sufficient. When the small rate is to be applied, banding or spot application is preferred to get the same impact.

Fertigation allows an additional way to supply different nutrients such as nitrogen, sulfur and potassium as required. It allows a high degree of flexibility in nutrient management because nutrients may be continuously applied throughout the growing period of the crop. Fertigation makes it possible to synchronize nutrient applications with crop demand. This is an effective strategy to prevent the luxury consumption of nutrients.

Foliar fertilizers supply plant cells with nutrients more rapidly than the soil. Several nutrient elements are readily absorbed by leaves when they are dissolved in water and sprayed on them. Thus, foliar fertilizers can provide a quick way to correct nutrient deficiencies for soluble nutrients using safe concentration levels.

A meta analysis of fertilizer placement studies demonstrated a 3.7% higher yield, 3.7% higher nutrient concentration and 11.9% higher nutrient content in above ground parts due to fertilizer placement than fertilizer broadcast. Urea fertilizer subsurface placement led to a 27.3% increase in yield as compared to broadcast. Hence, subsurface fertilizer placement could be one more tool to mitigate the negative consequences of increasingly frequent high temperatures and droughts that threaten food production globally.

If the soil is not moist enough at planting, consider placing the fertilizer away from the seed.

HOW TO APPLY AT THE RIGHT PLACE?

Fertilizer placement must consider factors that are known to influence nutrient availability to the crop and their various losses to the environment. These include:

- the nutrient source, rate and time of application

crop growth stage is an important factor for the right placement mobility of nutrients in the soil and soil characteristics

THE NUTRIENT SOURCE, RATE AND TIME OF APPLICATION DETERMINE THE RIGHT PLACEMENT

Fertilizers best suited for infurrow or near the seed furrow in band application must have a low salt index, relatively high phosphorus content and minimized content of compounds that liberate NH3. Potassium chloride is among high salt index fertilizers. Its application will increase the soluble salt concentration in the soil. Hence, KCl if needed for use, must be placed to the side of the seed row to avoid damage to the germinating plant. Urea is also considered among the high salt index fertilizer that needs caution when it is applied at planting at high rates. Problems associated with salt damage include:

- If the concentration of salt in the soil is greater than the salt concentration in plant roots, water will not be absorbed by the plant. Instead, water will leave the plant and enter the soil.
- High concentrations of soluble salts may also result in elemental toxicities of sodium and chlorine.

Like inorganic fertilizers, organic fertilizers (compost, vermicompost and manures) in a solid, liquid or slurry may be broadcasted or placed in surface or subsurface bands. For surface application, mixing into soils is vital to reduce losses. Organic fertilizers with an acceptable high C: N ratio are applied 15 to 30 days before planting to give sufficient time for mineralization by the time the plant roots are ready for nutrient uptake. High quality (lower C: N) ratio organic fertilizers can be placed in surface bands at planting.

Band application is preferred particularly for low rate fertilizer application of immobile nutrients such as phosphorus sources in high P-fixing soils and for side dressing in row planted crop fields. Band application at about 5 to 10 cm below the row or about 5 cm below and to the side of seed rows is preferred. Banded P tends to be more efficient on very acid soils, highly calcareous soils and those soils with very low levels of available soil P.

Banding of phosphorus fertilizer near seed row can increase phosphorus use efficiency by reducing the level of fixation in soil.

Banding away from the seed row is recommended for seed row application under most conditions when applying higher nutrient rates, especially N, K and S. Plants can efficiently use nutrients banded away from the seed row without adversely affecting seed germination or seedling emergence.

Placing high rates of nitrogen and/or potassium fertilizer near seeds can cause seedling injury.

Side or topdressing is not an effective method for immobile nutrients since it does not allow time for these nutrients to become available to plants.

When fertigation is used, care must be taken, in relation to the concentration, not to hurt the crop. Successful fertigation requires a well managed and equipped irrigation system for uniform and maximum efficiency. Applying phosphorus is not commonly advised because it forms a precipitant if the irrigation water contains Ca, Mg and HCO_3^- and clogs the irrigation system. Fertilizer application at planting must be incorporated into the soil, particularly urea fertilizer. At planting, broadcasting is not advised unless it is for crops sown on a small seeded by broadcast. Broadcasting nitrogen fertilizer is usually most effective later in the season when the roots of a row crop have explored the space between the rows.

CROP GROWTH STAGE IS AN IMPORTANT FACTOR FOR THE RIGHT PLACEMENT

The right placement also depends on the crop's growth stage. As the crop develops, the root and shoot system expands and maximizes the likelihood of nutrient uptake or absorption by the plant. For instance, at planting, nitrogen fertilizer can be added in a band while during in season, side or topdressing or leaf spray can be made depending on the environmental condition at the time of application. Fertilizer placement should consider the mobility of a nutrient in the soil. Phosphorus, relatively immobile in the soil, should be applied in bands close to the plant for its better availability to the plant particularly in soils with phosphorus fixing characteristics.

MOBILITY OF NUTRIENTS IN THE SOIL AND SOIL CHARACTERISTICS

Micronutrients can easily be fixed in the soil, in which case band placement of the chelated form is the recommended practice. Leaf spray with different liquid fertilizers could also be the preferred option. In general, due to the poor mobility of most micronutrients, placement of chelated micronutrients near the seed or foliar applications has proven most successful at producing growth responses. Foliar application of fertilizers is a common way to apply micronutrients since micronutrients are required in much smaller quantities than macronutrients. Due to the risk of foliage burn, the rates of nutrients in foliar fertilizers are much smaller (less than 1–2%) and several applications may be necessary.

POSTASSESSMENT: TO BE COMPLETED ONCE THE MODULE IS COVERED

- Describe the major scientific principles that define the right place for nutrient applications.
- Describe fertilizer placement options that best suit for applying N and P fertilizers and for combined use of organic and inorganic fertilizers for wheat production in your area. Evaluate the farmers' experience in this regard and indicate what went right and what needs improvement.

SESSION 5. THE RIGHT MANAGEMENT

As discussed above, the five Rs of nutrient stewardship are used to underline the accuracy and precision of nutrient management to apply the (1) right source of fertilizer at the (2) right rate, at the (3) right time and the (4) right place with the (5) right management. Therefore, the fifth R is imperative for sustainable nutrient management for crop production. These main points of nutrient management (source, rate, time, place, management) may help enhance sustainability by reducing pollution from nitrate leaching, nitrogen loss through ammonia volatilization and climate change from soil greenhouse gas emission.

WATER MANAGEMENT

Economically and environmentally sustainable food production is essential to meet food demands as the human population continues to increase. While genetic improvement for enhanced productivity of crops is in progress, adopting appropriate crop management practices to utilize production inputs, particularly fertilizer and water, effectively will be key to reaching the genetic potential and economic sustainability of those field crops. Improvements in nutrient use efficiency of crops are mostly dependent on the soil moisture content.

Improving nutrient and water use efficiencies by optimizing field management practices are important strategies to increase the economic and environmental sustainability of crop production. Water is an important consideration for fertilizer efficiency in water deficit areas, where the association between fertilization and irrigation is of particular importance. Satisfactory soil moisture is crucial for high yields of crops. Therefore, there is an emphasis on the fifth R for nutrient stewardship. Selecting the right irrigation includes considering irrigation schedules, systems and water sources. Irrigation scheduling outlines the time and frequency of applying irrigation. Maintenance of adequate soil moisture conditions during the reproductive phase of crops, from flowering until physiological maturity, improves water use efficiency. Supplementary irrigation improves nutrient use efficiency, though most crops are grown under rainfed conditions in Ethiopia. Maintaining crop stubbles and incorporating them with N could improve both nutrient and water use efficiency in crops. In water deficit areas where moisture stress is a problem in crop development stages, applying supplementary irrigation is critical to attaining achievable yields of crops. The availability of adequate soil moisture during the different crop growth stages would enable more split applications of nitrogen fertilizer to increase the N recovery and use efficiency of crops.

SOIL MANAGEMENT

Fertilizer use efficiency is one of the critical issues that affect sustainable crop production. It does not mean that application of nutrients alone will be a sustainable solution for improving agricultural productivity. Hence, beyond applying fertilizer, improving the overall soil properties could enhance the efficiency of applied nutrients. For instance, maintenance of soil organic matter content, reclamation of acid soils and managing waterlogged soils through improved drainage systems greatly reduce the loss of applied nutrients via different means and improve their uptake efficiency by plants. It means that improving the overall soil properties could hold nutrients in the soil and increases their availability in the soil for better plant uptake. Nutrient management necessitates special attention as it is critical to both optimizing production potential and environmental stewardship.

Good soils are better responsive to applied nutrients than poor and degraded soils. In acidic soils, most of the applied P fertilizer is fixed and may not be available to plants without amelioration of soil acidity. Soils with high fertility could have improved capacity to take up and store water and thus reduce water stress. So, applying integrated soil and crop management practices may ensure sustainable soil and crop productivity in a changing climate.

MANAGEMENT OF WEEDS AND OTHER PESTS

Good soil fertility combined with effective weed management is key for enhancing crop yield. Soil fertility management can directly reduce plant susceptibility to pests, which means healthy soils are a prerequisite for healthy plants. Water and other types of stress increase pest problems. Fertilization practices can influence the relative resistance of crops to insect pests. When weeds and crops are grown together in an environment, they will impact the resources available for one another and will do so differently depending on the amount of N and other resources. regardless of the timing of application, weed biomass is often greater when N is applied. Nitrogen application method generally has larger and more consistent effects than application timing on weed growth and crop yield. For instance, shoot N concentration and biomass of weeds were lower with subsurface banded or point injected N than with surface broadcast N. So, appropriate control of weeds and other crop pests before and after nutrient applications may greatly help improve nutrient recovery and use efficiency of most crops.

Weeds compete with crops for sunlight, water, nutrients and space. In addition, they harbour insects and pathogens, which attack crop plants. Weed crop competition for nutrients, especially for nitrogen, is one of the most important problems since the availability of nitrogen is often the limiting factor in plant growth, especially in soils with low supplementary ability. Nitrogen uptake efficiency can be influenced by tillage, soil properties, interactions among crops and weeds and the rate and source of N applied. The length of time weeds interfere with crops should be minimized by removing weeds. Generally, timely weed control is critical to improving the water and nutrient use of crops. The control of other insect pests and plant diseases is also vital to sustain healthy crops and thereby enhance efficiency of applied plant nutrients.

SESSION 6: A DECISION SUPPORT TOOL (DST) FOR SITE SPECIFIC NUTRIENT MANAGEMENT

The objectives of developing a DST are to improve the overall soil fertility to make it responsive, develop a soil fertility map and apply site specific fertilizer recommendations following the 5 nutrient stewardship, where the fifth stewardship is the management which is included a new component.

Fertilizer recommendations and decisions of crop management in Ethiopia are often based on traditional field experimentation. This usually ignores the variability of production factors in space and time and hence difficult to scale out such decisions and recommendations outside of the experimental sites. The use of complementary decision support approaches such as modelling or decision support tools is limited. Decision Support Tools (DSTs) are software developed to support analysts and decision-makers (farmers) on the amount of fertilizer or nutrient to be applied for different crops. DSTs integrate multiple parameters known to affect the response of crops to fertilizer/nutrient application such as rainfall distribution, type of soil, crop type and crop variety in simulating crop yield. The DSTs are, hence, an appropriate tool to enhance farmer decision-making especially regarding site specific fertilizer recommendations.

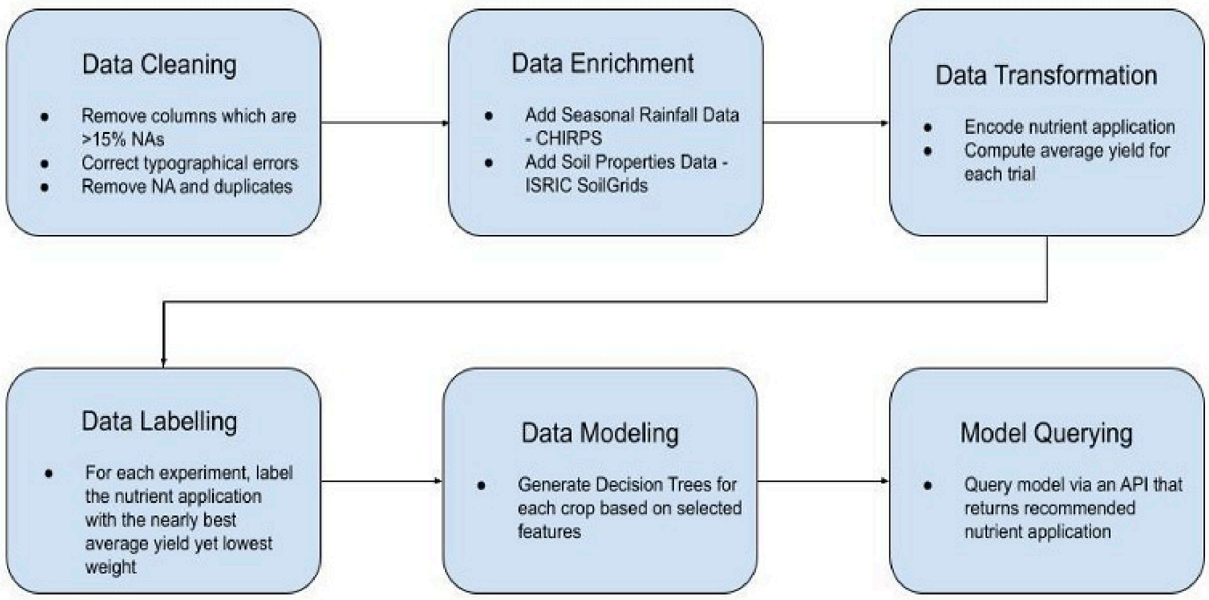
Recently, there are attempts to calibrate, validate and evaluate different models and even the development of decision support tools for site specific fertilizer recommendations that account for the production situation in Ethiopia. Evaluation results have also demonstrated the potential of decision support tools for site specific nutrient management to improve production, reduce yield gaps and improve the resource use efficiency of smallholder farmers. The findings suggest including site specific decision support tools in extension programs to accrue the potential benefits on yields, fertilizer use efficiency, reduction of production risks and sustainable agriculture development. Despite such potentials demonstrated with the use of DSTs and modelling to inform agricultural management and planning, the use of DSTs for fertilizer recommendation is at the infant stage in the country except for the recent attempts by different research institutions.

Taking these facts into consideration, ICRISAT conducted robust fertilizer trials over locations and years and has developed a decision support tool (DST) for site specific fertilizer recommendations, using important soil and crop parameters, weather and geographical information. Excellence in Agronomy–ICRISAT in collaboration with woreda agricultural offices and research centres validated the DST against the current extension fertilizer rate for selected woredas for wheat, teff and sorghum. The results were evaluated and have been found successful for the demonstration on a wider scale. The DST is developed into a mobile app by embedding the decision model algorithm. Hence, farmers or development agents will provide minimum data related to soil, cropping system and crop variety to be grown to get the amount of N and P fertilizers to be applied for the targeted yield currently for the three crops.

It is important to exploit the potential of the DSTs to improve productivity, reduce production risk and reduce nutrient losses to the environment. However, its application for fertilizer recommendation in Ethiopia requires capacity building support for the research and learning institutes on modelling works and extension personnel to use the DSTs. Demonstrating the use of DSTs beyond research to policy decision-makers and implementing bodies is also vital. Developing new models and improving the existing ones to account for peculiar soil and cropping system challenges such as soil acidity, salinity, low soil organic carbon related constraints and landscape positions in mixed cropping systems can also enhance their applicability in the Ethiopian agricultural production system.

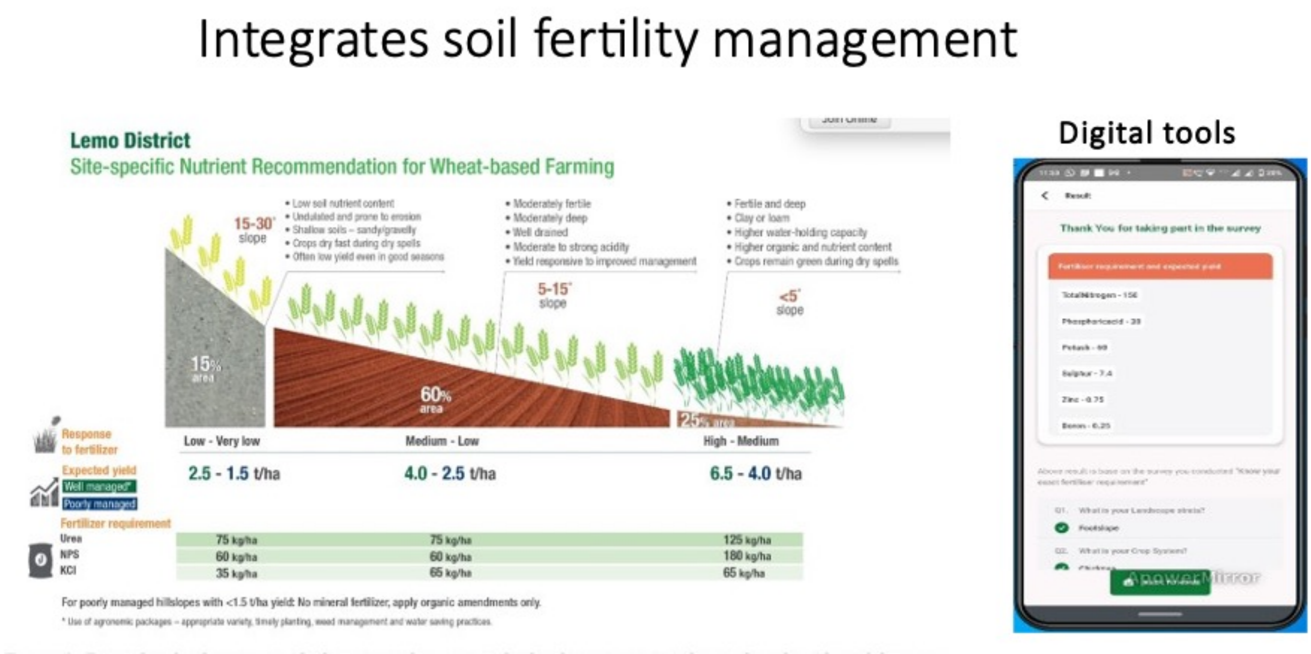
THE STEPS FOLLOWED TO DEVELOP THE DECISION MODEL ARE AS FOLLOWS:

Approach: The methodological framework followed to develop the DST is presented below. It involves cleaning the crop response dataset, enriching the data with spatial rainfall and soil properties, data transformation and labelling, developing a decision model using the most influencing features and finally developing a query model that returns the required nutrient application and hence, providing maximum yield for the specific location.



For example, a decision guide for targeted, site specific fertilizer recommendations for wheat based farming systems under different landscape positions in the Lemo district of southern Ethiopia is given below in Figure 12.

Figure 12. Example of a decision guide for site specific fertilizer recommendation for the wheat based farming system in Lemo district of Hadiya zone, southern Ethiopia.



SUMMARY OF THE MODULE

Agricultural farmlands have varying biophysical characteristics that influence soil properties and crop yield. Matching fertilizer types, rates, time and placement to the varying soil properties, crop requirements and the production season depends on the ability to identify the limiting factors and related farm characteristics. This requires identifying nutrient management zones which require collecting, analysis and interpreting spatial data for soils, crops, climate and location descriptors and farmers' soil fertility and productivity potential classification criteria. Such intensive data used in the development and validation of the DSTs contributes towards site specific nutrient management development to address the varying response potential of farmlands in different landscapes and their improvement to produce the target yields. The site specific nutrient management approach is a dynamic, plant based, field and season specific nutrient management approach that optimizes the supply of soil nutrients over time and space to match the requirements of crops through four key principles, namely 4Rs: Right product, Right rate, Right time and Right place. These 4Rs provide a basis for defining strategies for the effective use of nutrients in specific areas, crops and seasons using decision support tools.

It is high time to adapt and promote the SSNM approach with DSTs to Ethiopian farming conditions to increase returns to the investments made for fertilizer import and improve environmental sustainability. Creating awareness and capacitating the extension officers and development agents for the necessary advice to be delivered to farmers in this regard is essential. The major scientific principles behind the SSNM are addressed in the module to aid the extension agents while training DAs and model/progressive farmers.

Improper or excess nutrient application is economically unsustainable and may also result in environmental damage such as eutrophication, ammonia volatilization, greenhouse gas emission from soils, soil acidification or contamination of water supplies. To reduce these adverse impacts, it will help keep in mind the five Rs of nutrient stewardship: right source, right rate, right time, right place and right management. If the nutrient application effectively fulfils these categories it may help an agro-ecosystem operate with better water and nutrient use efficiency. A nutrient balance needs to be considered in all soil fertility investigations for improved crop yield and quality. Overall, the timing and quantity of fertilizer especially N application, source of fertilizer, a combination of nutrient contents and their interactions with land and land use conditions are crucial factors for getting an optimum response to fertilizer

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