IPI International Potash Institute

Technical Manual on Potash Fertilizer

Use for Soil Fertility Experts and Development Agents

INTERNATIONAL POTASH INSTITUTE SINCE 1952

Ministry of Agriculture

Ethiopian ATA Agricultural Transformation Agency

Cover photo: Response of bread wheat to KCl fertilizer application in Jihur Kebele, Moretina Jiru woreda, Amhara region, Ethiopia (2014). Left: Plot receiving blended fertilizer and urea only. Right: Plot receiving the same treatment with 100 kg/ha KCl.
Source: *Obtained from ATA and MoANR collections, courtesy of Prof. T. Mamo.*

Compiled by experts from The Ministry of Agriculture and Natural Resources (MoANR) and Agricultural Transformation Agency (ATA) led by Prof. Tekalign Mamo.

ISBN 978-3-905887-22-8
DOI 10.3235/978-3-905887-22-8

Contents

Plate 1. Teff research by Ethiopian student at the Center for Fertilization and Plant Nutrition (CFPN), Israel. Source: *CFPN.*

Introduction

The African continent is home to more than 1 billion people. With current population growth rates, Africa will need to accommodate more than 2 billion by 2050. However, food production in sub-Saharan Africa is significantly lower than other parts of the world: less than 150 kg of grain per capita are produced in the region each year compared to more than 300 kg of grain per capita in other parts of the world. If a growing population is to be fed, this worrying level of agricultural productivity must change rapidly. One of the immediate tools to stimulate improved yields and crop quality is balanced use of fertilizers.

Fertilizer recommendations differ from region to region and from crop to crop, as soil fertility and agro-climatic conditions, as well as crops' root systems and the physiological response of plants and varieties, differ. Such variation has resulted in the term 'balanced fertilization'. This acknowledges that an understanding of site and crop-specific nutrient management requirements will lead to accurate fertilizer recommendations. These, in turn, should lead to increased yields, improved crop quality, enhanced soil fertility, and increased resistance to biotic and abiotic stresses. As a result, farming communities will be able to make a greater contribution to the economy at every level.

Potash was first used in Europe during the 19th century; German potato growers were quick to understand that potash application increased yields, lowered the risk of frost damage, improved storability of the harvested tubers, and significantly reduced damage from soil and plant diseases. It is unacceptable, however, that in the 21st century, African farmers should continue to be deprived of the farming methods so widely practiced elsewhere with respect to fertilizers. It is urgent that the needs of African farmers are better served.

The International Potash Institute (IPI) was established in 1952 and, through more than 60 years of activity, has gained considerable experience in potassium research across many parts of the world. In 2012, IPI launched a program in Ethiopia, in partnership and in close collaboration with the Ministry of Agriculture and Natural Resources (MoANR) of the Federal Democratic Republic of Ethiopia and the Agricultural Transformation Agency (ATA).

This *Technical Manual on Potash Fertilizer Use for Soil Fertility Experts and Development Agents* provides concise and accurate information on potash fertilization to enable effective and responsible knowledge transfer to Ethiopian farmers. IPI is honored to have the opportunity work with its Ethiopian partners in achieving this worthwhile mission.

Hillel Magen
Director, IPI, Switzerland

Foreword

The Ministry of Agriculture and Natural Resources (MoANR) of the Federal Democratic Republic of Ethiopia, together with its key stakeholders, has set Growth and Transformation Plan II agriculture targets to increase production and productivity of smallholder farmers and link them with market opportunities. In order to realize this, one major priority is to replenish the declining soil fertility of agricultural lands.

Cognizant of this fact, the Ethiopian Government is highly committed to promoting soil health and fertility through sustainable land management, reclamation of acid soils, replenishing soil fertility and improving the productivity of waterlogged soils, all aimed at maintaining the soil for current and future generations while improving food security. These actions are leading to increased crop yields across all the key agro-ecosystems of Ethiopia. To this end, potash fertilizer has been recognized as one of the recommended fertilizers for restoring soil fertility and increasing crop yields in most of Ethiopia's degraded lands.

The overall objective of this manual is to contribute to increased food security and poverty reduction by promoting appropriate use of potash fertilizer among smallholder farmers in Ethiopia. We believe this manual will also promote access to potash fertilizer information for key stakeholders and build capacity and enhance knowledge among agricultural extension staff.

We would like to recognize the contribution of technical experts and key institutions, mainly the soil fertility improvement directorate of our Ministry, the Agricultural Transformation Agency (ATA) and the International Potash Institute (IPI) for the key role they have played in realizing the timely preparation and publication of this potassium fertilizer extension manual. We look forward to other similar joint ventures.

Frenesh Mekuria
State Minister of Natural Resources, MoANR

Foreword

Balanced fertilization is the path to sustainable crop production and maintenance of good soil health and fertility. It has both economic and environmental implications. Unbalanced fertilizer use, as we have been practicing for decades in Ethiopia, results in low fertilizer use efficiency, leading to low economic returns and greater harm to the environment. It is therefore imperative that fertilizers are used in a judicious way based on crop demand and soil nutrient status. In addition, nutrient requirements may vary according to the type of crop grown, harvest levels and other site-specific conditions.

It was felt necessary to prepare this technical manual and distribute it to federal and regional experts because: (1) Ethiopia has successfully launched and implemented digital soil fertility mapping of the majority of its agricultural soils through the Ethiopian Soil Information System (EthioSIS), and generated useful information that proves the need for potash fertilizer application in many areas; (2) during the past 4-5 decades, potash fertilizers have not been used or distributed to farmers through the regular extension system due to the prevailing belief that Ethiopian soils are not deficient in potassium; (3) very encouraging results have been obtained from research and thousands of potash fertilizer demonstrations conducted in many areas on farmers' plots and Farmer Training Centers; (4) since 2014, the then Ministry of Agriculture has endorsed the direct application of potash fertilizers and dissemination of the fertilizers to farmers in areas where they are required; (5) no potash fertilizer extension materials or technical manuals currently exist for use by agricultural experts and development agents. It is expected that each regional bureau of agriculture, in collaboration with the soil fertility experts of the Ministry of Agriculture and Natural Resources (MoANR) and ATA, will translate the manual into local languages.

Key soil fertility experts from MoANR and Agricultural Transformation Agency (ATA) have participated in the preparation of this technical manual. The International Potash Institute (IPI) has made a thorough review of the document and also covered the publication cost. All deserve acknowledgement.

Prof. Tekalign Mamo
Senior Director, Agricultural Commercialization Clusters (ACC), ATA

Background

Potassium (K) is an essential nutrient for plant growth. Because large amounts are absorbed from the root zone in the production of most agronomic crops, it is classified as a macronutrient. As one of the 17 chemical elements required for plant growth and reproduction, K is often referred to as 'the regulator' since it is involved in over 60 different enzyme systems in plants. Potassium helps plants to resist drought, disease and excessive temperatures. Potassium aids plants in the production of starches, controls root growth, and regulates the opening and closing of pores in plant cells (known as stomata), which is important for efficient water use. All plants require K, especially crops high in carbohydrate, such as potatoes. Studies have shown that K can promote the growth of long, strong cotton fibers, increase the shelf life of fruits, increase the stem length and quantity of roses, enhance the green color and growth of turf grass, and increase the size and quality of fruits, grains, and vegetables (www.calfertilizer.org).

Potassium is the most abundant nutrient in plants. Like other nutrients, it is naturally found in the soil but can be depleted by poor agricultural land management, such as continuous cultivation, complete removal of crop residues from farmlands, absence of crop rotation and unbalanced fertilizer application. Soil erosion, high surface runoff, and inadequate runoff management also lead to leaching (loss of water-soluble nutrients), especially of nutrients such as nitrogen (N) and K.

In order to achieve their maximum yield potential, crops need K in large quantities. Potassium is relatively immobile in the soil and hence its availability depends on several factors including soil temperature and pH. The availability of K is at its greatest when soils have a pH of 6.0-7.0. Soil moisture is essential for K to move in the soil, so dry conditions also limit its availability. Soils that have high clay content can retain high levels of K reserves, meaning that the amount and type of clay in the soil also impacts K availability. Thus, while soils can supply some K for crop production, if the availability is poor, K must be supplied as a fertilizer.

When farmers practice long-term intensive cropping using only N and phosphorus (P)-based fertilizers, the low level of K in the soil that results reduces K supply to crop plants, impacting on crop yields, as evidenced in India (Singh and Swarup, 2000). For a long time, Ethiopia used only urea and Diammonium phosphate (DAP) as sources of N and N+P fertilizers respectively. Currently, there is growing evidence of increasing K deficiency as a result of using only N and P fertilizers, resulting in negative K balance under most cropping systems in Ethiopia. Potassium deficiencies are now more widespread, specifically on acid soils and heavy textured soils in Ethiopia. Many soils that had high K concentrations in the mid-1960s are now in the range of low to optimum (EthioSIS, 2013). However, several hundred K fertilizer demonstrations conducted on many crops in Ethiopia over the past 3-4 years have also resulted in significant yield increases, especially on highland Vertisols that feature higher K values.

Plates 2. *Some of the soil K depletion factors in Ethiopia. Source: Istockphoto.*

Potassium is symbolized as K_2O on fertilizer labels and is the third number on the fertilizer grade label. Plants absorb K in the form of the ion K^+, which dissolves readily in water. Ninety five percent of all potash fertilizers come in the form of muriate of potash (MOP), also known as potassium chloride (KCl). It contains 60-62% K_2O (50% K^+). For crops unable to tolerate high chloride contents, potassium sulfate (K_2SO_4) is the common alternative fertilizer. This has 50% K content but also contains 16% sulfur (S). KCl comes in both granular and powder forms, but for ease of application, the granular form is preferred. Color-wise, it is either white or brown.

This manual provides important information related to K nutrition of plants, its reaction in soils, its function in plants, and its role in balanced fertilization and efficient crop production.

Role of potassium in the plant

Most of the functions of K in the plant are indirect, in the sense that K is necessary for other chemical reactions to operate properly. Some 60 enzymes require the presence of K, with high concentrations found in the active growing points and immature seeds. The plant uses K in photosynthesis, carbohydrate transport, water regulation, and in protein synthesis.

Potassium is associated with movement of water, nutrients, and carbohydrates in plant tissue. The nutrient is found within the plant cell solution and is used for maintaining the turgor pressure of the cell (meaning it keeps the plant from wilting). In addition, K plays a role in the proper functioning of the stomata (cells located on the bottom of the leaf that open and close to allow water vapor and waste gases to escape) and acts as an enzyme activator.

Some of the benefits of proper K nutrition are listed below. These roles or functions are general, but all are important to profitable crop production.

- **Regulation of enzyme systems:** K is known to influence more than 60 enzyme reactions. Thus, K is associated with almost every major plant function.
- **Photosynthesis:** K regulates the carbon dioxide supply by controlling the opening of leaf pores (stomata).
- **Respiration:** K improves the efficiency of a plant's use of sugars for maintenance and normal growth functions.
- **Translocation:** K moves sugars from sites of photosynthesis to cotton bolls or other storage depots.
- **Root development:** K works with P to stimulate and maintain rapid root growth of seedling plants.
- **Legume nodulation:** K is needed for optimum nodule formation and efficient fixation of N by legume plants.
- **Winter hardiness:** K serves as an 'anti-freeze' by lowering the freezing point of the cell sap in roots and by building plant tolerance to low temperature stress.

- **Protein synthesis:** K stimulates the synthesis of true protein in plants from the amino acid building blocks.
- **Disease resistance:** K improves plant health and natural resistance to many leaf, root and shoot diseases.
- **Insect tolerance:** K healthy plants better tolerate pests and often recover more quickly from root and shoot injury inflicted by nematodes and insects.
- **Drought tolerance:** Under water-deficit conditions, K nutrition increases crop tolerance to water stress by utilizing the soil moisture more efficiently than in K deficient plants. The positive effects of K on water stress tolerance may be through promotion of root growth accompanied by a greater uptake of nutrients and water by plants.
- **Tolerance to waterlogging:** K supplementation under waterlogging not only increases plant growth, photosynthetic pigments and photosynthetic capacity, but also improves plant nutrient uptake as a result of higher K^+, Calcium (Ca^{2+}), N, Manganese (Mn^{2+}) and Iron (Fe^{2+}) accumulation (Ashraf *et al.*,2011).

As a result, besides its role in increasing crop yield, K fertilization is frequently associated with improved crop quality as well as better handling and storage properties.

If K is deficient, growth is stunted and plants develop poor root systems resulting in reduced crop yields. Deficiency symptoms are most obvious on the older, lower leaves since this element is readily translocated within the plant. Symptoms begin as interveinal chlorosis or 'bronzing' near the edges of lower leaves, and develop into a firing or scorch as the deficiency continues. This firing moves inward until the entire leaf dies and is shed. Severe deficiency causes premature defoliation, delayed maturity, and plant death. Since K deficiency can result in leaf shedding, this reduces the ability of the plant to produce carbohydrates and, ultimately, reduces yields. Plants, especially small grains and maize, are prone to lodging when they are K deficient. This phenomenon is also common in Ethiopia where tef plants lodge when top dressed with urea. In this case, application of potash fertilizer will help the tef plant withstand lodging and attain full vegetative growth.

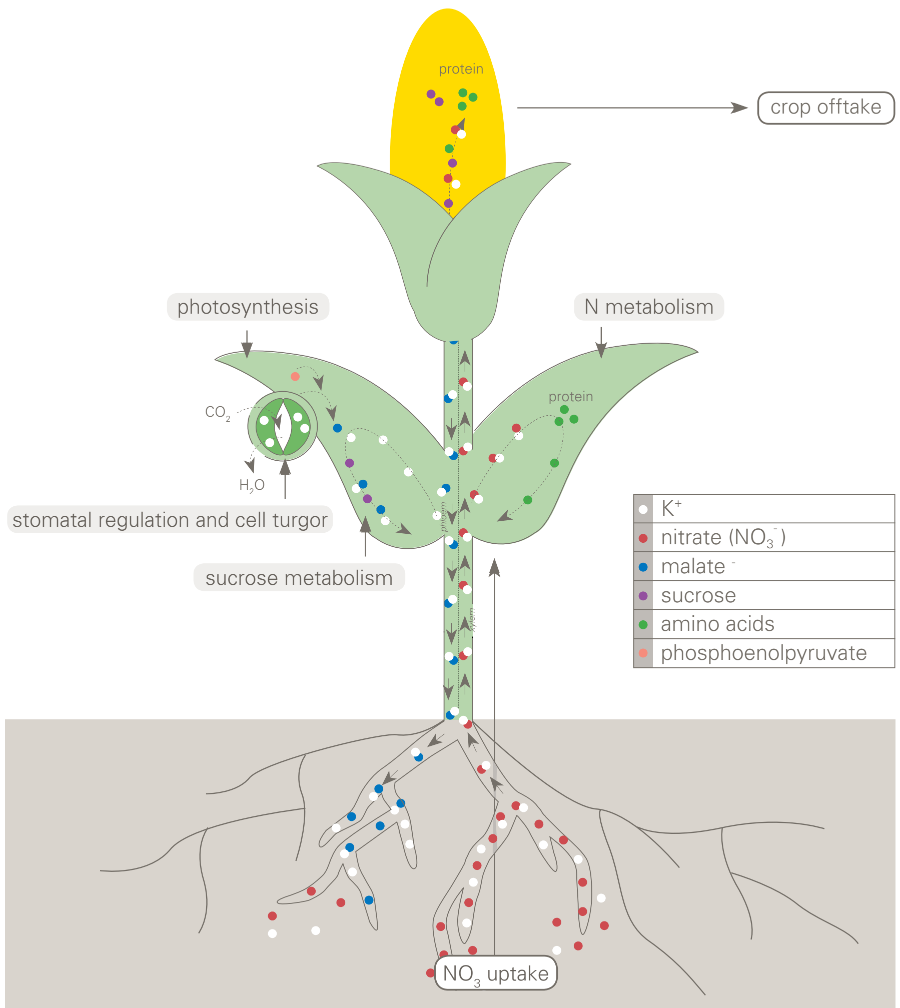

Figure 1. Schematic of K in plant systems. Sources: *Marschner* et al., *1996 (based on Benzioni* et al., *1971 and Kirkby and Knight, 1977); Syers, 1998; Krauss, 2003; Pettigrew, 2008; Römheld and Kirkby, 2010.*

Potassium in soils

Potassium does not move readily in most soils, as the movement is primarily through diffusion. Potassium is much less mobile than nitrate, but more mobile than P. However, on sandy soils with low cation exchange capacity (CEC), K can move by mass flow, and loss from the surface soil can be significant, especially after periods of heavy rainfall. The fate of applied K depends on the CEC and clay minerals present. Potassium may be leached from the root zone before it interacts with soil mineral, or it can exchange for other cations on the exchange complex and be held in a readily available form for future use by plant roots. If strongly charged smectites (2:1 clay minerals) are present, K may be fixed in an interlayer region of these 2:1 clays, and be slowly released as the minerals are subjected to wetting and drying cycles, or acid weathering.

Potassium is not known to cause any environmental problems, but needs to be managed in a way that minimizes losses. This involves implementing good erosion control practices, maintaining good soil pH, building soil organic residues where possible, and using split applications to reduce leaching losses on soils with low CEC.

Three forms of K (unavailable, slowly available or fixed, and readily available or exchangeable) exist in soils. A description of the K forms and their relationship to each other is provided in the paragraphs that follow. The general relationships of these forms to each other are illustrated in Figure 2.

Unavailable K: Depending on soil type, approximately 90-98% of total soil K is found in this form. Feldspars and micas are minerals that contain most of the K. Plants cannot use the K in this crystalline, insoluble form. Over long periods of time, these minerals weather (break down) and K is released, with some K moving to the slowly available pool and some to the readily available pool (see Figure 2). This process is too slow, however, to supply the full K needs of field crops.

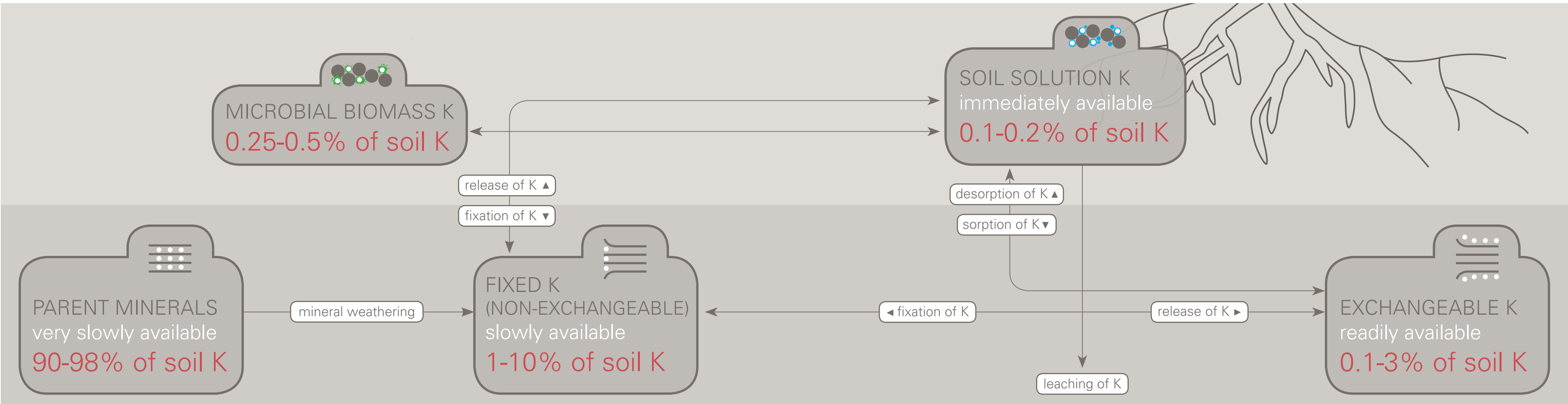

Figure 2. Schematic of potassium in soil systems. Sources: *Marschner* et al., *1996 (based on Benzioni* et al., *1971 and Kirkby and Knight, 1977); Syers, 1998; Krauss, 2003; Pettigrew, 2008; Römheld and Kirkby, 2010.*

Slowly available K: This form of K is thought to be trapped between layers of clay minerals and is frequently referred to as being 'fixed'. This slowly available K is not measured by routine soil testing procedures. Growing plants cannot use much of the slowly available K during a single growing season, but slowly available K can serve as a reservoir for readily available K. While some slowly available K can be released for plant use during a growing season, some of the readily available K can also be fixed between clay layers and thus converted into slowly available K (Figure 2).

The amount of K fixed in the slowly available form varies with the type of clay that dominates in the soil. Smectite clays are dominant in Vertisols or heavy textured soils in Ethiopia. These clays fix K when soils become dry because K is trapped between the layers in the clay mineral. This K, however, is released when the soil becomes wet. There are other soil clay minerals (illite clays) which can also fix K between layers when they become dry, but do not release all of the fixed K when water is added. This fixation without release causes problems for management of potash fertilizers for crop production.

Readily available K: K that is dissolved in soil water (water soluble) plus that held on the exchange sites on clay particles (exchangeable K) is considered readily available for plant growth. The exchange sites are found on the surface of clay particles. This is the form of K measured by routine soil testing procedures.

Plants readily absorb the K dissolved in the soil water. As soon as the K concentration in soil water drops, more is released into this solution from the K attached to the clay minerals. The K attached to the exchange sites on the clay minerals is more readily available for plant growth than the K trapped between the layers of the clay minerals.

The relationships among slowly available K, exchangeable K, and water-soluble K are summarized in Figure 2 (page 14).

One form of K is converted to another in both directions as simulated by the arrows in Figure 2. The rate of conversion is affected by such factors such as root uptake, fertilizer K applied, soil moisture, and soil temperature.

Potassium availability and uptake by plants

Plants differ in their ability to take up K depending on several factors. The factors that affect the availability of K in the soil and result in plant uptake are soil factors, plant factors, and fertilizer and management practices.

Soil factors

This includes the material from which the soil was formed, the amounts and types of clay minerals in it, the vegetation and climate under which it was formed, topography and drainage, and the length of time it has been forming.

CEC of the soil: This reflects the soil's ability to hold K^+ and other cations and store them in the soil for crop uptake. Clay minerals and soil organic matter are the two properties of soil that contribute to CEC. In general, the higher the soil CEC, the greater the storage capacity and supplying power for K.

Quantity of available K in the soil: This is the value the K soil test reflects. It is the sum of exchangeable K and water soluble K. As the level of soil test K decreases, the crop response to applied K increases.

Non-exchangeable or slowly available K: This is the K that is in equilibrium with available K and renews the soil's supply of exchangeable K. For most soils, the more crops depend on non-exchangeable K, the lower the yields.

K fixation capacity of the soil: Some soils have clay types that can fix large amounts of K from fertilizers or other sources. This reduces the availability of K to the crop.

Amount of K in the subsoil and the density or consistency of subsoil layers: Some subsoils are high in K available to roots. Others, such as those formed under grass, have low K availability. If dense layers (e.g. fragipans) develop in the subsoil, root penetration and rooting volumes are decreased, reducing the availability of K and other nutrients. Root systems are frequently shallow, with roots concentrated in the upper layers where K supply may be adequate, but where shortage of water can make it unavailable to plants.

Soil temperature: Low soil temperatures reduce K availability and uptake rates by crops. The optimum soil temperature for K uptake for a crop such as maize is about 29.5°C. Effects of low temperature can be somewhat offset by increasing soil K levels. Row application of K can be important with lower soil temperatures, especially for early planted and minimum till crops.

Soil aeration and oxygen level: Air is necessary for root respiration and K uptake. Root activity and subsequent K uptake decrease as soil moisture content increases to saturation. Oxygen levels are very low in saturated soils (Barber, 1962; 1985).

Soil moisture: Moisture is needed for K to move to plant roots (Rosolem *et al.*, 2003). For example, it is needed for mass-flow movement of K to the plant roots with water and for the diffusion of K to the roots to resupply that taken up by the roots. Drought stress and excess moisture reduce K availability and uptake by crops; increasing soil K levels can help to overcome these barriers to K uptake.

Soil tilth: Tilth is related to the friability of soil (its tendency to crumble under pressure) and the extent of soil aeration. Air is needed for root respiration for K uptake. Availability of soil K is reduced in no-till and ridge-till planting systems. The exact cause of this reduction is not known.

Plant factors

Crop type: Crops differ in their ability to take up K from a given soil. This is associated with the type of root system and surface area of the roots. Grasses, for example, have a much greater capacity to take up K from the plow layer than alfalfa does. Grasses have many more fibrous, branching roots, increasing the K absorbing surface.

Plant population: As plant population increases, yields of some crops are greater and demands on soil K are increased. Yields often will not increase with higher populations unless adequate levels of K are in the soil, from natural or fertilizer sources.

Crop yield: As crop yields increase, total K uptake increases. The uptake per unit of crop yield, such as kg of K per ha or ton, may be nearly constant at optimum yield levels.

Fertilizer use and soil management practices: When adequate K is available, addition of N and/or P fertilizer greatly increases K uptake. Usually, the uptake of K by crops closely parallels N uptake and may be greater. So, as limiting nutrients are added and yields are increased, the demands on soil K increase.

Placement of K: Band (subsurface) applied K is more available than surface applied K. Row applied K at moderate rates and soil test levels is usually twice as available to maize as similar amounts broadcast.

Drainage-induced K availability: Draining excess moisture helps soils to warm up earlier and improves the aeration of the soil. This improves the availability of soil K.

Weed and insect control: Controlling weeds and insects reduces competition for moisture and nutrients, making more K available to the crop.

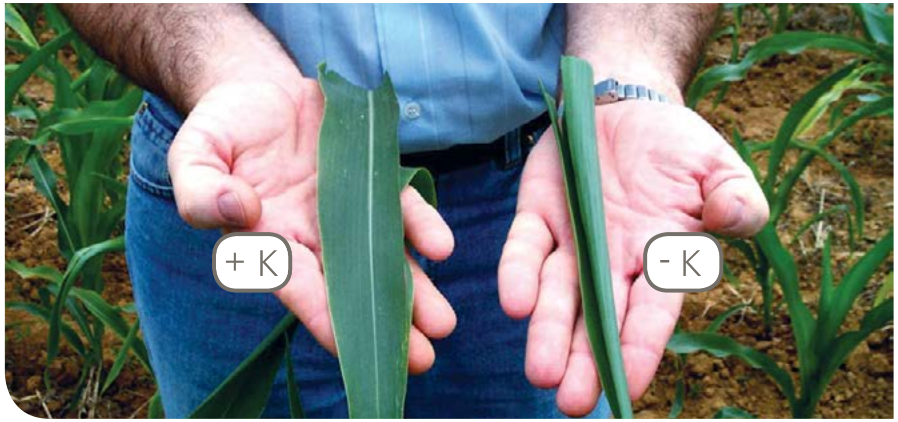

Plate 3. *Drought stress in maize leaves is not visible when K is applied to the crop.*
Source: *IPI.*

Potassium and balanced crop nutrition

Balanced nutrition of plants should be a high priority for every farmer and for all crops. Properly nourished plants grow stronger, produce more consistently, have better disease resistance, and are more tolerant to stress. Plants should obtain balanced nutrition either from the soil or, if necessary, through fertilizer application. To meet plant K needs, the nutrient reservoir must be monitored frequently by soil testing and resupplied from fertilizer sources. Adequate supplies of other plant nutrients are required to obtain maximum responses to K fertilizer, there being several important relationships between K and other nutrients.

High K fertilization can decrease the availability of magnesium (Mg) to the plant, and may result in Mg deficiency of crops grown on soils that are already low in Mg. This problem is often encountered with crops grown on sandy soils. Conversely, crops grown on soils high in Mg can suffer K deficiency, especially if the soils are high in P and low in K.

Interacting nutrients have many plant functions in common

Potassium and 15 other nutrients are equally essential for plant growth. How K interacts with each nutrient is best illustrated by the number of crop functions they have in common. Such interactions are the reasons why nutrient balance is so important. The following are examples:

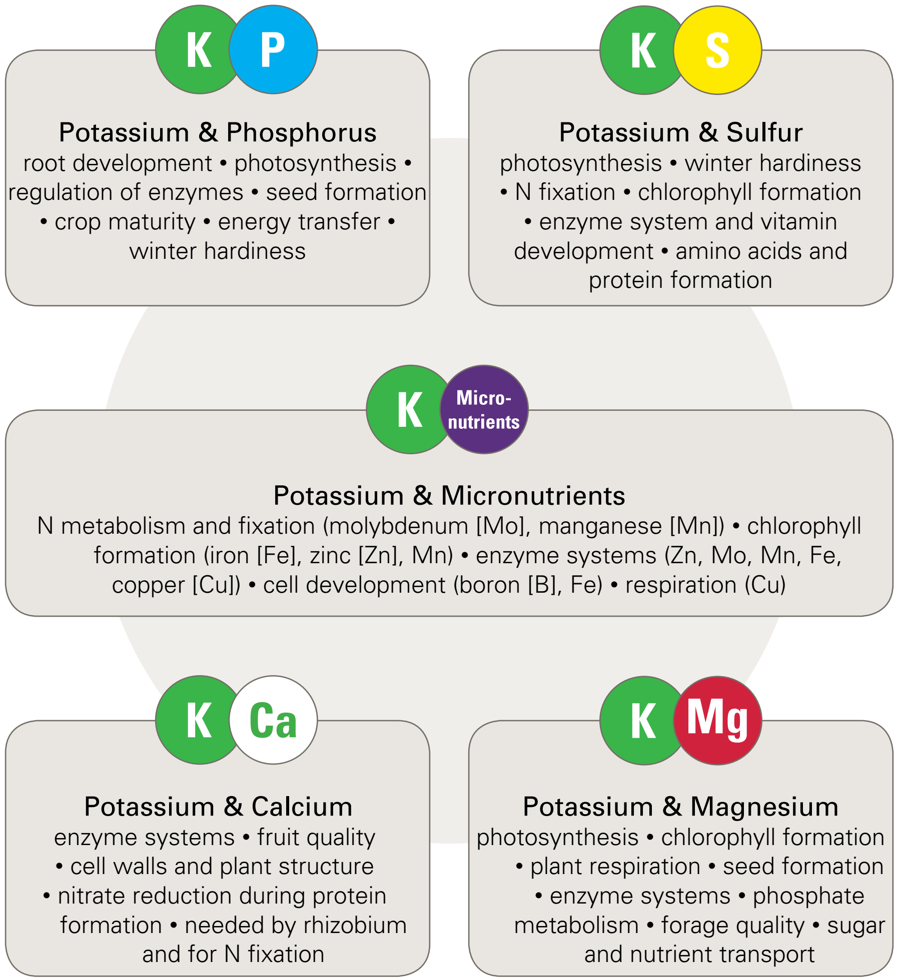

Figure 3. *Interaction of K with other nutrients in plant functions.*

Potassium deficiency and its symptoms

Potassium deficiency in soil causes serious reductions in crop yield and K deficient crops become easily susceptible to diseases, pests, and frost damage and have poor yield and quality (Umar and Moinuddin, 2001). Potassium deficiency is more prevalent in sandy, leached and eroded soils, and in intensive cropping systems where fertilizer application is not practiced. Typically, K deficiency is associated with soil acidity in areas where there is high rainfall and crop production has been practiced for many years. In acid soils, most of the cations, including K, are leached and mined and, as a result, deficiency of such essential elements can occur (Agegnehu, 2009).

Potassium deficiency symptoms are often seen as necrosis of the leaf tips or margins. However, crops can be deficient in K without any visible symptoms; this effect is commonly referred to as *hidden hunger* (International Potash Institute, 2014). Symptoms of K deficiency also include slow growth, a poorly developed root system, and a grayish tinge to the plant. Potassium deficiency is corrected by applying potash fertilizer to the soil during and after sowing, as discussed earlier.

Since K is mobile within the plant, deficiency symptoms appear in older leaves. For maize, the margins of the lower leaves turn brown (Plate 4). This development of dead tissue is accompanied by a striped appearance in the remainder of the leaf. The entire leaf has a very distinct light green appearance when viewed from a distance. However, the striping associated with K deficiency in maize can be easily confused with deficiency symptoms for S, Mg and Zn.

One of the most common signs of K deficiency is the yellow scorching or firing (chlorosis) along the leaf margin. In severe cases, the fired margin of the leaf may fall off. However, with broadleaf crops such as soybeans and cotton the entire leaf may shed, resulting in premature defoliation of the crop.

Seeds from K deficient plants are small, shriveled, and more susceptible to diseases. Fruit often lack their normal coloration and are low in sugar content. Vegetables and fruit deteriorate rapidly when shipped and have a short shelf life in the market.

Plate 4. *Potassium deficiency symptoms in soybean.* Source: *IPI.*

Potash fertilizer use in Ethiopia

In Ethiopia, application of potash fertilizer received little attention prior to 2014, mainly because it was believed that K was 'adequate' in soils. Yet removal of K is very high in Ethiopian cropping systems, particularly those involving cereal crops.

Earlier findings from FAO-assisted fertilizer demonstration trials carried out in Ethiopia in the 1970s, through the Freedom from Hunger Campaign, showed inconsistent and/or non-significant responses to potash fertilizer. In addition, the exchangeable K content of most agricultural soils (which are mainly clay soils), exceeded the universally accepted 0.25 cmol/kg critical level set by the ammonium acetate extraction method. Thus, until recently, many researchers believed that K fertilizers were not necessary. However, recent information from different areas of Ethiopia shows that there has been a gradual decline in K status in Ethiopian soils from high to medium and medium to low. As a result, widespread K deficiency in soils and crops has been observed in recent years (Abayneh and Berhanu, 2006; Haile and Boke, 2011). Recent findings of the national digital soil fertility survey have proved that 58% of Tigray region requires K fertilization.

There are also reports that indicate rapid increases in wheat, barley, tef, and potato crop yields as a result of potash fertilizer application on soils. For example, the works of Astatke *et al*. (2004) and Wassie Haile (2009) proved a sharp increase in wheat and potato yields grown on Vertisols and Nitisols with an application of 50 kg/ha K_2SO_4 and KCl, respectively. There is strong belief that exchangeable K gets fixed in clay crystal lattices in Vertisols, while in Nitisols, the deficiency is most likely caused due to leaching of K along with the other base cations. Consequently, the 0.25 cmol/kg index needs to be revised for these soils, as is the case for Indian Vertisols (Subba Rao and Srivastava, 2012).

In a similar study on potato crops conducted in Hagere Selam, southern Ethiopia (Wassie and Tekalign, 2013), total yield and marketable tuber yield significantly increased by an average of 36 Mt/ha compared to the control treatment due to fertilization with K_2SO_4. It was also found that potash fertilizer use resulted in a very high marginal rate of return.

From demonstrations carried out in 2013 on farmers' plots and Farmers' Training Center sites in Basona Warana (north Shoa), Ada'a and Gimbichu (east Shoa) woredas in collaboration with the Ethiopian Soil Information System (EthioSIS)

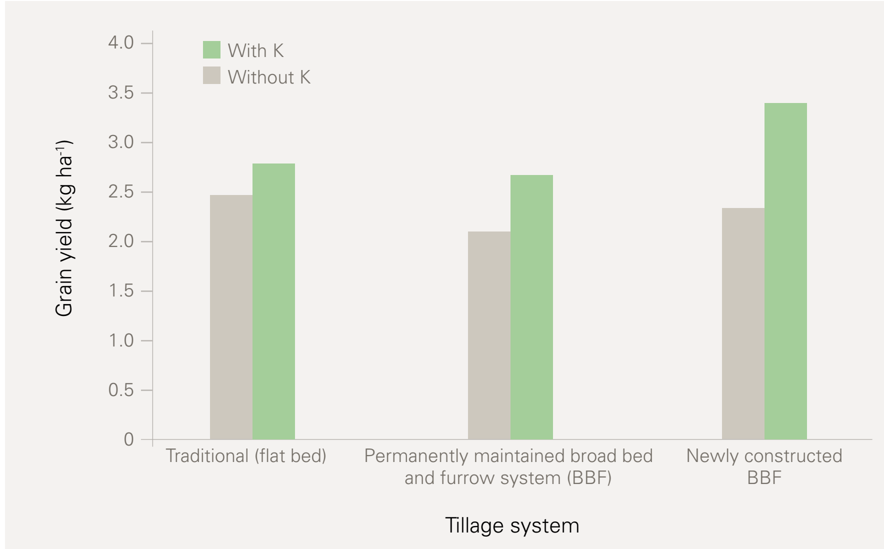

Figure 4. *Effect of K fertilization on wheat grain yield under three tillage systems at Chefe Donsa, East Shoa, Ethiopia (adapted from Astatke* et al.*, 2004.)*

and the then Ministry of Agriculture (MoA), it was found that application of potash fertilizer (KCl) increased crop yield by a mean of about 13% to 62%. In Basona Werana woreda, barley and bread wheat grain yields were increased by 14% and 20% respectively by application of MOP. In Gimbichu woreda, KCl fertilizer application to bread wheat increased the yield by 25% while in Ada'a woreda, tef yield increased by 38%. These results were obtained by the application of 100 kg/ha of KCl along with the recommended rates of urea and NPS fertilizers.

Results from thousands of K fertilizer demonstrations conducted so far in many locations in the country have shown that plots receiving K fertilizer have deep green leaves with good stand, a high number of tillers, long spikes and large seed size. Typically, the vegetative growth on K-treated plots was relatively fast, enabling the crop to reach the heading stage earlier than plots that did not receive KCl fertilizer. The latter exhibited slow and incomplete vegetative growth, a smaller number of tillers, short and weak stems, short spikes, pale green leaves and matured early.

Another useful observation made on highland Vertisols (dark clay soils) was that, despite the high exchangeable K level in the soils, crops responded to K fertilizers, proving that the soil exchangeable K was fixed by the clay and unavailable to plants. In some cases, Mg induced K deficiency has also been found; according to Loide (2004), higher levels of exchangeable Mg suppress K availability to plants by occupying the exchange complex. In Ethiopia, the latest recommendation to apply potash as straight fertilizer in the needy woredas and kebeles take these facts into account.

The role of K fertilizers was more widely recognized and acclaimed by farmers in Ethiopia as a result of the moisture shortage that took place due to the 2015 El Niño weather pattern. Related to this, plots that received K fertilizer were healthier and continued to grow while those plots that did not receive K fertilizer were more affected by moisture stress and were weak to the extent that most died. Similarly, in those areas where yellow rust or septoria disease was detected, those plots that received K fertilizer were observed to be more tolerant and less affected.

One other positive effect of K fertilization on small-grained cereals (e.g. tef) has been the production of many productive and thick tillers. Plate 5 shows such effects on a tef crop. Farmers witnessing these fertilizer trials have already started to request the ‘white salt fertilizer’, a name they gave to KCl fertilizer. In a recent survey in Moretna Jiru, north Shoa, it was found that a wheat plot (Danda’a variety) fertilized with 100 kg/ha of MOP and blended fertilizer could give 7.5 Mt grain yield. This is not surprising since in the same woreda, high rainfall, wet conditions and waterlogged Vertisols are common features; previous K fertilization efforts have also resulted in higher overall growth and yield in wheat, as shown in Plate 6.

In recent K fertilizer demonstration work conducted in Dugda woreda, Oromia region, it was found that irrigated wheat (Digelu variety) performed very well when

Plate 5. *Response of tef (Kuncho variety) to KCl fertilizer application in Arerty Kebele, Menjarna Shenkora woreda, Amhara region, Ethiopia (2015). Note number of well-developed tillers.* Source: *Obtained from ATA and MoANR collections, courtesy of Prof. T. Mamo.*

Plate 6. *Response of bread wheat (Danda’a variety) to fertilizer treatment (NPSZnB) with and without KCl on Vertisols in Woyra Amba Kebele, North Shoa Zone, Moret and Jiru woreda, Ethiopia (2014).* Source: *Obtained from ATA and MoANR collections, courtesy of Prof. T. Mamo.*

supplemented with KCl fertilizer, the plots being dense, greenish and with a better stand compared to the non-K treated plot (Plate 7). In a previous K demonstration conducted on wheat in rainfed farmers’ plots, similar results were found, even under moisture stressed conditions that prevailed in the area.

Plates 7. Effect of KCl fertilizer application on irrigated bread wheat (Digelu variety) at a farmers' training center in Dugda woreda, Meki town, Oromia region of Ethiopia (2015). Source: *Obtained from ATA and MoANR collections, courtesy of Prof. T. Mamo.*

In general, the effects of K fertilizer application on all crops in various locations were very encouraging. The smallholder farmers have understood the invaluable role K plays in increasing crop yield and quality, and persistently ask for the fertilizer. Therefore, agricultural experts and development agents should work hard to make sure that farmers have easy access to potash fertilizers. This should include discouraging farmers from using wood ash, which has high pH and will increase the pH of the soil. Since many international fertilizer and mining companies are progressing very well in their efforts to mine and produce potash fertilizers for both domestic and export markets, Ethiopian farmers can expect to get potash fertilizer on their doorsteps within a few years. Until then, we have to depend on imported potash fertilizers.

Based on the evidence obtained so far, potash fertilizer is recommended to be applied independently as a fertilizer in the required areas. Farmers are encouraged to apply 100 kg/ha of the fertilizer for cereals. In cases where farmers have financial limitations, they should be advised to apply not less than 50 kg/ha of potash fertilizer. However, on clay soils, the 100 kg/ha application rate is to be strongly encouraged, since numerous demonstrations have shown that applied potash becomes fixed by the clay and is not easily available to plants unless higher rates are applied. Other recommended agronomic practices, such as use of improved varieties, row planting, proper weeding and moisture conservation also help in increasing fertilizer use efficiency generally, including that of K.

Placement of potassium fertilizers

Most K fertilizers are completely water-soluble and in some cases have a high salt index. Consequently, when placed too close to seeds or transplanted seedlings they can decrease seed germination and plant survival. This fertilizer injury is most severe on sandy soils under dry conditions and with high rates of fertilization, especially N and K. Some crops, such as soybeans and cotton, are much more sensitive to fertilizer injury than maize. Placement of the fertilizer in a band approximately 7.5 cm to the side and 5 cm below the seed is an effective method of preventing fertilizer injury. Row placement of K fertilizer is generally more efficient than broadcast application when the rate of application is low or soil levels of K are low.

Plants require large quantities of K for proper growth and development. In sandy soils, highly weathered soils and clayey soils or Vertisols, applied K may be exposed to leaching, adsorption by the clay surface or washed away during drainage. A second type of problem can occur if the full recommended quantity of potash fertilizer is applied in a single dose during sowing, as this may lead to salt damage of young crop roots, particularly during dry periods. To reduce both these problems, split application of potash fertilizers is recommended at two growth stages, with half of the fertilizer applied in basal form during sowing/planting and the rest top dressed after weeding at the full tillering stage (30-40 days after sowing, depending on moisture availability in the area). The second dose of potash fertilizer can be applied together with the remaining urea. Split application of K together with N can be a useful strategy where leaching losses of K and N are considerable due to high rainfall. In addition, potash fertilizer applied directly is more efficient than K applied as a component of blended fertilizer.

Broadcasting and mixing with the soil before planting is usually a convenient and effective method of applying K fertilizers. Fertilizer injury is minimized by this method but on deep sandy soils some K may be lost by leaching, especially if considerable time elapses between application and planting and heavy rainfall occurs. In soils containing clay minerals (2:1 type) that fix K, some fertilizer may become unavailable.

Sources of potassium

There are many unrefined and manufactured sources of K, but plants always absorb K in the same form, K^+. Some of the most commonly used K sources are KCl (60% K_2O), K_2SO_4 (50% K_2O), potassium magnesium sulfate (22% K_2O), potassium nitrate (44% K_2O), and animal manures (1-2% K_2O). KCl is the most common K source used. The K content of fertilizer is usually expressed as K_2O even though K does not exist in this form in the fertilizer. To calculate the amount of K_2O, simply multiply K by 1.2; to calculate the amount of K in K_2O, multiply by 0.83.

Manure is also a source of K. The K content of manure varies with animal type, feed ration, storage, and handling practices. Manure should be analyzed to determine the amount of K it contains.

References

Abayne, E., and D. Berhanu. 2006. Soil survey in Ethiopia: The past, present and future. Proceedings of the seventh conference of the Ethiopian Society of Soil Science on soils for sustainable development, 27-28, April 2006, Addis Ababa, Ethiopia. p. 61-79.

Agegnehu, G. 2009. Ameliorating effects of organic and inorganic fertilizers on crop productivity and soil properties on reddish-Brown soils. *In*: ESSS (ed.). Improved natural resource management technologies for food security, poverty reduction and sustainable development. p. 127-140. Proceedings of the 10th conference of the Ethiopian Society of Soil Science, 25-27 March 2009, Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa, Ethiopia. http://www.calfertilizer.org (accessed in April, 2016).

Ashraf, M.A., Ahmad M.S.A., Ashraf. M., Al-Qurainy, F., and Ashraf M.Y. 2011. Alleviation of waterlogging stress in upland cotton (*Gossypium hirsutum* L.) by exogenous application of potassium in soil and as a foliar spray. Crop Pasture Sci. 62:25-38.

Astatke, A., T. Mamo, D. Peden, and M. Diedhiou. 2004. Participatory on-farm conservation tillage trial in the Ethiopian highlands: the impact of potassium application on Vertisols. Experimental Agriculture 40, 369-379.

Barber, S.A. 1962. A diffusion and mass-flow concept of soil nutrient availability. Soil Sci. 93:39-49.

Barber, S.A. 1985. Potassium availability at the soil–root interface and factors influencing potassium uptake. *In:* Munson, R.d. (ed.). Potassium in agriculture. Madison, Wisconsin, USA: American Society of Agronomy. p. 309–324.

Ethiopian Soil Information System (EthioSIS). 2013. towards improved fertilizer recommendations in Ethiopia – Nutrient indices for categorization of fertilizer blends from EthioSIS woreda soil inventory data. A discussion paper. Addis Ababa, Ethiopia. http://www.cropnutrition.com/efu-potassium#in-soil (accessed in April, 2016). International Potash Institute. 2014. Potassium a Nutrient Essential for Life. IPI booklet.

Haile, W. On farm verification of potassium fertilizer Effect on the yield of Irish potato grown on Acidic soils of Hagere Selam, Southern Ethiopia. Ethiopian Journal of Natural Resources, 11(2):207-221.

Haile, W., and S. Boke. 2011. Response of Irish Potato (*Solanum tuberosum*) to the Application of Potassium at Acidic Soils of Chencha, Southern Ethiopia. Int. J. Agric. Biol. 13:595-598.

Haile, W., and T. Mamo. 2013. The Effect of Potassium on the Yields of Potato and Wheat grown on the Acidic Soils of Chencha and Hagere Selam in Southern Ethiopia. International Potash Institute *e-ifc* 35:3-8.

Loide, V. 2004. About the effect of the contents and ratios of soil's available calcium, potassium, and magnesium in liming of acid soil. Agron. Res. 2:71-82.

Rosolem, C.A., G.P. Mateus, L.J.G. Godoy, J.C. Feltran, and S.R. Brancaliao. 2003. Root morphology and potassium supply to pearl millet roots as affected by soil water and potassium contents. Revista Brasileira De Ciencia Do Solo 27:875-884.

Singh, G.B., and A. Swarup. 2000. Lessons from long-term fertility experiments. Fertiliser News 45(2):13-24.

Subba Rao, A., and S. Srivastava. 2012. Assessment of Potassium availability in Vertisols and its implication on fertilizer K recommendations. 7th IPI-FAI Round Table discussion in Collaboration with IPNI. New Delhi, India.

Umar, S., and K. Moinuddin. 2001. Effect of sources and rates of potassium application on potato yield and economic returns. Better Crops Int. 15:13-15.

International Potash Institute
Industriestrasse 31
CH-6300 Zug, Switzerland
T +41 43 810 49 22
F +41 43 810 49 25
ipi@ipipotash.org
www.ipipotash.org

IPI Coordinator for
sub-Saharan Africa and China
Mr. Eldad Sokolowski,
c/o ICL Fertilizers
P.O. Box 75, Beer Sheva
8410001, Israel
T + 972 8 646 57 39
F + 972 8 628 09 95
Eldad.Sokolowski@icl-group.com

Prof. Tekalign Mamo
State Minister and Minister`s Advisor
Ministry of Agriculture
P.O. Box 62347, Addis Ababa, Ethiopia
T +251 116 462410
F +251 116 462202
Tekalign.Mamo@moa.gov.et
t.mamo@ethionet.et