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The First National Potash Symposium
Dar es Salaam, Tanzania, 28-29 July 2015

Potassium for Sustainable Crop Production and Food Security

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Potassium for Sustainable Crop Production and Food Security

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Foreword

Over five decades, potassium (K) has been regarded as sufficient in most Tanzanian soils. This generalization has led to limited research with regards to soil K status, plant nutrition and to the development of fertilizer recommendations which include K in fertilizer formulations. Tanzania has K-blended fertilizer recommendations for just a few crops like sisal, tea and tobacco, with other crops depending on inherent K supply from the soil, which is gradually declining due to inadequate K supplies. In recent years, it has been recognized that K levels in some soils are lower than anticipated, and that K deficiency symptoms are now common in certain major crops like cassava, maize, and rice. With such observed deficiencies, it is not possible to provide fertilizer recommendations – that include K – with certainty.

In response to declining potash levels in Tanzanian soils, the first **Tanzania National Potash Symposium** was held at the Protea Hotel Courtyard, Dar es Salaam, Tanzania from 28-29 July 2015. The Symposium's objectives/themes were to:

1) obtain baseline information on K research in Tanzania;
2) synthesize available information; and
3) identify research gaps which will establish a K research agenda.

These proceedings are an outcome of the Symposium, which was relevant and timely to address K fertilizer demand in Tanzania, and include the papers presented at the event.

The main theme of the symposium was *Potassium for Sustainable Crop Production, Food Security and Poverty Reduction.* In this Symposium, two keynote and 11 research papers were presented. The research papers presented were divided into four sub-themes, namely:
Sub-theme 1: Potash distribution in the soils of Tanzania
Sub-theme 2: Role of potash for sustainable crop productivity in Tanzania
Sub-theme 3: Trends of potassium levels in soils of Tanzania
Sub-theme 4: Economics of K-based fertilizers for sustainable crop production

A presentation was also made on K-based fertilizer formulation and packaging, but this paper was not made available for inclusion in this publication. The proceedings also include a chapter on the way forward, which provides recommendations for the K research agenda in Tanzania.

The papers presented at the Symposium highlighted the extent of potash deficiency, which was not previously known and is among the major soil fertility constraints resulting in low crop yields. Over the years, research has concentrated only on nitrogen and phosphorus-containing fertilizers which, in order to balance nutrient ratios, have resulted in the greater acceleration of potash uptake from soil reserves.

The Tanzanian Department of Research and Development of the Ministry of Agriculture, Livestock and Fisheries is keen to ensure that a K research agenda is implemented for the benefit of local farmers. The Department of Research and Development will also include potash research in the priority areas.

On behalf of the Department of Research and Development, I would like to acknowledge the African Fertilizer and Agribusiness Partnership, in collaboration with the Agricultural Research Institute-Mlingano, for organizing this wonderful symposium; as well as the International Potash Institute of Switzerland for providing the financial support needed to hold this symposium and produce these proceedings. I sincerely thank them all for their efforts, determination and commitments in this endeavour.

Dr. Hussein Mansoor
Ag. Director, Research and Development
Ministry of Agriculture, Livestock and Fisheries

Keynote Papers

1. The status of exchangeable potassium in major soils of Tanzania

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Introduction

Tanzania has a total area of 945,000 km^2 and is the largest country in the East African Community. The area covered by inland lakes is 59,000 km^2 (6% of the total area) and the remaining land covers 886,000 km^2 (94% of total area). Over 100,000 km^2 are devoted to reserves and national parks (NBS, 2012a). The physiography ranges from coastal plains along the Indian Ocean to the highest mountain in Africa, Mount Kilimanjaro (5,895 m). The occurrence of a wide range of climatic conditions with the potential to support substantial growth in agricultural production highlights this complex physiography. About 66% of the land area is planted with annual crops, while permanent or perennial crops occupy 15% and about 8% is planted with a mixture of annual and permanent crops. The remaining area (11%) is under fallow (FAO, 2004).

Tanzania currently has a population of 45 million of which approximately 80% obtain their livelihood mainly from smallholder agriculture. Nationwide, maize is the crop of choice for an overwhelming majority of households. Other food crops are beans, paddy rice, groundnuts, sorghum and sweet potatoes, in that order, each engaging at least 500,000 farm families. Major cash crops are coffee, tea, sugarcane, wheat, barley, tobacco, sisal, cotton, sunflower, sesame and cashew (NBS, 2012b). Nationwide, a significant proportion of all crops are planted during the long rainy season. The area planted with cereal crops during the short rainy season is about a fifth of the area planted during the long rainy season (NBS, 2012a).

Despite the dependency on agriculture for livelihood and economic development, fertilizers are only used on a small proportion of the area under cultivation and amounts used vary greatly across regions. For example, organic fertilizers are widely used in Shinyanga (on 67,439 ha) followed by Singida (54,586 ha) and Tabora (53,339 ha). Mbeya region uses the most inorganic fertilizers (on 131,208 ha) followed by Iringa (103,697 ha) and Ruvuma (83,182 ha) (NBS, 2012a). As a result of this there has been a gradual decrease of land productivity during recent decades. Evidence has shown continuous cropping without replenishment of nutrients through mineral or organic fertilizers to be one of the major causes of declining land productivity. This paper analyses the status of exchangeable potassium (K) of major soils in Tanzania.

The approach

The main source of information for this paper is the *Soils, Physiography and Agro-Ecological Zones of Tanzania* at a scale of 1:2,000,000 (De Pauw, 1984). The map and database presents land units with descriptions of the dominant parent materials. Information on the general topography is also presented to emphasize the spatial distribution or the generalized pattern of dominant and subdominant soils in the landscape. This database was used alongside the SOTER database (SDB) for Tanzania (Eschweiler, 1998). Additional information used to analyze the exchangeable K status of major soils was obtained from existing soil profile datasets.

Compilation of the soil database conforms to the pedogenetic approach. For each pedogenetic group major soils occur on the basis of geographical setting and coverage (area). The soil database finally identified five genetic soil groups.

- Soils whose formation was markedly influenced by their topographic setting (e.g. Fluvisols and Vertisols);
- Soils whose formation was conditioned by the particular properties of their parent material (e.g. Arenosols);
- Soils that are only moderately developed on account of their limited pedogenetic age or because of rejuvenation of the soil material (e.g. Cambisols);
- Typical red and yellow soils of wet tropical and subtropical regions (e.g. Ferralsols, Nitisols, Acrisols and Alisols); and
- Soils that occur in the zones between the dry climates and the humid climates (e.g. Luvisols and Phaeozems).

The land use or cropping systems of the reference sites occur in existing records such as Farming Systems Zonation of the Eastern zone (Chilagane *et al.*, 2011) and the Africover database for Tanzania (FAO, 2004). The information on land use included soil management practices with potential to influence the nutrient content of soils. The land resources data records were useful for identifying factors that are likely to influence the soil levels of exchangeable K.

Major soil groups covered are Fluvisols, Vertisols, Arenosols, Cambisols, Ferralsols, Nitisols, Acrisols, Alisols, Luvisols and Phaeozems. Table 1 presents criteria for ranking the levels of exchangeable K in soils.

Table 1. Criteria for ranking levels of exchangeable K in soils.

Level of K (cmol/kg)	Very low	Low	Medium	High	Very high
K (clayey soils)	<0.20	0.20-0.40	0.41-1.20	1.21-2.00	>2.00
K (loamy soils)	<0.13	0.13-0.25	0.26-0.80	0.81-1.35	>1.35
K (sandy soils)	<0.05	0.05-0.10	0.11-0.40	0.41-0.70	>0.70

Source: NSS, 1990

Levels of exchangeable K for major soils

a) Soils whose formation was markedly influenced by their topographic setting

Fluvisols (26,223.13 km^2; 2.77%)

Fluvisols are dominant soils in the plains associated with important rivers in Tanzania. The rivers are part of the Rufiji, Pangani, Ruaha, Ruvu, Kilombero and Wami basins. Fluvisols also occur to a limited extent in lacustrine plains and coastal areas. Fluvisols are genetically young, azonal soils in alluvial deposits. Soil datasets describe them to be generally deep soils that are imperfectly to poorly-drained. Topsoil texture varies widely from coarse, almost pure bleached sands, to brownish fine sands and dark grey or grey-brown clays, sandy clays or clay loams. Subsoils vary from pure sand to sandy clay loams with high texture variability over short distances and highly stratified with more sandy or more clayey layers. The natural fertility varies greatly but generally contain high levels of weatherable minerals. Fluvisols are planted with annual crops, mainly rice, sugarcane, maize, banana, cassava and vegetables. Orchards are also grown on the well-drained Fluvisols.

Figure 1 present the K status of some cultivated Fluvisols of Tanzania. These are seasonally flooded or irrigated lands from five districts (Kilindi, Mbulu, Rufiji, Bagamoyo and Kilombero). Lowland rice is cultivated in the sampled areas. It is evident that wide variations in the K status of Fluvisols exist. The lowest levels of exchangeable K occur in parts of the Kilombero and Rufiji basins, with soils in the Kilombero basin recording the lowest average levels of K. The sampled sites in the Kilombero basin are part of an extensive alluvial fan.

Soils in these areas have a high content of fine and very fine quartz in the fine earth fraction. They are also often subjected to extended periods of flooding during the rainy season (De Pauw, 1984). There are low variations in the K status of soils from irrigated schemes in parts of Mbulu (Makoi and Ndakidemi, 2008) and Bagamoyo districts (Mbogoni *et al*., 2011). The soils are fine textured and have a high content of swelling and shrinking clays. The parent material has had a significant influence on differences in the K status of these soils.

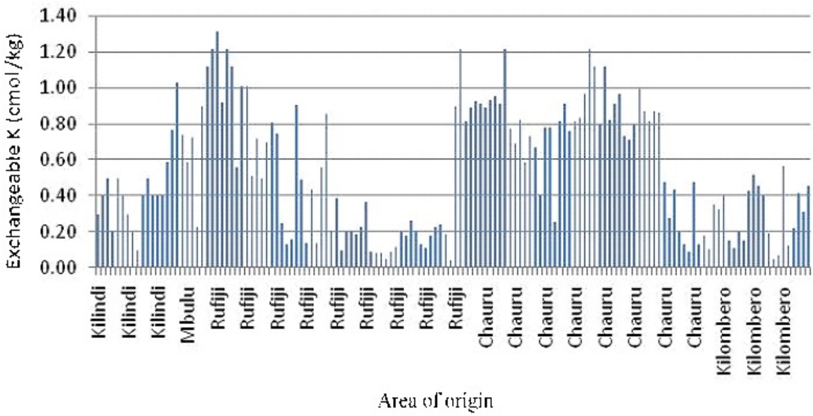

Fig. 1. K status of some cultivated Fluvisols of Tanzania.

Figure 2 shows in detail the K status of Fluvisols in Chauru farm in the Ruvu Basin, in Bagamoyo district. It is evident that despite some variations, the majority of the fields generally have an identical average content of exchangeable K due to similar soil management practices in use by farmers on the farm. They include raking and burning of crop residues followed by disc plowing and harrowing or pulverization. During planting DAP fertilizer is broadcast and urea is used for top dressing. It is generally accepted that response to K fertilizers is likely when a soil has an exchangeable K value of < 0.2 cmol(+)kg^{-1} and unlikely when it is above 0.4 cmol(+)kg^{-1} (Anderson, 1973; NSS, 1990). However, despite the high K content of soils at Chauru farm, yields of rice increase with application of N (Mbogoni *et al*., 2011).

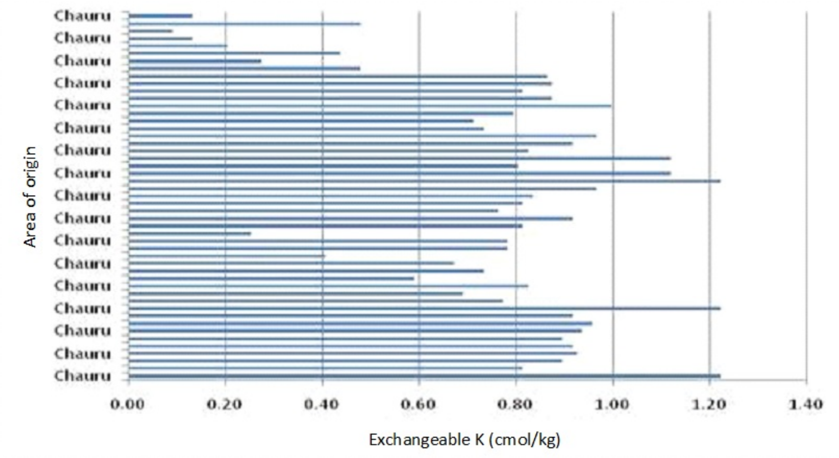

Fig. 2. K status of some Fluvisols of Ruvu Basin in Tanzania.

Vertisols (47,497.85 km²; 5.02%)

Vertisols occur in Mwanza, Shinyanga, Mara, Tabora, Kigoma, Morogoro, Tanga, Coast, Dodoma, Arusha and Lindi regions. Vertisols are churning heavy clay soils with a high proportion of swelling 2:1 lattice clays. These soils form deep wide cracks from the surface downward when they dry out, which happens in most years. Some common soil subunits in Tanzania are Chromi-Natric Vertisols, Eutri-Pellic Vertisols and Endosodi-Pellic Vertisols.

Vertisols occur on flat to almost flat terrain with slopes ranging between 0 and 1%. However, they are also extensive on gently undulating terrain in some parts of the coastal plains in Tanga and Coast regions (Mbogoni *et al*., 2012). They generally have low gilgai microrelief, with acacia woodland, scrubs and grasses as the major land cover types. Vertisols in Tanzania are considered to have moderate to high natural fertility but are often associated with salinity and sodicity. They are used for cultivation of annual crops such as rice, maize, cotton, sugarcane and vegetables. They also serve as important sources of natural pasture for livestock.

Figure 3 presents levels of exchangeable K for some Vertisols in Tanzania. Representative samples originate from Tabora, Shinyanga, Coast, Morogoro and Arusha regions. The average level of exchangeable K in many areas is 1.89 cmol/kg. The range of exchangeable K is 0.6-2 cmol/kg. These levels of K are within the range of 0.41-1.2 cmol/kg which is considered to be 'medium' for clayey soils. Low levels of exchangeable K in Tabora, Shinyanga and parts of the Rufiji basin are probably the result of continuous cultivation of rice, cotton and other annual crops without replenishment of nutrients. High levels of K occur in non-agricultural land.

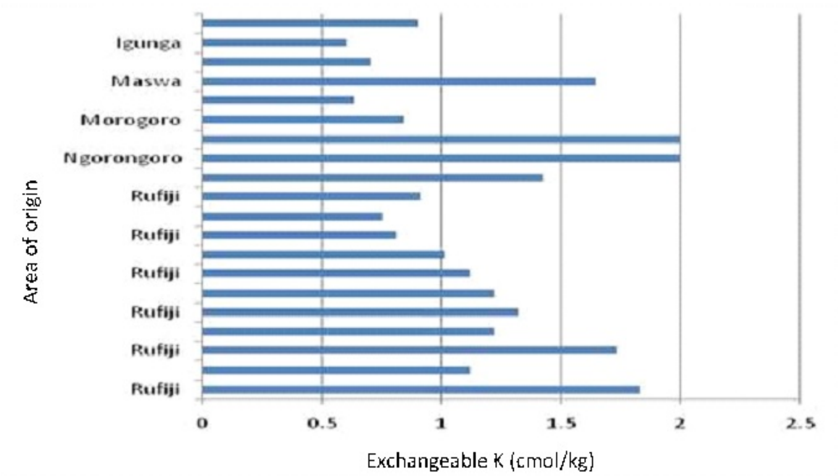

Fig. 3. Exchangeable K levels for some Vertisols in Tanzania.

b) Soils whose formation is conditioned by the particular properties of their parent material

Arenosols (21,926.33 km²; 2.32%)

Arenosols are extensive and occur in Tabora, Iringa, Mbeya, Rukwa, Shinyanga and Kagera regions and along the entire Indian Ocean coast. They consist of deep sandy soils, including soils in residual sands after in situ weathering of usually quartz-rich sediments or rock, and soils in recently deposited sands such as dunes and beach lands. The most common parent materials for Arenosols in Tanzania are unconsolidated translocated sand, residual sandstone or siliceous rock, stream deposits derived from biotite granites, leucogranites and undifferentiated granites.

Arenosols occur on various landforms such as river levees, dunes, beach ridges and sandy plains under scattered (mostly grassy) vegetation, and very old plateaus under light forest. All Arenosols have a coarse texture that induces generally high permeability and low water and nutrient storage capacity. In semi-arid areas these soils are predominantly used for extensive (nomadic) grazing. In areas where the mean annual rainfall exceeds 500 mm, good yields of small grains, melons, pulses and fodder crops are realized.

Figure 4 present levels of exchangeable K for some Arenosols of Tanzania. The sampled areas have low to very low levels of exchangeable K. For example, most of the Arenosols from Biharamulo district have very low levels of exchangeable K. The lands are used for smallholder rainfed cultivation of sorghum and cassava (Oosterom *et al*., 1999). The Arenosols of Tanga, Igunga, Tabora and Kahama have very low to low levels of exchangeable K. Some Arenosols of Tanga, where drought is a less serious constraint, are planted with perennial crops such as sisal, coconut and cashew. The perennial crops contribute to the buildup of biomass and nutrients in top soils, sustaining productivity (Hartemink, 1995).

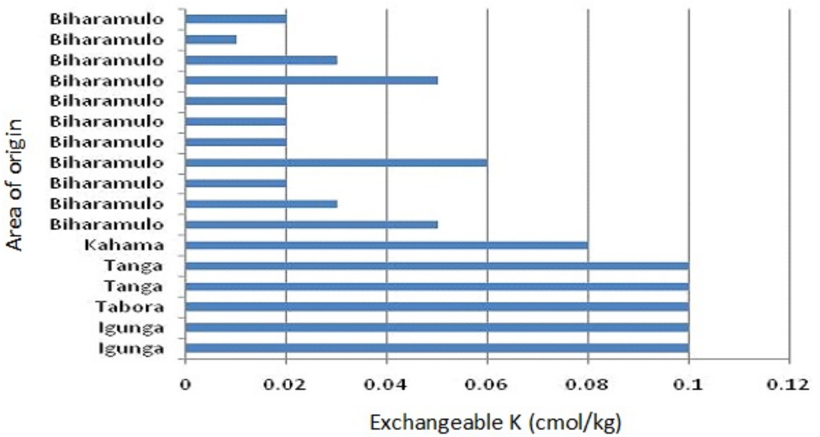

Fig. 4. Exchangeable K levels for some Arenosols in Tanzania.

c) Soils that are only moderately developed on account of their limited pedogenetic age or because of rejuvenation of the soil material

Cambisols (337,353.69 km^2; 35.64%)

Cambisols are the most extensive soils in Tanzania. Cambisols are weakly to moderately developed soils showing initial signs of soil formation. They occur mainly in the mid-western and south-eastern parts of the country, from sea level to the highlands, and under all kinds of vegetation. Common soil subunits in Tanzania are Chromi-Ferralic Cambisols, Eutri-Rhodic Cambisols, Eutric Cambisols, Ferralic Cambisols, Rhodic Cambisols and Sodi-Mollic Cambisols.

Cambisols make good agricultural land and are intensively cultivated with maize, sorghum, millet, cassava, groundnuts, beans, cowpeas, green gram, sunflower, cotton, coconuts, cashew, sisal and many other crops. The Eutric Cambisols are among the most productive soils in Tanzania. Cambisols in alluvial plains, such as in the Wami basin, are used for paddy cultivation.

Figure 5 presents exchangeable K levels of representative Cambisols in Tanzania. It is evident that all representative soils (sands and loams) have low levels of exchangeable K (0.1-2.5 cmol/kg). The effect of parent material is evident for some Cambisols of Tabora, Nzega, Igunga and Biharamulo. They developed on sandstones, old alluvium, granites, siltstones, as well as old colluvium and sandy and clayey deposits with low K content. Soils in other areas developed on material with relatively high K content, such as young alluvium (irrigation schemes in Kilosa district).

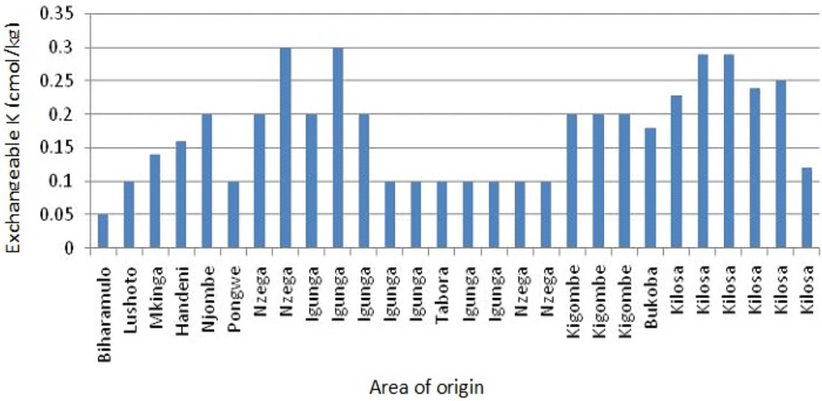

Fig. 5. Exchangeable potassium levels of representative Cambisols of Tanzania.

d) The typical red and yellow soils of wet tropical and subtropical regions

Ferralsols (59,852.62 km^2; 6.32%)

Ferralsols are scattered throughout the country but occur mainly in Kigoma, Rukwa, Mbeya, Morogoro, Tanga, Kilimanjaro, Dar-es-Salaam and Mtwara regions. Ferralsols are deeply weathered, red or yellow soils of the humid tropics. They have diffuse horizon boundaries, a clay assemblage dominated by low activity clays (mainly kaolinite) and a high content of sesquioxides. They developed on strongly weathered material on old, stable geomorphic surfaces; predominantly on weathering material from basic rock rather than on siliceous material. Ferralsols occur typically in level to undulating land of Pleistocene age or older; they occur less commonly on younger, easily weathering rocks (IUSS Working Group WRB, 2014).

Most Ferralsols in Tanzania have good physical properties. They are deep to very deep, with favorable drainage and have a stable microstructure which makes Ferralsols less susceptible to erosion than most other intensely weathered red tropical soils. Moist Ferralsols are friable and easy to work but may at times be prone to drought because of their low water storage capacity.

Figure 6 presents exchangeable K levels of representative Ferralsols in Tanzania. The levels of exchangeable K in most areas are very low. This is caused by continuous cultivation without replenishment of nutrients. For example most areas that have been under sisal cultivation for many years are depleted of nutrients, including exchangeable K (Hartemink, 1995). However, areas that receive fresh colluvium from surrounding hills have relatively high levels of K (Kwashemshi and Kwalukonge in Tanga region).

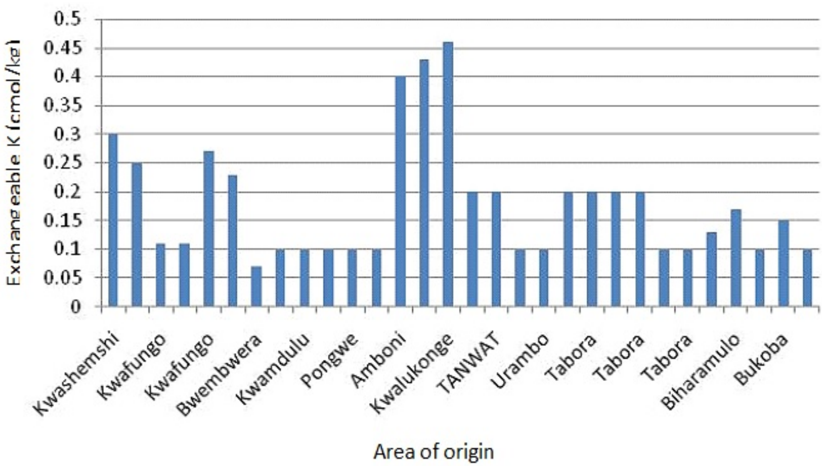

Fig. 6. Exchangeable K levels of represented Ferralsols of Tanzania.

Nitisols (21,001.11 km^2; 2.22%)

Nitisols occur in Mbeya, Iringa, Manyara, Kilimanjaro and Mara regions. Generally Nitisols are formed in finely textured weathering products of intermediate to basic parent rock, possibly rejuvenated by recent admixtures of volcanic ash. The Nitisols are deep, well-drained, red tropical soils with diffuse horizon boundaries and a subsurface horizon with more than 30% clay and moderate to strong angular blocky structure elements that easily fall apart into characteristic shiny, polyhedric ('nutty') elements. The clay assemblage of Nitisols is dominated by kaolinite/(meta) halloysite. Nitisols are rich in iron and have little water-dispersible clay (IUSS Working Group WRB, 2014). Common soil subunits in Tanzania are Eutric Nitisols, Haplic Nitisols and Humi-Umbric Nitisols.

Nitisols are deep porous soils and their stable structure permit deep rooting and render them quite resistant to erosion. The good workability of Nitisols, their good internal drainage and fair water holding properties are complemented by chemical (fertility) properties that compare favorably to those of most other tropical soils. In Tanzania Nitisols are planted with plantation crops such as tea, coffee, rubber and pineapple, and are also widely used for food crop production on smallholdings.

Figure 7 presents the status of exchangeable K in some Nitisols of Tanzania. The representative soils developed in weathering products of volcanic ash and volcanic lava that are known to have high K content (GSD, 1965). All areas have medium to high levels of exchangeable K. The Gona, Lotima and Makuyuni areas (Moshi Rural district) have the highest levels of K. In other areas the levels of K have been influenced by land use (Mbogoni and Mwango, 2011).

Acrisols (81,642.50 km^2; 8.63%)

Acrisols are the second most extensive soils in the country. They occur in Mara, Tabora, Singida, Dodoma, Tanga, Kilimanjaro, Morogoro, Iringa, Mbeya, Ruvuma, Lindi and Mtwara regions. Acrisols are characterized by accumulation of low activity clays in an argic subsurface horizon and by a low base saturation level. Acrisols develop on a diversity of parent materials, consisting mainly of acid rocks and strongly weathered clays which are undergoing further degradation. Common soil subunits in Tanzania are Chromi-Ferric Acrisols and Haplic Acrisols. Acrisols occur mostly on old land surfaces with hilly or undulating topography.

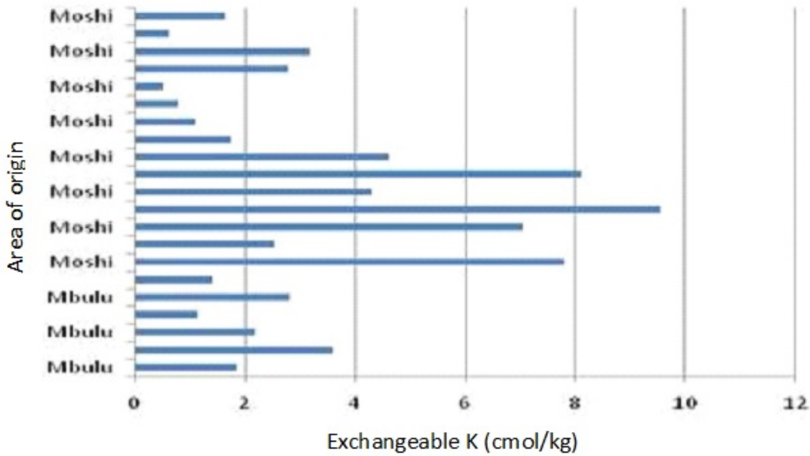

Fig. 7. Exchangeable K levels in some Nitisols of Tanzania.

Acrisols are used for smallholder cultivation of annual crops such as maize, sorghum, cassava, round potatoes and banana. Cash crops grown on these soils are pineapple, cashew, sisal, coconut, oil palm, tea and coffee.

Figure 8 presents the status of exchangeable K in some Acrisols of Tanzania. It is evident that most Acrisols have very low to low exchangeable K. This is caused primarily by the intensity of weathering and the nature of the parent materials on which they developed. Secondly, continuous cultivation without replenishing nutrients contributes to depletion of nutrients (including K) from the soils as has happened in Biharamulo district (Oosterom *et al.*, 1999).

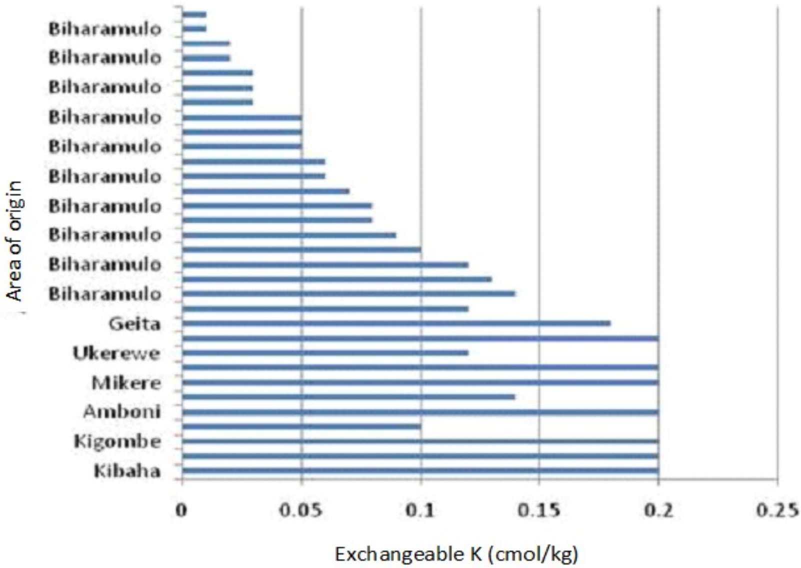

Fig. 8. Exchangeable K levels in some Acrisols of Tanzania.

Alisols (not yet delineated on soil maps)

Alisols occur in many parts of Tanzania particularly Kagera, Shinyanga, Mwanza, Mara, Tanga, Morogoro, Iringa and Njombe regions. Alisols are susceptible to erosion due to the general unstable surface soil. They are characterized by higher clay content in the subsoil than in the topsoil due to pedogenetic processes (especially clay migration). Alisols have an argic subsoil horizon with high-activity clays throughout and a low base saturation in the 50-100 cm depth. They have toxic levels of aluminum (Al) at shallow depth and poor natural soil fertility. Alisols develop in a wide variety of parent materials, particularly weathering products of basic rocks and unconsolidated materials.

Figure 9 presents the status of exchangeable K for some Alisols of Tanzania. The representative soils show low to very low levels of exchangeable K. This is associated with strong acidity and high Al saturation in the soils. A significant proportion of the Alisols are used for cultivation of shallow-rooting, acid-tolerant crops or low-volume grazing. Alisols are increasingly planted with Al-tolerant crops such as tea, coffee, round potatoes, sugarcane and vegetables.

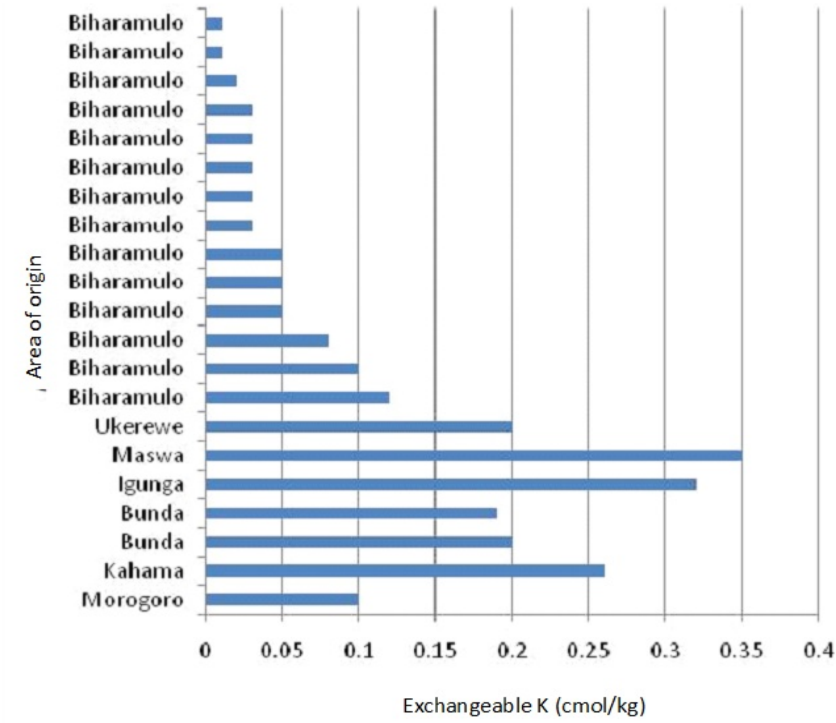

Fig. 9. Exchangeable K levels in some Alisols of Tanzania.

d) Soils that occur in the zones between the dry climates and the humid climates

Luvisols (68,706.15 km^2; 7.26%)

Luvisols occur in Morogoro, Dodoma, Arusha, Manyara, Kilimanjaro, Tanga and Ruvuma regions. Luvisols have an argic horizon with a cation exchange capacity (in 1 M NH_4OAc at pH 7.0) equal to or greater than 24 cmol(+)kg^{-1} clay, either starting within 100 cm from the soil surface or within 200 cm from the soil surface if the argic horizon is overlain by material that is loamy sand or coarser throughout. The dominant characteristic of Luvisols is a marked textural differentiation within the soil profile, with the surface horizon being depleted of clay and with accumulation of clay in a subsurface argic horizon. Common soil subunits in Tanzania are Cutani-Chromic Luvisols, Haplic Luvisols, Humi-Rhodic Luvisols and Profondic Luvisols.

Luvisols developed on a wide variety of parent materials and are commonly found in flat or gently sloping land with distinct dry and wet seasons. Luvisols are fertile soils and suitable for a wide range of agricultural uses. They are used for growing annual and perennial crops, either rainfed or with irrigation.

Figure 10 presents the exchangeable K status of representative Luvisols of Tanzania. The mean content of exchangeable K is 0.47 cmol/kg while the range is 0.1-1.02 cmol/kg. Most of the cultivated Luvisols have low to medium levels of exchangeable K. Parent material has had a large influence on the K status of soils. For example Luvisols of Moshi Rural district developed on volcanic lava with a high content of phenocrysts of alkali feldspar in a virtually dark grey matrix (GSD, 1965). Upon weathering they form soils with high K content. Most Luvisols of Moshi Rural district have exchangeable potassium/total exchangeable bases (K/TEB) ratio higher than two, implying that levels of exchangeable K are high relative to other basic cations (Mbogoni and Mwango, 2011). This is unfavorable as it induces magnesium deficiency (Lombin and Fayemi, 1976; NSS, 1990). The high levels of exchangeable K in the Naberera area are related to semi-aridity which favors K accumulation. In other areas the levels of K are influenced by cropping intensity.

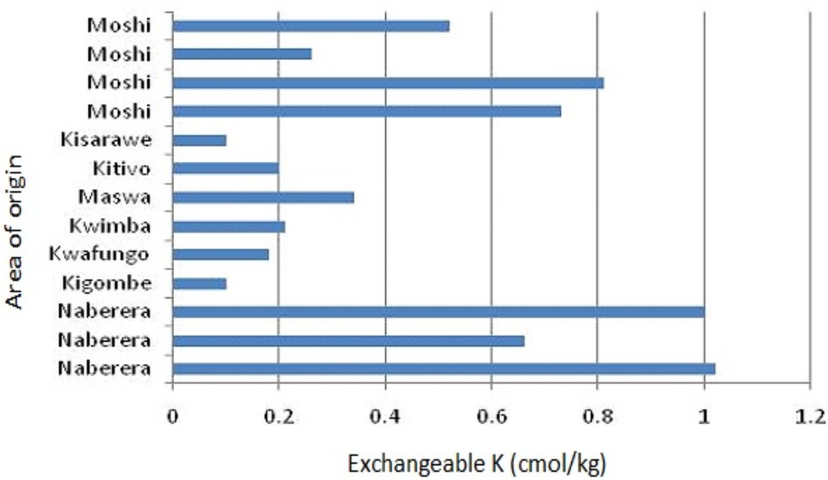

Fig. 10. Exchangeable K levels in some representative Luvisols of Tanzania.

Phaeozems (22,190.10 km²; 2.34%)

Phaeozems occur in Kilimanjaro, Mara, Arusha, Manyara, Dodoma, Shinyanga, Tanga and Morogoro regions. The Phaeozems are soils of humid regions. Phaeozems are somewhat leached soils with dark surface soil and have no signs of secondary carbonates in the upper meter of soil. Common soil subunits in Tanzania are Chromi-Luvic Phaeozems and Haplic Phaeozems and develop in unconsolidated predominantly basic materials.

Phaeozems occur in flat to undulating land in warm to cool environments that are humid enough to allow some percolation of water in most years but also with periods in which the soil dries out. In Tanzania, Phaeozems are used for the production of various crops such as maize, beans, sorghum, cassava, sunflower, wheat, pigeon peas, oil palm, and coffee (and other small grains). Phaeozems on the volcanic outwash plains in Mwanga, Moshi and Rombo districts support rainfed as well as irrigated maize, beans and vegetables. Wind and water erosion are serious hazards. Phaeozems are also susceptible to salinity and sodicity, especially when practicing irrigation farming without adequate drainage (Banzi *et al*., 1990; Mbogoni, 1991).

Figure 11 presents the status of exchangeable K in some Phaeozems of Kilimanjaro and Kagera areas of Tanzania. Soils of the Bukoba and Biharamulo areas have low to medium levels of exchangeable K while those from Hai in Kilimanjaro have high to very high levels. These lands have all been under cultivation for many years and have not been receiving fertilizers. This difference in levels of exchangeable K is due to differences in parent materials of the soils.

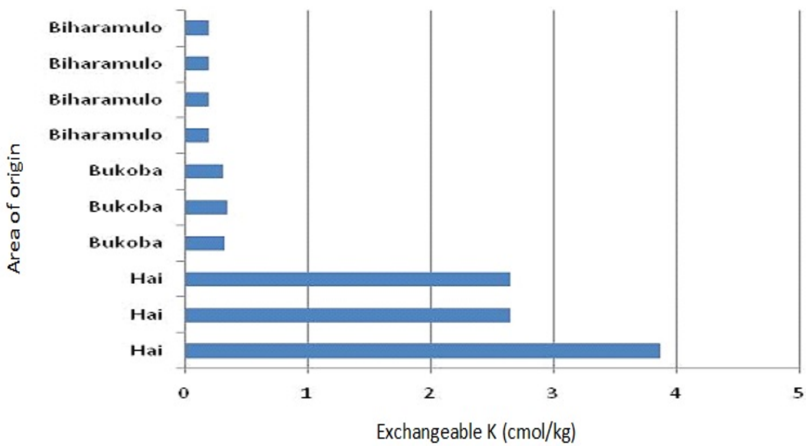

Fig. 11. Exchangeable K levels in some Phaeozems of Kilimanjaro and Kagera regions.

The representative soils from Hai developed in weathering products of volcanic ashes and lava flows characterized by abundant phenocrysts of alkali feldspars (GSD, 1965). As the soils are still young the release of nutrients is an ongoing and continuous process. Moreover as rainfall is low the loss of nutrients through leaching is low. Soils of Bukoba and the Biharamulo area developed in various types of parent materials with relatively low K content in the mineral structure. They include residual deposits derived from leucogranites, lake shore deposits derived from greenstones and quartzites, stream deposits and slope wash deposits derived from schists, dolerites and phyllites (GSD, 1965). Some of these lands are cultivated with maize, beans, sorghum, cassava, banana, coffee, wheat and barley.

Figure 12 presents the status of exchangeable K for some more Phaeozems of Biharamulo district in Kagera region. It is evident that the status of exchangeable K is very low to low. Some of these lands are cultivated with maize, sorghum and cassava (Oosterom *et al*., 1999).

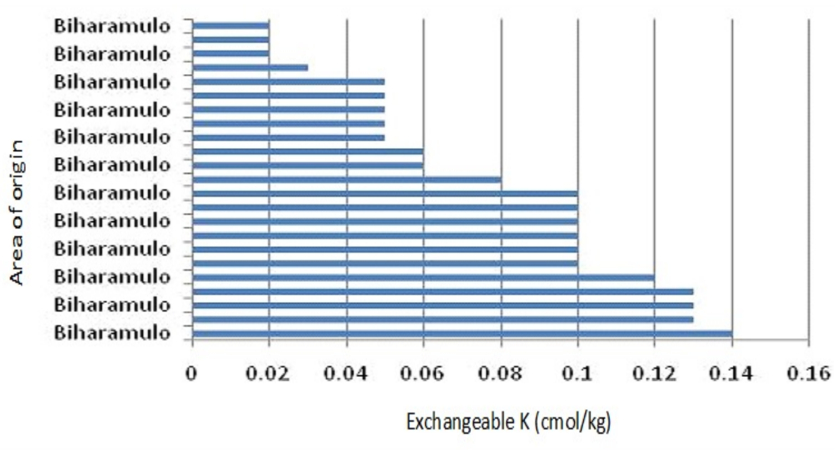

Fig. 12. Exchangeable K levels in some Phaeozems of Kagera region.

Discussion

The major soils of Tanzania are divided into five genetic soil groups. The main factors influencing the pedogenetic processes are topography, parent materials, time (age), vegetation and climate. The major soil groups investigated exhibit wide variations in exchangeable K status. The variations are due to various factors, particularly those related to natural phenomena as well as human factors.

In many cases the status of K in the soils is the result of interplay between natural and human factors.

The influence of parent material for high exchangeable K content is evident in Fluvisols (Mbulu and Bagamoyo districts), Nitisols, Luvisols and Phaeozems. Volcanic ash and volcanic lava have high K content and upon weathering they form Nitisols, Luvisols and Phaeozems with high exchangeable K content. These soils are productive and with adequate rainfall and suitable soil management give high yields of maize, banana, beans, coffee, tea and other crops. Once cultivated continuously without replenishment of nutrients, these soils become depleted and develop acidity. It is worth mentioning that with poor irrigation management, Luvisols and Phaeozems can develop salinity and sodicity as is the case in some irrigation schemes in Mwanga and Moshi Rural districts.

Parent materials with low K content weather to form soils with low exchangeable K. This is evident for Fluvisols of the alluvial fans with high quartz content in the Kilombero area (Mlimba division), Arenosols of Biharamulo, Cambisols in some areas, and Alisols. These soils are less productive due to low to very low nutrient levels. Optimum crop yield is normally realized only with the addition of organic matter and fertilizers.

Pedogenetic processes, particularly weathering of parent materials, have had a large influence on present levels of exchangeable K in the soils. Ferralsols, Acrisols and Alisols have low to very low levels of exchangeable K due to intense weathering. This is also influenced by climate, including high levels of rainfall and humidity, and warm temperatures. In arid and semi-arid areas that experience low rainfall and humidity, and warm temperatures, dominant phenomena are in favor of the accumulation of nutrients, including exchangeable K. This is the most likely reason for high levels of exchangeable K in some Vertisols, Cambisols and Luvisols of semi-arid areas.

Exchangeable K content is also influenced by cultivation. Where lands are cultivated continuously without application of fertilizers, nutrients are depleted. Cultivated soils most affected by nutrient mining are Ferralsols, Acrisols and Alisols.

Conclusions

There are five genetic soil groups in Tanzania that developed under the influence of topography, parent materials, time (age), vegetation and climate. The major soils related to these genetic groups have wide variations in the status of exchangeable K. This variation is largely due to an interplay between natural and human factors.

Parent materials have a large influence on the natural fertility and status of exchangeable K in soils. Parent materials with high contents of quartz develop soils with low to very low exchangeable K contents. Soils developed on volcanic ash and volcanic lava contain high levels of exchangeable K.

The intensity of weathering has a large influence on present levels of exchangeable K in the soils. Climate conditions consisting of high levels of rainfall and humidity, and warm temperatures, enhance weathering and leaching of nutrients, including exchangeable K.

Soils of arid and semi-arid areas with low rainfall and humidity, and warm temperatures accumulate nutrients due to restricted leaching. This is the most likely cause for high levels of exchangeable K in some Vertisols, Cambisols and Luvisols of semi-arid areas.

Soils with high quartz content, such as Arenosols and some Fluvisols, have low to very low levels of exchangeable K. These occur in some flood plains, alluvial fans and mountain foot slopes.

Exchangeable K content is also influenced by soil management. Where lands are cultivated continuously without application of fertilizers, nutrients are depleted. Cultivated soils most affected by nutrient mining are Ferralsols, Acrisols and Alisols.

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2. Role of potassium in human nutrition

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Abstract

Potassium (K) is a chemical element, identified by the symbol ^{39}K, with nineteen protons (atomic number 19). It is an essential nutrient that is needed for maintenance of total body water, acid and electrolyte balance, and normal cell function. In the pre-agricultural and post-agricultural diets of our human ancestors, K intake was very high, often exceeding 200 mmol day^{-1}. In modern society, these levels have been markedly reduced. Food processing reduces the K content of food, and a diet high in processed foods and low in fresh fruits and vegetables is often lacking in K. Data from around the world suggests that average K consumption in many countries is below 70-80 mmol day^{-1}. Adequate K consumption is important for normal physiological and metabolic functions of cells and the body in general. Potassium is central to the maintenance of a potential difference across cell membranes, enabling nutrients and waste materials to cross the cell membrane. It also plays an important role in the functioning of the heart and in the generation of nerve and muscle action potentials. It is responsible for regulating DNA, protein and glycogen synthesis via its action as an enzyme cofactor. This paper examines the role of K in the body and the consequences of K deficiency or over consumption of K on K homeostasis in the body.

Introduction

In the periodic table, potassium (K) is one of the seven elements in group (column) 1, which all have an outer electron shell with one filled and one unfilled atomic orbital. It is also found in period (row) 4 of the periodic table. Sodium (Na), being in column 1 and adjacent to K in row 3, is chemically similar to K. They each have a similar ionization energy, which is the amount of energy required to remove the one outer electron, creating a positively charged ion, i.e. cation. They have the ability to lose an extra electron and acquire an overall positive charge and it is a bit difficult to gain one and acquire a negative charge. Elemental K is a soft silvery-white alkali metal with a melting point of 63°C and a boiling point of 770°C. Its density is 0.862 gcm^{-3} which is less than that of water (1gcm^{-3}), it oxidizes rapidly in air and is very reactive with water. These properties give K its characteristics; therefore most of its functions are based on

K’s overall positive charge. Naturally occurring K is composed of three isotopes (^{39}K, ^{40}K and ^{41}K), with ^{40}K being radioactive. Traces of ^{40}K are found in all K, and is the most common radioisotope in the human body.

Potassium is a mineral found in food. Foods obtain K from soils in which crops are grown. In the body it acts as an electrolyte, which conducts electrical impulses through the body. The human body does not possess the ability to synthesize K so it is therefore considered an essential nutrient that must be obtained from food. It is therefore important to consume the right balance of K-rich foods and beverages. For many years K has not been considered an important nutrient in nutrition, however it is becoming increasingly obvious that it is important due to its role in reducing hypertension and other disorders related to nervous and muscular functions.

Plants, animals and humans, all depend on K for survival and good health. The element is found in body fluids, several cell types (skeletal, smooth muscle, endocrine, cardiac and central nervous), and assists various body functions, as well as maintaining osmotic pressure and cell size. It plays an important role in electrolyte regulation, nerve function, muscle control, and blood pressure. Potassium is found within all body cells and its levels are controlled by the kidneys. Primarily, K functions to regulate water and mineral balance throughout the body.

Occurrence of K in the body

Potassium is the eighth most common element by mass (0.2%) in the human body. It is also one of the most abundant minerals, constituting 70% of the positive ions inside cells. A 70 kg adult contains about 140 g of K, with about 2.5 milligrams in blood serum. The absorption of K takes place in the intestinal tract, in the portions of the intestine called the ileum and the jejunum. It is a passive process; therefore K diffuses into the blood on its own according to the concentration gradient. The concentration of K is higher on the inside than the outside of the cell. The plasma K is normally kept at 3.5-5 millimoles (mmol) per liter of plasma. Potassium is the primary inorganic cation within the living cell, and is one of the electrolytes essential to the smooth running of the human body.

Functions of K

Potassium ions are necessary for the function of all living cells. Some of the cell functions that depend on K include:

Cell membrane potential

The cell membrane is a biological membrane that separates the interior of all cells from the outside environment. It is selectively permeable to ions and organic molecules. The cell membrane controls the movement of substances in and out of cells and protects cells from the harmful effects of its surroundings. The cell membrane consists of the phospholipid bilayer with embedded proteins and carbohydrates. It is involved in a variety of cellular processes such as cell adhesion, ion conductivity and signaling, as well as serves as an attachment surface for a number of extracellular and intracellular structures. Due to these characteristics, the cell membrane is able to regulate materials exchange between the cell and its environment. In this way, the cell membrane facilitates entry of nutrients into the cells and removal of waste products, ensuring survival of the cell and the entire body. Because of its selectivity, cell membrane filters only allow certain materials to enter or leave the cell, consequently maintaining optimal metabolism and homeostasis. In order for the cell membrane to perform this function, a membrane potential must be generated.

Cell membrane potential is generated by the difference in ionic concentration between the interior and exterior of the cell membrane. Normally the concentration of K is high inside the cell and Na concentration is high on the outside. This concentration gradient provides the potential energy to drive the formation of the membrane potential. Movement of K and Na across the cell membrane uses energy derived from Adenosine Triphosphate (ATP). The mechanism is referred to as Na^+-K^+ (ion) pump and uses a protein called Na-K Adenosine Tri-Phosphotase (ATPase). This is part of the membrane proteins that use cellular energy to pump ions from one side of the cell membrane and release them on the other side. For three Na ions pumped outside the cell, two K ions are pumped inside the membrane, against the concentration gradient of the ions, hence creating a membrane potential that is used to move materials such as glucose, amino acids and other nutrients across the cell membrane and provide for the cell's nutritional requirements and other physiological mechanisms. A similar mechanism is used by carrier processes in the intestines to absorb glucose and reabsorb Na and K in the renal tubule. The Na^+-K^+ pump is important for maintenance of cell osmolality. If the Na^+-K^+ pump fails it results in swelling and bursting of the cell.

Fluid balance

Fluid compartments comprise intracellular fluid compartments (cytoplasm within a cell which accounts for 2/3 volume of body fluids) and extracellular fluid (ECF) compartments (water outside cells, such as plasma and interstitial fluid, cerebrospinal fluid, serous fluid, and other fluid in the lymph, eyes, and gastrointestinal secretions. Fluid balance is a concept of human homeostasis, that the amount of fluid lost from the body is equal to the amount of fluid taken in and equilibrated within cell compartments. Fluid balance in the body is vital for all life processes. It is maintained by Na, K, and chloride (Cl) ions. Fluid balance is regulated by charged Na and Cl ions in the extracellular fluid (outside the cell), K in the intracellular fluid (inside the cell), and some other electrolytes across cell membranes. Tight control is critical for normal muscle contraction, nerve impulse transmission, heart function, and blood pressure. Potassium and Na act as cofactors for certain enzymes. Water balance is achieved in the body by ensuring that the amount of water consumed in food and drink, and that generated by metabolism, equals the amount of water excreted. Consumption is regulated by behavioral mechanisms (thirst and salt cravings).

When fluid volume decreases in the body, the concentration of Na in the blood will increase, leading to increased osmolarity (the amount of solute per unit volume), which in turn stimulates the hypothalamus and the posterior pituitary gland to release the hormone antidiuretic (ADH, sometimes called vasopressin) into the bloodstream. This acts on the kidneys to enable it to reabsorb water and return it to the ECF, thus correcting the volume depletion. On the contrary, when Na concentration in the blood decreases, the adrenal cortex is stimulated into secreting the hormone aldosterone, which influences the distal nephrons of the kidney to retain more Na and release K. Normal levels of Na in the ECF will attract and maintain the optimum amount of water. Increased fluid volume triggers ADH release, thus conserving water in the kidneys at the expense of Na.

In addition to regulating total volume, the regulation of osmolality of bodily fluids is important. Variations may cause damage to cellular structure (swelling or shrinking), and disrupt normal cellular function. Regulation of ECF osmolarity is achieved by balancing the intake and output of Na with that of water as well as K and magnesium (Mg). If there is too much or too little of any of these electrolytes this can cause physiological problems. For example, low K and Mg levels tend to trigger cardiac arrhythmias.

Electrolyte balance

Electrolytes are minerals found in bodily fluids that carry an electric charge and acquire the capacity to conduct electricity. They are essential for the heart, nerves and muscles to function properly. The balance of the electrolytes in the body is essential for normal function of these organs. One of the major roles of electrolytes is to ensure that fluid levels inside and outside the cell are balanced. An increase in electrolytes within the cell leads to more fluid entering the cell (swelling) and a decrease in electrolytes promotes fluid movement outside the cell (shrinking). Sustaining this type of osmotic gradient is essential for nerve and muscle function, hydration, and maintenance of blood pH levels. An electrolyte imbalance can develop as a result of either having an excess or a deficiency of electrolytes in the body. An electrolyte imbalance may be caused by loss of body fluids through prolonged vomiting, diarrhea, sweating or high fever, poor diet, mal-absorption, hormonal or endocrine disorders, kidney disease and medications such as chemotherapy drugs, diuretics, antibiotics, and corticosteroids.

Acid-base homeostasis

All biochemical reactions are influenced by pH of their fluid environment; therefore optimum conditions and balance (acid-base) are required to ensure optimal biochemical reactions in the body. Optimal pH of various body fluids differ but not by much (pH of body fluids: arterial blood = 7.4, venous blood and interstitial fluid = 7.35, intracellular fluid = 7).

Potassium is indirectly involved with regulation of the acid-base balance. During K deficiency, K migrates out of the cell and causes the cell fluid to become acidic (lower pH). Enzyme systems are often sensitive to acidity (including those that destroy infectious microbes engulfed by white cells), the drift towards acidity could easily be the reason why for pains in people usually cannot get over arthritis, and may be responsible for some symptoms of K deficiency, such as heart disease. Consumption of high acid foods may lead to some of the food be absorbed into the bloodstream as acid waste but some that remain in the digestive system putrefy cause release of acid into the bloodstream. Excessive accumulation may result into a degeneration of body's systems, including the cardiovascular system. This is because when the acid stays in the bloodstream for a long time, it attaches to the artery walls and forms a plaque, which reduces blood flow to all cells hence nutrients and oxygen are not delivered to the cells properly. Therefore organs affected become vulnerable to degenerative disease. If the acid plaque breaks off and clogs the bloodstream, it can cause a heart attack

Systemic blood pressure control

When the heart beats, it pumps blood round the body to give it the energy and oxygen it needs. As the blood moves, it pushes against the sides of the blood vessels. The force exerted by blood against the walls of the blood vessels is blood pressure. If blood pressure is too high, it means that it puts extra strain on the arteries (and the heart). If this continues for a long period of time, it may lead to a heart attack or stroke. Blood pressure is influenced by dietary K intake, both in normal people and hypertensive subjects. Potassium is a vasodilator and has a relaxation effect on the tiny blood vessels called arterioles and this results in increased local blood flow. Vasodilation results from hyperpolarization of the vascular smooth muscle cell following K stimulation by the ion of the electrogenic Na^+-K^+ pump and/or activating the inwardly rectifying K channels. In the case of skeletal muscle and the brain, the increased flow sustains the augmented metabolic needs of the tissues. There is evidence to suggest that K intake by humans may be inversely related to the level of arterial blood pressure. This may be brought about by a reduction in the Na/K ratio within the human. Possible mechanisms include the diuretic effect of K which reduces extracellular fluid volume, in turn resulting in decreased blood pressure. In addition, K may alter the activity of the renin-angiotens in system and reduce angiotensin influences on vascular, adrenal, or renal receptors. Potassium also modifies central or the peripheral neural mechanisms that regulate blood pressure. High K diets could reduce blood pressure by relaxing vascular smooth muscle and reducing peripheral vascular resistance directly. The increased prevalence of high blood pressure in the population does not appear to be related to greater dietary intake of sodium chloride but rather due to low K intake. Dietary K depletion raises blood pressure in normal humans. Low levels of K lead to vasoconstriction in the peripheral blood vessels and increased blood pressure. In addition, excessive Na consumption results in urinary K loss to balance the electrolytes in the body, consequently increasing blood pressure. Another mechanism is that kidneys help to control blood pressure by controlling the amount of fluid stored in the body. The greater the fluid, the higher the blood pressure. Kidneys filter the blood to remove extra fluid and store it as urine in the bladder. For this to happen the kidney requires a delicate balance of Na and K in order to absorb water across a wall of cells from the blood stream into a collecting channel that leads to the bladder.

Nerve impulse transmission

A nerve impulse is an electrical signal that travels along an axon (neural fiber). There is an electrical difference between the inside of the axon and its surroundings. When the nerve is activated, there is a sudden change in the voltage across the wall of the axon, caused by the movement of K and Na ions in and out of the neuron. This triggers a wave of electrical activity that passes from the cell body along the length of the axon to the synapse. In neural cells, electrical potentials are created by the separation of positive and negative electrical charges that are carried on ions (charged K^+ and Na^+ atoms) across the cell membrane. When the nerve cells are not stimulated they are in a resting state or potential. This means that the intracellular fluid has slightly more electrolytes with a negative charge (K^+ and HPO_4^{2-}). Therefore there is no impulse being transmitted. When the nerve cell membrane is in the polarized state it means there is a balance between charges on either side of the membrane. When there is nerve stimulation Na migrates into the interior of the cell through Na^+ gates, therefore increases the proportion of Na inside the cell. In this regard the charge inside the cell becomes more positive and outside more negative, which implies that the cell membrane is depolarized. This causes an imbalance in the concentration of ions, which prompts the movement of K ions outside the cell to try to restore the balance. This creates an action potential which is then transmitted to adjacent regions of the cell membrane and the process continues until the impulse reaches the target cell or organ. As the stimulus moves to the next neuron the preceding membrane becomes repolarized due to the release of K to the exterior of the cell, which allows the first portion of the membrane to return to the resting state until the next stimulation. It is important to note that in the absence of K ions, this sequence of events will not take place and therefore no nervous impulse transmission can occur. This may explain the paralysis that is experienced by people who suffer from a stroke.

Muscle contractions

Muscle contraction is the movement of muscle fibers in response to force or load. It also fulfils some important functions in the body, including movements (walking and running), posture (sitting and standing), joint stability, breathing and heat production. Electrolytes are especially important for normal contraction of skeletal, smooth and cardiac muscle fibers. Without the appropriate balance of electrolytes such as K and Na, heart contractions become abnormal and the risk of heart attack increases. Potassium is crucial to the functioning of the heart because it is needed to work in the outer membranes of cardiac muscle cells. These channels open in response to a change in voltage and are responsible for terminating action potentials and contractions while initiating repolarization. Therefore low levels of K in the body (hypokalemia) lead to irregular contractions and abnormal electrocardiograms. This is something that many people are not aware of but if undiagnosed it may lead to serious consequences, including death. However, too much K in the body (hyperkalemia) causes reduced electrical conduction and often leads to palpitations and disrupted heart rhythm. In other muscles the electrical impulse generated by K stimulates calcium (Ca) ions to move across the cell membrane to the fluid surrounding the cell. This movement of Ca ions triggers the muscle cells to contract and aids movement. Therefore low K levels inhibit muscle relaxation, causing rigid muscles that lead to tension and impaired function. Common symptoms of K deficiency include muscle weakness and spasms.

Gastrointestinal motility

The digestion process is facilitated by rhythmic intestinal contractions called peristalsis, which are responsible for propelling the food along the gastro intestinal tract. Peristalsis involves alternating contraction and relaxation of the smooth muscle tissue in the walls of the intestines and pushes the contents of the tract forward, towards the end of the tract. The muscles of the intestines rely on K and other minerals such as Na, Ca and Mg for normal tone to facilitate contraction. Hypokalemia (low K) negatively affects peristalsis and leads to stomach upset, abdominal cramps, constipation and even intestinal paralysis. It is estimated that one in three people globally has a functional gastrointestinal or motility disorder, but data on prevalence in Tanzania is not available.

Glucose and insulin metabolism

Potassium (serum and extent of dietary intake levels) has been associated with the incidence of diabetes. Lower levels of K have been found to be associated with a higher risk of diabetes through interference with the functioning of beta cells in the pancreas. Hypokalemia leads to impaired glucose tolerance by reducing insulin secretion in response to glucose load, as well as interruption of glucose transportation at the cell membrane.

Sources of K in the Diet

Potassium occurs in all living cells. Therefore it is present in all plants (crops) and animals products, green leafy vegetables and non leafy vegetables, mushrooms, legumes, roots and tubers (potatoes and sweet potatoes) and fruits such as bananas, kiwi, citrus fruits, avocado as well as nuts (Table 1). Eating a variety of foods that contain K is the best way to get an adequate amount. Although many fruits, vegetables, legumes and meats contain K, common foods that contain very high levels of K are beans (such as white beans), dark leafy greens (spinach, Swiss chard), potatoes, fruit (apricots, peaches, prunes, raisins, figs, dates), squash, yoghurt, fish (salmon), avocado, banana, nuts (pistachios, almonds, walnuts) and seeds (squash, pumpkin, sunflower). Baobab fruit is also an excellent source of K, so people should be encouraged to consume this fruit because it is readily available in Tanzania.

Recommended intake of K for optimal nutrition

The proper level of K is essential for normal cell and body function. An abnormal increase in K (hyperkalemia) or decrease in K (hypokalemia) can profoundly affect the nervous system and heart, and when extreme, it can be fatal. The normal blood K level is 3.5-5 milli equivalents/liter (mEq/L), or 3.5 international units (3.5-5 mmol per liter of plasma). Levels lower or higher than these normal levels are associated with increased rate of death of any cause. Cardiac, kidney and lung diseases are accelerated if serum K levels are not maintained within the normal range. Therefore a healthy diet should include 4,700 milligrams of K each day. Not enough attention has been paid to this nutrient despite its important role in metabolism and control of hypertension. Currently there are no recommended intake levels for Tanzania's population or even data on prevalence of K deficiency. It should be noted that globally a high proportion of populations do not meet the recommended intake for K. This is caused by consumption of highly processed foods and/or limited consumption of fruits and vegetables.

Table 1. K content in foods grown in Tanzania.

Food item	K (mg/100g)
Maize flour	287
Bulrush millet	307
Finger millet	408
Rice	81
Sorghum	131
Wheat	107
Cowpea	278
Pigeon pea	777
Cassava	243
Sweet potatoes	303
Beans	1,036
Bambara	539
Chickpea	291
Cowpea	278
Lentil	303
Groundnuts	705
Cashewnuts	732
Beef	230
Fish	122
Cassava leaves	550
Spinach	466
Carrot	320
Sweet potato leaves	315
Mushroom	318
Okra	304
Chinese cabbage	202
Baobab	1,221
Banana	385
Bread fruit	490
Guava	417
Jackfruit	303
Orange	181

Imbalanced K levels in the body

Hypokalemia can be caused by loss of K due to vomiting, diarrhea and renal loss due to diuresis. Symptoms include muscle weakness, paralytic ileum, ECG abnormalities, decreased reflex response, respiratory paralysis and cardiac arrhythmia.

Symptoms of hyperkalemia include malaise, palpitations, muscle weakness and mild hyperventilation, which may indicate a compensatory response to metabolic acidosis, which is one of the possible causes of hyperkalemia. In any case it is important to maintain a balanced intake of K to avoid health related consequences, which may affect the functioning of the human body.

Factors influencing K availability in foods

Soil factors

High levels of K in soil increases available K by increasing the amount and balance of K relative to other cations. More importantly, high levels of K affect cation balance because where there is a significant imbalance between available K and other major cations (e.g. Ca, Mg, and sometimes hydrogen, aluminum, or Na) it may affect the availability of K to the crop. In addition, soil moisture is important as K is transported within the soil and is absorbed by plant roots from water in the soil. Therefore water deficiency results in less K absorption. Similarly, as the soil pH is reduced (increasing soil acidity) the availability of K is often reduced. Cold and compacted soils also often reduce the availability of K in soils and crops.

Food factors

Almost every nutrient is affected by food processing in one way or another. Potassium is often severely affected, and is lost in most processes. Milling is the process by which cereal grains are ground into flour. Traditionally, and in some parts of the world to this day, this is accomplished by grinding the grain between two stones to produce coarse whole meal flour. When a grain is refined, most of the bran and some of the germ is removed, resulting in losses of fiber, vitamin B and E, trace minerals, unsaturated fat, and about 75% of the phyto-chemicals, as well as Ca, Mg and K.

Modern food processing and preparation methods use high amounts of salt which increases the amount of salt that is consumed. The high prevalence of hypertension in many countries is related to the consumption of salty foods and limited consumption of K. Canned processed vegetables and fruits also contain high amounts of Na and tend to inhibit K absorption. Snack foods, such as chips and cookies, contain high levels of Na and tend to influence K levels in the body.

Dietary factors for K deficiency include consumption of foods high in Na, processed meats and trans fats, and poor consumption of fruits, nuts, seeds and vegetables.

Body factors

The presence of substances that inhibit absorption, transportation and utilization of K and protein deficiency may interfere with movement of K into and out of cells. Too much Na can block K absorption and raise fluid levels, causing swelling.

Conclusions

Potassium is the chief intracellular cation, and relative intracellular-extracellular K concentrations directly affect a cells resting membrane potential. Therefore a slight change on either side of the membrane has profound effects on neurons and muscle fibers, affecting nervous transmission and muscle contraction. Potassium is part of the body's buffer system, which resists changes in pH of body fluids; ECF K levels rise with acidosis (decrease pH) as K leave cells, and fall with alkalosis (increase pH) as K moves into cells. Potassium balance is maintained primarily through renal mechanisms (i.e. influenced by aldosterone) and K reabsorption from the filtrate is constant, with 10-15% lost in urine regardless of need. If K content of ECF is low (compared to Na concentration), K balance is accomplished by changing the amount of K secreted into the filtrate and regulated by collecting tubules. Potassium is crucial for human as well as animal nutrition and foods are good sources of the mineral. The mineral is essential because the body has no ability to make K so has to obtain it from foods. Crops obtain K from the soil so it is crucial that the soils in which food crops are grown should have sufficient quantities of the mineral. Therefore as we strive to improve crop productivity we also need to consider nutritional quality of crops. Efforts to improve soil fertility should be seen as efforts to improve human health, since this is our overall goal. Soil scientists are urged to consider nutritional quality of crops in soil improvement and management programs.

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Potash Distribution in the Soils of Tanzania

3. Potassium status in some soils: the case of Northern, Central and Eastern zones of Tanzania

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Abstract

Crop productivity in Tanzania is limited by many factors, low soil fertility being one of them. However, in attending the problem of low soil fertility, more emphasis is given to nitrogen (N) and phosphorus (P) as they are the most limiting nutrients. In the past, potassium (K) was regarded as adequate. But due to high output of K through losses and crop removal without K input, there is a likelihood of a net negative K balance in the soil that ultimately will have a negative effect on crop production. In Tanzania, this could be true as K deficiency has begun to be noted in some crops and parts of the country. Information on soil K is vital in guiding the targeting of fertilizer recommendations. This study was conducted to establish K status of some major soils in the Eastern, Northern and Central zones of Tanzania. Data was obtained from secondary data that include papers, reports and databases. The study concentrated on three soils that are under crop production and have large coverage. The amount of data varies between zones depending on the extent of soil research conducted. Information on soil K in particular is limited. From the limited available data obtained there are indications that K levels in Ferralic Cambisols are high in the Northern zone, medium in the Central zone and in some parts of the Eastern zone in Kilombero and Kilindi, and low in the coast region, Muheza, Korowe, Pangani and Mkinga districts in Tanga region, Morogoro rural and Mvomero in Morogoro region. For Chromic Luvisols, K levels are high in the Northern zone and medium in the Central and Eastern zones. Rhodic Ferralsols have medium K levels in Morogoro region but low levels in Tanga and Coast regions. Potassium levels in soils vary depending on physiographic position, being higher in foothills and subsidence basins than in mountain block foot slopes and semi-arid plains. Due to limited data available, there is a need for more research work to generate up-to-date soil information to complement these findings and inform stakeholders on the areas which require interventions regarding soil K status and plant nutrition in Tanzania.

Keywords: potash status, northern, central, eastern, Tanzania, Cambisols

Introduction

Low soil fertility is one of the main factors leading to low crop productivity which ultimately contributes to food insecurity and poverty. Soils are progressively becoming less fertile due to nutrient losses through soil degradation and nutrient mining. Losses of more than 30 $kgha^{-1}$ have been attributed to nutrient mining in Africa (Henao and Baanante, 2006). The use of mineral fertilizers has been one of approaches to improve soil fertility. However due to lack of knowledge and the high cost of fertilizers, most smallholder farmers in Tanzania do not use fertilizers and those who use them apply very small amounts. The percentage of farmers using fertilizers could be as low as 1-3% in Tanzania (Nkonya *et al*., 2011). There is a need therefore to develop package that will make fertilizer use cost effective by targeting recommendations, and training farmers on proper soil nutrient management. Knowledge on soil nutrient status is crucial information required for accurate fertilizer targeting. Nitrogen (N), phosphorus (P) and potassium (K) are nutrients that are taken up by plants in large quantities, consequently being removed from the soil in large amounts. Some of these nutrients are recycled back through leaves and crop residues if returned back to the field. In most cases, the amount of nutrients recycled are very low compared to what is taken out, resulting in a negative nutrient balance. Nutrient input from external sources is therefore an important requirement for sustainable crop production. Research is a key tool in identification of nutrient need and appropriate rates of fertilizer to apply. For the past few years research on fertilizer use and fertilizer recommendations have focused on N and P, while K has been regarded as adequate in soils of Tanzania (Sillanpää, 1982). Research on K has been limited to few crops like sisal, tobacco, sugarcane and tea. However K plays a major role in plant growth and yield through its involvement in photosynthesis, starch formation, translocation of sugars, grain formation, development of plump and kernel, and tuber development (Brady, 1984). Potassium requirements for optimum plant growth ranges between 2-5% of the dry weight of vegetative parts, fresh fruits and tubers (Marschner, 1986).

Since land has been cultivated over many years, K status will have changed due to land degradation and nutrient mining. Potassium is becoming a potential problem in some parts of the country (Ikerra *et al*., 2006). A study by Bressers (2014) in Lushoto showed that exchangeable K in the soil ranged from 0.11-0.25 $cmol(+)kg^{-1}$, with six out of nine locations scoring lower than the recommended value of 0.20 $cmol(+)kg^{-1}$ for adequate crop growth. Potassium deficiency is likely under high rainfall, and on low clay soils and soils where high K demanding crops are grown. This paper intends to establish the K status of major soils in the Eastern, Northern and Central zones and to identify research gaps and where K fertilizer application is needed.

Methodology

The study involved three zones, namely Northern, Eastern and Central zones of Tanzania. Various sources were used to obtain information including soil survey and fertility reports, papers, ISRIC – World Soil Information database and analytical data from Soil central laboratory database and SOTERsoil maps of Tanzania. The focus was on soils of agricultural importance and with large coverage in these zones. Tanzania is covered by various soil types, including Cambisols (35.34%), Acrisols (8.63%), Leptosols (8.11%), Luvisols (7.26%), Ferralsols (6.32%), Vertisols (5.02%), Lixisols (4.95%) and Fluvisols (2.77%). Three soil types Ferralic Cambisols, Chromic Luvisols and Rhodic Ferralsols were selected for study. The distribution of these soil types in the study area is shown in Figure 1.

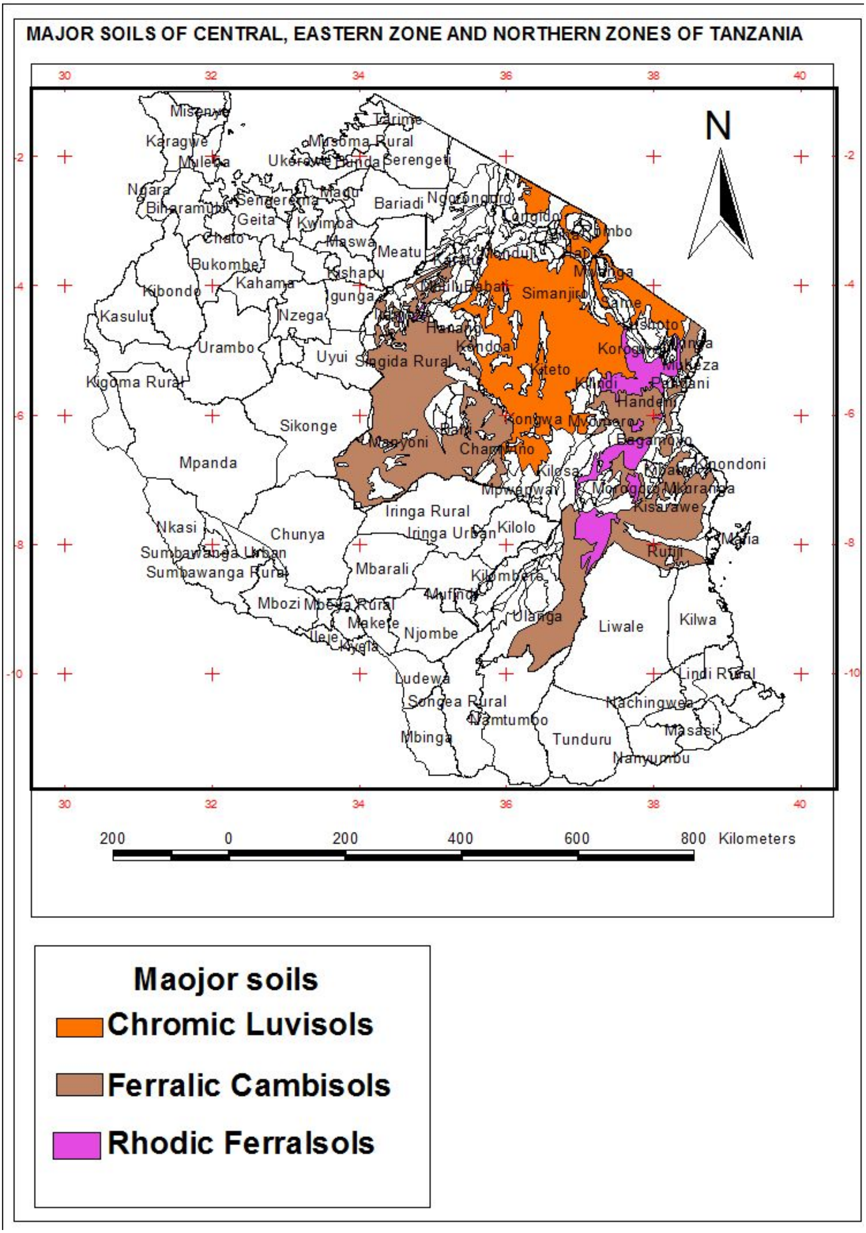

Fig. 1. Major soils in the study area.

Topsoil to the depth of 20 cm was collected from sources identified in Figure 1 and synthesized to determine exchangeable K. Data from each soil type were analyzed separately for K levels and distribution. Criterion used to categorize K levels is shown in Table 1.

Table 1. Criteria for rating Soil exchangeable K.

Texture	Low	Medium	High	Very high	Very low
	(me/100g)				
K (clayey soils)	<0.20	0.20-0.40	0.41-1.20	1.21-2.00	>2.00
K (loamy soils)	<0.13	0.13-0.25	0.26-0.80	0.81-1.35	>1.35
K (sandy soils)	<0.05	0.05-0.10	0.11-0.40	0.41-0.70	>0.70

Source: NSS, 1989

Results and discussion

Data availability

The quantity of data obtained varied between the zones, depending on soil research coverage. The Eastern zone had more soil research so more data were generated. For Tanga region data were obtained from research and survey work in various sisal estates and from soil fertility research work carried outin Muheza, Korogwe, Handeni, Lushoto, Mkinga, Pangani and Kilindi districts. Data for Coast region were from surveysin 2007-2008 in Bagamoyo (from Razaba Farm) and in 2010 in Bagamoyo and Kibaha. Additional data was obtained from soil fertility work carried outin Kibaha and Bagamoyo in 2012 and 2013. In Morogoro data was derived from surveys in Morogoro by the National Soil Service (NSS) from 1987-1989, Agricultural Research Institute (ARI) Mlingano in 2010, and Land Use Planning unit in 2014. For the Northern zone data wastaken from work carried out in 1974 in wheat growing areas and surveys in Mbulu district by NSS in 1988-1989. A little data was obtained for recent years, mainly from irrigation schemes. In the Central zone data was obtained from analytical results from Bahi, Hombolo, Singida and Manyoni.

The data covered a period from 1974-2015. However very little data had been generated in the past five years, and what little existed was mainly from the Eastern zone.

Soil distribution

The major soils in the three zones that were studied are Cambisols, Luvisols and Ferralsols. Other soil types are Arenosols, Vertisols, Planosols, Phaeozems, Nitisols, Fluvisols and Acrisols. Ferralic Cambisols are very extensive in the study area. Their distribution and K status are shown in Table 2. Potassium levels in these soils range from very low to medium. Generally they are very low in the Eastern zone, except in Kilombero and Ulanga districts. These soils are likely to respond to K inputs.

Table 2. Distribution and K levels in Ferralic Cambisols.

Zone	Region	Representative sites	K levels
Central	Singida	Singida, Iramba	(0.7) Medium
	Dodoma	Dodoma, Manyoni, Mpwapwa	
Eastern	Morogoro	Ulanga, Kilombero	(0.5) Medium
Eastern	Coast	Mkuranga, Rufiji, Kisarawe, Kibaha	(0.1) Very low
	Dar-es-Salaam	Temeke, Ilala	
	Tanga	Pangani, Mkinga	
	Morogoro	Morogoro rural	

Luvisols have a large coverage in the study area. Their distribution and K status are shown in Table 3. Potassium levels in these soils range from medium in the Central and Eastern zone to high in the Northern zone.

Table 3. Distribution and K levels in Chromic Luvisols.

Zone	Region	Representative sites	K levels
Northern	Arusha	Simanjiro, Moduli	(1.86) High
	Manyara	Kiteto	
	Kilimanjaro	Mwanga, Same	
Central	Dodoma	Kondoa, Kongwa, Dodoma, Rufiji, Mpwapwa	(0.62) Medium
Eastern	Tanga	Handeni, Muheza	(0.87) Medium

It was observed that levels of K are influenced by the physiography of the land. Potassium levels in mountains and foothills are medium, and in mountain block foot slopes and semi-arid plains is very variable, ranging from very low to very high (Table 4). Thirty percent of the observations in mountain block foot slopes have low levels. In semi-arid plains, low levels of K were found in 12% of the observations. This shows that the likelihood of having K deficient Luvisols in some mountain block foot slopes and semi-arid plains in the Eastern zone is high.

Rhodic Ferralsols are found in Morogoro, Coast and Tanga in the Eastern zone. Potassium levels in these soils are medium in Morogoro and Coast and range from low to medium in Tanga. These soils either were once or are now under sisal cultivation, a crop with high requirements of K.

Potassium levels in Rhodic Ferralsols in semi humid plains vary widely, ranging from very low to very high. About 45% of these soils have very low to low values of K. Land use and management could explain the variability observed. Soils that were under sisal cultivation (sisal estates) have low to very low K values. The levels of K in other land units are generally medium.

Table 4. Potassium status in Chromic Luvisols on various physiographic units.

	Foot hills	**Mountain block foot slopes**	**Semi-arid plains**	**Mountains**
Range	0.31-0.91	0.07-3.29	0.17-2.05	0.48-1.03
Mean	0.61	0.83	0.89	0.75
Category	Medium	Medium	Medium	Medium
Proportion with low (K< 0.2)	0	30%	16%	0

Table 5. Distribution and K levels in Rhodic Ferralsols.

Zone	**Region**	**Representative sites**	**K levels**
Eastern	Morogoro	Morogoro rural, Mvomero	(0.64) Medium
	Tanga	Mkinga, Pangani, Tanga, Muheza, Korogwe, Handeni	(0.09) - Low-Medium
	Coast	Kibaha, Bagamoyo, Kisarawe	Medium

Table 6. Potassium status in Ferralsols on various physiographic units.

	Semi humid plans	**Subsidence basins**	**Coastal hinterland hills and dissected uplands**	**River basins**
Range	0.09-2.13	0.22-1.32	0.63	0.14-1.75
Mean	0.56	0.64		0.91
Category	Medium	Medium	Medium	Medium
Proportion with low (K< 0.2)	45%			20%

Conclusions

In the process of data collection it was observed that there is limited soil information in some parts of Tanzania, and there is limited recent information. As the data used were generated for different purposes there was no uniformity in the way they were collected in terms of depth, identity of the sites or coverage. Most sites from which data was generated in the past were not geo-referenced. Due to these challenges there is no concrete conclusion but an indication of the following:

- High level of K in the Northern zone.
- Medium levels of K in the Central zone and in some parts of Morogoro and Tanga regions (Kilombero, Kilindi).
- Variable levels of Kin the Eastern zone, being low in the Coast region, Muheza, Korowe, Pangani and Mkinga districts in Tanga region, and Morogororural and Mvomero in Morogoro region.
- Variability of K levels is due to physiographic position and land use (crop grown).
- Need for more research to generate up-to-date soil information is required to complement these findings and identify areas that need interventions regarding K status and plant nutrition in Tanzania.

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4. Status of exchangeable potassium in soils of selected landscapes of the Southern Highlands in Tanzania

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Abstract

Potassium (K) is a major constituent of the earth's crust, with igneous rock containing more K than sedimentary rock. Potassium comprises, on an average, 2.6% of the earth's crust, making it the seventh most abundant element and fourth most abundant mineral nutrient in the lithosphere. Among the most important groups of minerals found in soil that contain K are feldspars and micas (primary minerals), and illites and transitional clay (secondary minerals). Soil K-minerals such as feldspars, illites and micas are present in abundant amounts in some soils, even in the Southern Highlands of Tanzania. An exploratory study on the levels of exchangeable K was carried out in the Southern Highlands which is located in the South-West of Tanzania, between Latitudes 5° and 9° south of the Equator and Longitudes 30° and 38° east of Greenwich. The soils were sampled at a depth of 0-30 cm from three broad physiographic units in the Southern Highlands, namely the highlands, the midlands and the lowlands. The lowlands comprise the largest part of SH. Soil analysis results show that exchangeable K, which forms the major source of immediate plant-available K, was found to be high in most Southern Highlands soils. Correlation studies showed that the exchangeable forms of K were positively and significantly correlated with cation exchange capacity (CEC) ($r=0.916$), organic carbon ($r=0.919$), and with clay ($r=0.917$) content of the soils. They were negatively correlated with sand ($r=-0.916$) content. It is concluded that most soils in the Southern Highlands aren't deficient in plant available K. However, it is recommended that specific studies be carried out at field level. This will allow site specific K crop requirements to be established for sustainable crop production.

Keywords: soil physico-chemical properties, exchangeable potassium, correlation, Southern Highlands, Tanzania

Introduction

Potassium (K) is a major constituent in many igneous rocks and their petrographic classification is often based on K concentrations or abundances. It is progressively concentrated during magmatic fractionation, and is thus enriched in felsic relative to mafic igneous rocks. This is seen in the difference in K content of basalts found in the Southern Highlands of Tanzania, commonly <1%. The K content of argillaceous sediments and shale is primarily a function of the clay mineral content, commonly illite in shale units. Impure carbonates tend to have high K concentrations, up to 6%, because of the occurrence of detrital silicate material (clays) in the non-carbonate fraction. It is a lithophile and biophile metallic element, and is a major constituent of many rock-forming minerals, including important silicate minerals such as alkali feldspars, leucite, biotite, muscovite, phlogopite and some amphiboles. It is also a component of many phosphates, halides and sulfate minerals. Like any other element its availability varies in different soils. In areas with diverse landscapes and parent materials, such as the Southern Highlands, the variability of this element is a common phenomenon.

The Southern Highlands are located on the South-West of Tanzania between Latitudes 5° and 9° south of the Equator and Longitudes 30° and 38° east of Greenwich. This area borders Malawi, Mozambique and Zambia to the south, the Democratic Republic of Congo and Kigoma region to the west, Tabora, Singida and Dodoma regions to the north, and Morogoro, Lindi and Mtwara regions to the east. Administratively, the Southern Highlands are comprised of six regions, namely Iringa, Ruvuma, Mbeya, Rukwa, Njombe and Katavi. According to Mussei *et al*. (2013) one of the main physiographic regions is the highlands with an altitude over 2,000-3,000 meters above sea (m.a.s.l.), occupy 18.2% of the Southern Highlands and are dominated by volcanic mountains or hills and rift valleys. The soils are of medium to heavy texture, which are most commonly found in Mbeya, Iringa, Njombe and Rukwa and medium soil fertility in the Matengo highlands. The highlands are occupied by sparse and dense forests and some alpine vegetation, receive annual rainfall of between 1,200-1,500 mm and experience cold temperatures of below 0°C to 20°C.The second broad unit is the midlands which make up approximately 45.4% of the Southern Highlands, and is the largest unit. In some areas, undulating to rolling plateaus characterize the midlands. Generally, the altitude ranges from 1,000-2,000 m.a.s.l. Many of the soil types have low to medium fertility levels. The Miombo woodland's vegetation predominates in most of this area. The midlands receive annual rainfall of approximately 1,000-1,200 mm and have mean annual temperatures ranging between 11-to 23°C. Lastly, the lowlands make up about 36.4% of the Southern Highlands and have an altitude of 400-1,000 m.a.s.l. The soils are moderately fertile because of the continuous deposition of materials from land at higher altitudes. The annual rainfall ranges between 400-2,600 mm and temperatures are generally high, ranging between 20-30°C.The vegetation is composed of acacia woodland with areas of grassland.

The diversity in geology, landforms and soil types in these broad land units are linked to different parent materials. The various parent materials have resulted in formation of different soil types with different levels of plant nutrients. Some of these plant nutrients include phosphorus (P), calcium (Ca), K and many others. Nitrogen (N), another very important nutrient, is most abundant in the air which is often the main source of N.

General studies have been carried out in the Southern Highlands on soil fertility, but none have been conducted on the different forms of K in soils. Although some data are available from studies carried out by the Uyole Agricultural Centre (1986), newer data detailing the current situation are not available. In conjunction with other nutrients such as organic carbon (C), available N, available P, Ca, sodium and K has been extensively studied recently in the Southern Highlands through soil sample analyses as part of sites evaluations and other soil resource studies. Some of the data have been produced through field studies carried out by Malley (2007), Ngailo *et al*. (2011) and Ngailo and Mlowe (2015), when conducting studies on various crops such as maize, rice, coffee and beans. However, there is still a paucity of adequate information on different levels of exchangeable K in different Southern Highlands soils. With this view, this study was planned to discover the status of potash in Southern Highlands landscapes with different parent materials.

Specific objectives were:

- To identify gray areas or gaps that needs to be addressed.
- Provide justification for further organized research on potash to maintain sustainable crop production.

The study approach

A two-stage study approach was used:

1) The Farming Systems map of the Southern Highlands at a scale 1: 2,000,000 was carefully studied to find out the main physiographic units (Figure 1). These main physiographic units were taken as the basis of aggregating various soil types and units.
2) Soils from the different physiographic units were sampled and analyzed.

Previous soil analysis results, where available, were also included in this study. Representative soil samples were taken from the 0-25 cm depth. Exchangeable K was determined as part of other exchangeable bases (Ca and magnesium).The process used extracted only the exchangeable form of the nutrient. The other forms of the element were not taken into account during the analysis. The data obtained provided only an exploratory picture of the K status.

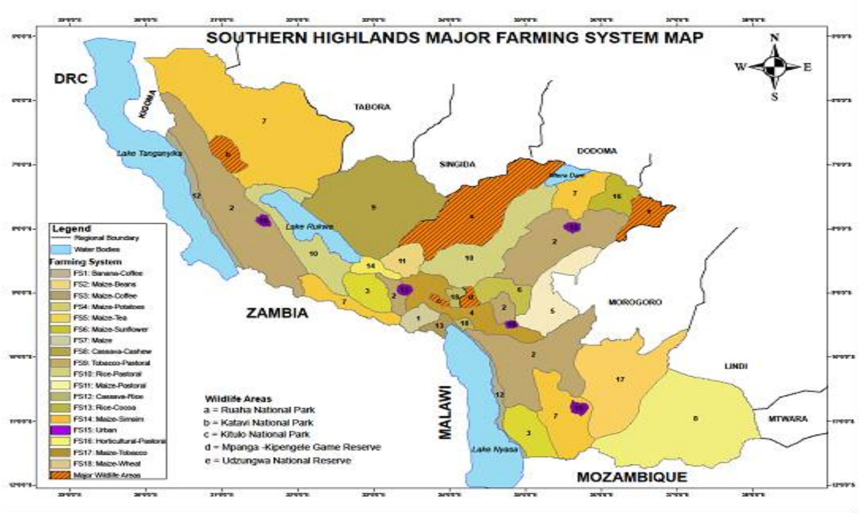

Fig. 1. Main physiographic units of the Southern Highlands.

Discussion of results

Table 1 provides a summary of the results of K status in the main physiographic units of the Southern Highlands.

Levels of potash in highland soils

Umatengo and the Uporoto highlands typify this unit. The Uporoto highlands' soils are formed from volcanic parent materials. Spatial distribution of K in mountain soils is governed by landforms, as the operational intensity of factors and processes of soil formation also vary with landforms.

In the Mporoto highlands, the average exchangeable K in the analyzed soil samples was found to be 0.86 cmol(+)kg^{-1} whereas the minimum was 0.21 cmol(+)kg^{-1} and maximum was 1.42 cmol(+)kg^{-1} (Table 1). Soil data indicating low K status in the highlands is found from studies carried out by Sanga and Ngailo *et al*. (2011). In the Umatengo highlands, the average exchangeable K from soils was 0.89 cmol(+)kg^{-1},with the minimum being 0.10 cmol(+)kg^{-1} and the maximum 0.19 cmol(+)kg^{-1} (Table 1). The levels are slightly lower in the Mporoto Mountains because of the intense leaching which occurs due to frequent high rainfall.

Table 1. Exchangeable K status for some soil units.

Major soil groups/types	N	Minimum exchangeable K levels	Maximum exchangeable K levels	Average exchangeable K levels	Interpretation
	$(cmol(+)kg^{-1})$				
Andisols	49	0.21	1.42	0.86	High
Ultisols and Luvisols	46	0.10	1.62	0.89	High
Eutric Regosol, Fluvisols or Gleyic Luvisols	160	0.10	1.87	0.62	High
Fluvisols	45	0.19	1.87	0.70	High
Fluvisols	48	0.32	2.0	1.06	High
Eutric Regosols	60	0.49	1.52	0.91	High

Usangu plains

Usangu is a flat and low land plain with main soil types including Eutric Regosols, Fluvisols and Gleyic Luvisols. The soils are deep and some are poorly drained. In general these plains seem to contain soils that are high in exchangeable K. It is clearly indicated that the source of K observed is not from fertilizer applications by farmers but rather originates from the prevailing parent materials which are mainly colluvial alluvial in nature. The Usangu plains have intensively been studied and the average exchangeable K was found to be 0.62 $cmol(+)kg^{-1}$ (high) whereas the minimum was 0.10 $cmol(+)kg^{-1}$ and maximum was 1.87 $cmol(+)kg^{-1}$.

Flood plains

Typical flood plains have soils that are stratified in nature. Such soils are a common feature observed in Kyela where water from the highlands flows to the flat areas lowlands (altitude 400- 650 m.a.s.l.) bringing with them a lot of material high in nutrients, including K.

The average exchangeable K was found to be 0.69 $cmol(+)kg^{-1}$ whereas the minimum was 0.19 $cmol(+)kg^{-1}$ and maximum was 1.87 $cmol(+)kg^{-1}$. Flood waters tend to follow the natural contours of the land, eventually terminating in lower end of Songwe River. This was discovered when the origins of samples were studied. Depending on soil type, approximately 90-98% of total soil K was found. In flooded soils, feldspars and micas contain most of the K but plants cannot use the K in this crystalline-insoluble form. Over long periods of time, these minerals break down and K is released. This process, however, is too slow to supply the full K needs of field crops. As these minerals weather, some K becomes 'slowly available' and some becomes 'readily available' or exchangeable. These results are similar to those reported by Kayeke *et al*. (2013)

for Kyela flood plains, and by Ngailo and Mlowe (2015) during their studies of the Usangu plains in Mbarali and Kyela floodplains.

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

Results showed that there was a strong link between high levels of K salts in the floodplains, which is due to the import of salts and minerals during floods. Potassium becomes concentrated when the floods evaporate, leaving residual salts behind.

Lake plains

Soils in the lake plains are sandier in texture but may become heavy in parts of alluvial fans. The typical lake plains are those that characterize the shores of Lake Nyasa. The soils are of various textures. The average exchangeable K levels were around 1.06 cmol(+)kg^{-1} (Table 1), with minimum levels of 0.32 cmol(+)kg^{-1}(low) and maximum values of 2 cmol(+)kg^{-1}(high).

Basins

Basins include Rukwa basin which is within the East African Rift Valley. This includes the whole area of Songwe division, forming what is called the Rukwa Rift Valley. The zone is characterized by flat lowlands drained by rivers from the Gold Mine zone which flow into Lake Rukwa.

The average exchangeable K in the analysed soil samples was found to be 0.91 cmol(+)kg^{-1} (high) whereas the minimum was 0.49 cmol(+)kg^{-1} (medium) and maximum was 1.52 cmol(+)kg^{-1} (high). These values are observed in many areas where sampling was carried out and concurs with results reported by Ngailo *et al*., (2011). Generally, the soils in the basin are sandy, sodic in places, and have low and/or medium fertility, with Eutric Regosols, coarse textured with Eutric Cambisols and Eutric Fluvisols dominating.

Correlation of K with cation exchange capacity (CEC), organic C and clay

Simple correlations were carried out between properties from the different geographical units with exchangeable K. The relationship between exchangeable forms of K in the studied soils and physico-chemical properties is presented in Table 2. Results show that exchangeable K was significantly and positively correlated with CEC (r=0.936**), organic C(r=0.916**), and clay (r=0.927**) content but was negatively correlated with pH (r=-0.490**) and sand (r=-0.899**). This indicated that it was possible to estimate the amount of exchangeable K from other soil properties like CEC, organic C and clay content.

Organic matter, for example, is a source of nutrients and indirectly influences the physical and chemical properties of soil. Increasing organic matter content in soil enhances the availability of plant nutrients, including K, and helps to improve the soil's physical and chemical properties.

The results also reveal that exchangeable K is depleted more easily in light textured soils than heavy textured soil, thus all light textured soils would need careful management of K.

Table 2. Correlation (r) between exchangeable K and other soil properties.

Forms of K	pH	CEC	OC	Sand	Clay
Exchangeable K	-0.548**	0.916**	0.919**	-0.916**	0.917**

CEC= cation exchange capacity; OC=organic C; ** significant at 1% levels

Conclusion

The average levels of exchangeable K in Southern Highlands soils were relatively high but variations do exist. Together with N and P, potash is essential for the survival of plants. Its presence is of great importance for soil health, plant growth and animal nutrition. A positive correlation exists between other soil properties, including clay content. This might be the cause of variations of levels of exchangeable K in different soils, requiring continuous monitoring through soil analysis.

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5. Potassium status in the major agricultural soils of Lake and Western zones of Tanzania and its role in sustainable crop production and food security

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Abstract

Lake Zone comprised Geita, Kagera, Mara, Mwanza, Shinyanga and Simiyu regions while Western zone contains Kigoma and Tabora regions (Appendix 1). Major crops being grown in these zones include maize, banana, beans, cassava, sweet potato, coffee, cotton, tobacco, Irish potato, sunflower, sugarcane, sorghum, pea, tea and horticultural crops. These crops need high levels of potassium (K) for growth and production. Crops deficient in K are less resistant to pest and disease attacks. Outbreaks of pests and diseases in Lake and Western zones for crops like cassava, cotton, banana and citrus are partially attributed to a decline in K in major soil types. Major agricultural soils include Eutric Cambisols, Arenosols, Planosols, Vertisols, Calcisols, Ferralic Cambisols, Rhodic Ferralsols, Rhodic Nitisols, Fluvisols, Leptosols and Gleysols in accordance to FAO - UNESCO (1988 and 1990) Soil Classification System (Appendix 2). Some of the factors which contribute to low levels of K include low inherent soil fertility, leaching, nutrient mining, K fixation by soils and nutrient imbalance. Strategies being used by farmers to manage soil nutrients include use of manure, incorporation of crop residues, fallowing and application of mineral fertilizers. Unfortunately, K mineral fertilizers are not easily available in most areas of Lake and Western zones. The objective of this paper was to review K status in major agricultural soils and identify gaps and strategies to manage K for sustainable agricultural production and food security improvement. The paper was prepared using soil laboratory data from various soils assessments conducted from year 2002 - 2014. Results have indicated the presence of very low to low levels of K in many soils. Few soil types indicated medium levels of K and very few soil types indicated high to very high K levels. Therefore, management of K is required to achieve sustainable land productivity and improvement of crop yield and food security. One potential strategy to manage K is to improve the availability of K-containing mineral fertilizers and undertake experiments to determine optimal K-Fertilizers rates for major soils in the two zones.

Keywords: major agricultural soils, role of potassium, potassium status, food security.

Introduction

Lake Zone contains Geita, Kagera, Mara, Mwanza, Shinyanga and Simiyu regions (Appendix 1). In general, the dominant farming system in Kagera and parts of Kigoma regions is a banana-beans-coffee system, although other crops like cassava, sorghum, chickpeas, sweet potato, ground nuts and bambara nuts are also grown. The dominant farming system in Geita, Mara, Mwanza, Shinyanga and Simiyu regions is cotton-maize-rice-cassava. Other crops like banana and coffee (in Tarime highland), sorghum, chickpeas, sweet potato, ground nuts and beans are also grown in these regions. Western zone contains Kigoma and Tabora regions (Appendix 1). Some of the major crops grown in this zone include maize, lowland rice (paddy), cassava, sweet potato, tobacco, cotton, groundnuts, beans and oilpalm.

Potassium (K) is very important in crop production. It plays important roles such as the activation of enzymes, protein synthesis, phloem loading and transport, osmoregulation and cell extension, stomatal movement, and photosynthesis. Crops deficient in K are less resistant to drought, excess water, and high and low temperatures. They are also less resistant to pests, diseases and nematode attacks. Since K improves the overall health of plants and enhances their resistance to diseases, it is known as the ‘quality’ nutrient. Potassium affects quality factors such as size, shape, color and vigor of the seed or grain, and improves the fiber quality of cotton.

For disease resistance and stress tolerance, a high supply of K in major agricultural soils is required. Some of the crops which are grown in the two zones that need a high supply of K (Sys *et al*., 1993) include coffee, banana, beans, cabbage, cassava, citrus fruits, cotton, pineapple, Irish potato, sunflower, sweet potato, tobacco, sugarcane and tomato. The objective of this paper was to review the K status in major agricultural soils and identify gaps and strategies to manage K for sustainable agricultural production and food security improvement.

Materials and methods

A review of soil data from soil assessments conducted from 2002 - 2014 in the Lake and Western zones was undertaken. Some of the data sources included agricultural libraries in Tanzania, the Sokoine University of Agriculture website, and institutions around the world that have worked on soil K and nutrition. Large and small-scale farmers, as well as other key players in the crop value chains, were also consulted.

Key soil analytical results considered were soil textural class, pH, electrical conductivity of saturation extract (ECe), cation exchange capacity and basic cations (calcium (Ca), magnesium (Mg) and K). Sodium was not considered although data are available. The ratings or interpretation of K status was done by using soil fertility rating guidelines produced by Agricultural Research Institute (ARI) Mlingano (National Soil Service - NSS, 1991) and the International Land Development Consultants (ILACO, 1981).

Results

Major agricultural soils in the Lake and Western zones are shown in Appendix 2. The chemical characteristics of surface soils obtained from various published and unpublished articles are shown in Table 1 and Table 2. Soil reaction (pH) values range from 4.1 to 7.7, which was extremely acid to mildly alkaline according to Landon (1991). The Ca content was 1.88 to 53 cmol(+)/kg soil, which was very low to very high and Mg content was low to high (0.35 to 3.3 cmol(+)/kg soil). Exchangeable K was present in very low to high levels (0.07 to 1.12 cmol(+)/kg soil). ECe levels were high for Vertisols and Gleysols, indicating some salt accumulation. Mg/K ratios varied from 0.3 to 41. Favorable Mg/K ratios for most crops are in the range of 1 to 4 (National Soil Sercice - NSS, 1991). Table 1 and Table 2 showed that 51% of the soil types indicate favorable Mg/K ratios and 49% indicated unfavorable ratio.

Table 3 and Table 4 show Mg and K levels in the surface and subsoils for deep sandy soils (Eutric Cambisols) found in Lake and Western zones. They also show Mg/K ratios as an example of nutrient imbalance in respect to K and availability of other plant nutrients. Out of 26 soil samples from the Lake zone, 16 soil samples (62%) showed unfavorable ratio and 10 samples (38%) showed favorable ratios of Mg/K, while in the Western zone out of 23 samples, 8 samples (35%) showed unfavourable ratio and 15 samples (65%) showed favourable ratio of Mg/K.

Table 1. Selected properties of some surface soils from Lake zone (mean values).

Variable	Eutric Cambisols	Ferralic Cambisols	Planosols	Vertisols	Calcisols	Rhodic Ferralsols	Rhodic Nitisols	Fluvisols	Leptosols
Number of samples	12	9	8	9	2	7	6	5	9
pH	6.4	6.2	7.2	7.1	7.7	5.6	4.7	4.5	5.9
ECe (dS/m)	0.2	1.6	0.41	1.02	1.52	0.19	0.3	0.23	0.28
CEC (cmol kg^{-1})	5.20	13.2	14.2	23.5	56	14.2	8.8	20.6	16.3
Ca (cmol kg^{-1})	3.52	2.48	11.0	18.6	53	3.63	5.37	9.25	6.48
Mg (cmol kg^{-1})	0.7	0.54	1.94	3.3	9.4	1.23	2.94	1.65	1.45
K (cmol kg^{-1})	0.15	0.11	0.18	0.08	0.43	0.15	0.46	0.07	0.36
K-rating	Low	Low	Low	Very low	Medium	Low	Medium	Low	Medium
Mg/K ratio	5	5	11	41	22	8	6	24	4

Table 2. Selected properties of some surface soils from Western zone (mean values).

Variable	Eutric Cambisols	Ferralic Cambisols	Planosols	Vertisols	Rhodic Ferralsols	Fluvisosl	Leptosols	Graysols
Number of samples	11	7	7	12	2	4	2	3
pH	5.5	5.2	5.7	6.7	5.7	4.1	4.8	4.6
ECe (dS/m)	0.13	0.17	0.1	0.77	0.2	1.62	0.38	0.69
CEC (cmol kg^{-1})	2.62	3.68	6.32	16.5	8.15	23.2	20.7	43.4
Ca (cmol kg^{-1})	1.88	2.28	4.73	10.6	6.15	6.43	5.42	17.4
Mg (cmol kg^{-1})	0.35	0.40	0.97	1.63	1.1	1.13	0.96	3.08
K (cmol kg^{-1})	0.10	0.10	0.08	0.18	0.23	0.64	0.73	1.12
K-rating	Low	Low	Low	Low	Low	High	High	High
Mg/K ratio	4	4	12	9	5	2	1	2

Table 3. Magnesium, K and Mg/K ratios for some soils from the Lake zone.

Village	Ward	District	Region	Depth(cm)	Mg(cmolkg^{-1})	K(cmolkg^{-1})	Mg/K
Lutalutale	Mbarika	Misungwi	Mwanza	0-50	0.49	0.08	6.1
				50-80	0.55	0.08	6.9
				80-110	0.53	0.21	2.5
				110-160	0.35	0.31	1.1
Isamilo	Idetemya	Misungwi	Mwanza	0-20	0.35	0.03	11.7
				20-50	0.37	0.03	12.3
				50-105	0.57	0.05	11.4
				105-140	0.37	0.05	7.4
Lamadi	Kalemela	Busega	Simiyu	0- 60	0.30	0.11	2.7
				60-90	0.40	0.10	4.0
				90-130 +	0.01	0.04	0.3
Rwamchanga		Serengeti	Mara	0-35	0.46	0.06	7.7
				35-70	2.06	0.21	9.8
Rwamchanga		Serengeti	Mara	0-35	0.80	0.21	3.8
				35-70	0.46	0.11	4.2
				70-100	0.38	0.06	6.3
Lutalutale	Mbarika	Misungwi	Mwanza	0-30	0.31	0.06	5.2
Isamilo	Idetemya	Misungwi	Mwanza	0-30	0.61	0.04	15.3
Lamadi	Kalemela	Busega	Simiyu	0-30	0.90	0.17	5.3
Rwamchanga		Serengeti	Mara	0-30	0.64	0.21	3.0
				30 -50	0.44	0.23	1.9
Rwamchanga		Serengeti	Mara	0-30	2.12	0.39	5.4
				30 -50	2.18	0.24	9.1
Rwamchanga		Serengeti	Mara	0-30	0.80	0.21	3.8
				30 -50	0.66	0.17	3.9
Rwamchanga		Serengeti	Mara	0-30	0.56	0.22	2.5

Table 4. Magnesium, K and Mg/K ratios of some selected soils from the Western zone.

Village	Ward	District	Region	Depth (cm)	Texture	Mg(cmol kg^{-1})	K (cmol kg^{-1})	Mg/K
Isunha	Puge	Nzega	Tabora	0 - 30	SL	0.20	0.04	5.00
				30 - 50	SL	0.20	0.11	1.82
Isunha	Puge	Nzega	Tabora	0 - 30	SL	0.20	0.14	1.43
				30 - 50	SL	0.30	0.06	5.00
Ndekeli	Tongi	Nzega	Tabora	0 - 30	SL	0.40	0.07	5.71
				30 - 50	SL	0.30	0.13	2.31
Ndekeli	Tongi	Nzega	Tabora	0 - 30	SL	0.30	0.12	2.50
				30 - 50	SL	0.10	0.08	1.25
Wela	Wela	Nzega	Tabora	0 - 30	SL	0.40	0.12	3.33
				30 - 50	SL	0.30	0.08	3.75
Wela	Wela	Nzega	Tabora	0 - 30	SL	0.50	0.08	6.25
				30 - 50	SL	0.50	0.06	8.33
Bulunde	Karitu	Nzega	Tabora	0 - 30	SL	0.40	0.15	2.67
				30 - 50	SL	0.40	0.15	2.67
Bulunde	Karitu	Nzega	Tabora	0 - 30	SL	0.40	0.06	6.67
				30 - 50	SL	0.40	0.10	4.00
Uduka	Uduka	Nzega	Tabora	0 - 30	SL	0.20	0.08	2.50
				30 - 50	SL	0.30	0.08	3.75
Uduka	Uduka	Nzega	Tabora	0 - 30	SL	0.30	0.12	2.50
				30 - 50	SL	0.30	0.12	2.50
Inala	Ndevelwa	Tabora M.	Tabora	0 - 30	SL	0.52	0.08	6.50
				30 -160	SL	0.30	0.06	5.00
				170 - 200	SCL	0.32	0.11	2.91

Key: SL = sandy loam soil textural class name; SCL = sandy clay loam

Discussions

Potassium status in Lake and Western Zones

Various soil assessment studies from the Lake and Western zones that are summarized in this paper have indicated that K levels in most major soils vary from very low to low (Bagarama *et al*., 2010; Jaspa *et al*., 2011; Kaboni *et al*., 2013h; Kaihura *et al*., 2013; Kaboni *et al*., 2014a; Kaboni *et al*., 2014b) while few indicated medium K levels. Very few samples indicated the presence of high to very high K levels. Some factors which contribute to low K levels include low inherent soil fertility of dominant sandy soils, leaching, nutrient mining due to continuous cropping without adding fertilizers (both organic and inorganic fertilizers) by smallholder farmers, soil erosion, K fixation by soils, imbalance of nutrients, and burning of crop and other plant residues. Therefore, for sustainable land productivity, crop yield and food security improvement, K addition in the form of fertilizer is urgently needed. Various options have been used to manage K and other plant nutrients in Lake and Western zones as indicated below. However, fertilizers that supply high levels of K, like muriate of potash, are not easily available in many parts of Lake and Western zones. Tobacco growers currently use NPK 10:18:24 (10 bags/ha) to supply K and top dress with CAN 27% (2.5 bags/ha) to supply Ca and N.

Major crops which demand high levels of K

Crops that demand high levels of K for good growth and better yield (Sys *et al*., 1993) produced in Lake and Western zones are coffee, banana, beans, cabbage, cassava, citrus (orange, lemon, lime, mandolin), cotton, pineapple, Irish potato, sunflower, sweet potato, tobacco, sugarcane and tomato. Other crops which perform better when there is good supply of K include maize, sorghum, green pepper, onion, pea and tea. From this secondary information it is obvious that the better supply of K is very important for crop yield improvement in Lake and Western zones.

Existing strategies to manage K and other nutrients

The following are some strategies being used to manage K and other plant nutrients.

- Use of animal manure, such as farmyard manure for those with cattle, at a rate of 5-10 tons/ha every after three years.
- Use of green manure.
- Incorporation of plant residues, grasses, household refuse and crop residues into the soil.
- Use of industrial fertilizers such as urea, CAN, sulfate of ammonia and NPK for those who can afford it.
- Use of fallow periods for those that have enough land.
- Crop rotation.

- Agroforestry technologies.
- Ridge cultivation for erosion control and soil water conservation.

Challenges for K inputs

- Limited availability of mineral K fertilizers in many areas of Lake and Western zones.
- Limited knowledge and information on effective and economic K rates for major agricultural soils.
- Lack of knowledge and information relating to low K supply and crop disease incidences, for example for banana, cotton and cassava.
- Lack of current clear standards for laboratory soil analytical K results interpretations (K levels in terms of very low, low, high and very high)

Conclusions and recommendations

Some of the major crops being grown in Lake and Western zones include maize, banana, beans, cassava, sweet potato, coffee, cotton, tobacco, Irish potato, sunflower, sugarcane, sorghum, pea, tea and horticultural crops. These crops need high levels of K from the soil.

The major agricultural soil types found in these zones include Eutric Cambisols, Planosols, Vertisols, Calcisols, Ferralic Cambisols, Rhodic Ferralsols, Rhodic Nitisols, Fluvisols, Leptosols and Gleysols. The review of available literature has indicated very low to low levels of K in many soils types. Few soil types had medium K levels while very few had high to very high K levels. Therefore, for sustainable land productivity, crop yield and food security improvement, K addition is needed.

The following are major recommendations for managing potash as a nutrient in Lake and Western zones:

- Make available K-containing mineral fertilizers to farmers.
- Conduct field experimentations to determine optimum K rates for major crops and soils.
- Undertake studies relating to low K supply and crop disease incidences, for example for banana, cotton and cassava.
- Capacity building of farmers on K fertilizer use.
- Provision of current and clear standards for laboratory soil K analytical results interpretation.

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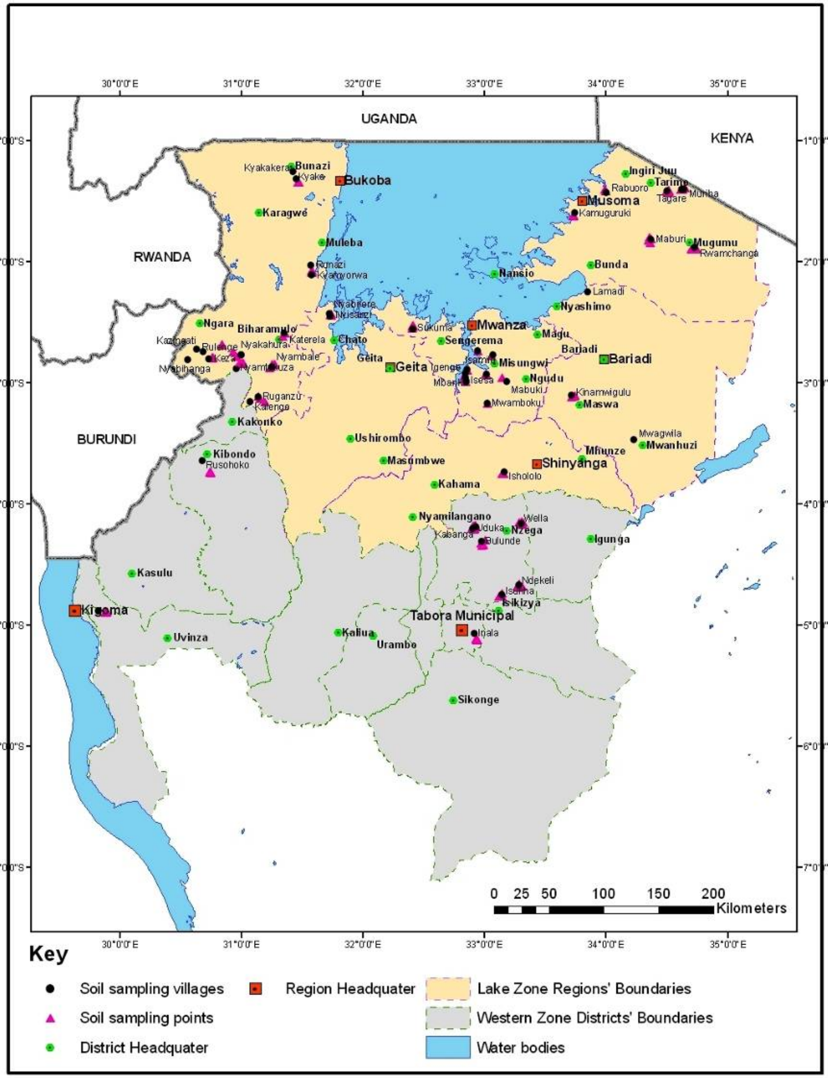
Appendix 1. Map of location of Lake and Western zones in Tanzania.



Appendix 2. Profiles of some major soils in Lake and Western zones.

1) Sandy soil with hardpan (Planosols), Mwanza

2) Reddish sandy soil (Ferralic Cambisols), Mwanza

3) Black clay or '*Mbuga*' (Pellic Vertisols)

4) Red clay soil (Rhodic Ferralsols)

5) Shallow soils (Leptosols)

6) Flooded soils (Fluvisols)

7) Red volcanic soil (Rhodic Nitisols), Tarime Highland

8) Black clay to clay loamwith soluble salts (Calcisols), Simiyu

9) Sandy soil with hardpan (Planosols), Tabora

10) Ferralic Cambisols at Mkuti Irrigation Scheme, Kigoma

6. Variability of exchangeable potassium in soils of Tanzania: A soil fertility challenge for sustainable crop production

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Abstract

A review was carried out to establish exchangeable soil potassium (K) variation in Tanzania. A total of 17 regions and over 50 districts were studied by extracting grey data from previous soil survey reports, and 827 data entries were collected and statistically analyzed using descriptive statistics, box plot and whiskers, and histograms to compare data within and between locations. Results show that the 1st quartile is 0.22 cmol(+) potassium (K)/kg soil, which suggests that one-quarter of the observation sites had less than 0.22 cmol(+) potassium(K)/kg soil. This level indicated that most crops would possibly suffer from K deficiency in the near future. The minimum value was 0.02 cmol(+)K/kg soil. The median and 3rd quartile levels were 0.48 and 0.85 cmol(+)K/kg soil, indicating variation of exchangeable K in the studied soils. Results further indicated that there was variation between regions, districts and within sampled sites. Furthermore, the data depicted the influence of land use on levels of exchangeable soil K. It is concluded that there was wide variation of soil K in soils of Tanzania associated with soil origin between rocks, parent materials and land uses. It is recommended to carry out verification trials in areas shown to have low or very high soil K.

Keywords: distribution of potassium, water soluble K, exchangeable soil K, distribution of K with land use

Introduction

Potassium (K) is an essential plant nutrient. Next to nitrogen (N), crops absorb Kin greater amounts than any other nutrient (Sparks, 2000). Soils are the products of weathered rock and minerals such as feldspar, mica and hornblende as well as secondary minerals (Brady and Weil, 2002). Therefore, K content varies depending on type of mineral, parent rock or parent materials from which the soils developed (Rangel, 2008).

Knowledge on variability of soil K is essential to determining location-specific plant constraints and management options that ensure profitable use of resources (Hartemink and Bourke, 2000; Sanginga and Woomer, 2009). The availability of soil K to plants depends on many factors, including low levels of available nutrients in the soil due to low amounts in the parent material from which the soil was derived (Hartemink and Bourke, 2000; Sanginga and Woomer, 2009). Soil reaction is a major inherent factor which may also cause limited availability of nutrients (Brady and Weil, 2002), and influence fixation and immobilization of nutrients due to the presence of acidic cations (Al^{3+} and H^{+}) or excessive basic cations (Na^{+}, K^{+}, Mg^{2+} and Ca^{2+}). Both of these influence soil pH and hence influence available macro and micronutrients (Hede *et al*., 2001; Abate *et al*., 2013; Hart *et al*., 2013; Cyamweshi *et al*., 2014; Kisinyo *et al*., 2014). Some nutrients, like K, experience heavy leaching losses under high rainfall conditions, whereby nutrients are leached from the soil (Hartemink and Bourke, 2000; Brady and Weils, 2002). These factors are location specific and prior knowledge would improve decision-making.

Poor agronomic practices lead to K mining, particularly in sub-Saharan Africa which has seen rapid population growth and increases in continuous cultivation of crops without use of fertilizers (Hartemink and Bourke, 2000; Drechsel *et al*., 2001). There is also a growing awareness that soil degradation is contributing to a decline in soil plant nutrients which is reducing agricultural productivity in sub-Saharan Africa. Unless controlled many parts of the continent will suffer from food insecurity (FAO, 2001). Furthermore, soil fertility and social economic studies in sub-Saharan Africa reveal that nutrient depletion causes a loss of about 7% of the agricultural share in the average Gross Domestic Product across sub-Saharan Africa, and in some countries, the losses increases up to 25%. This indicates that soil nutrient mining by continuous intensive cropping, with insufficient or no fertilizer input, is a major contributor to the progressive decline in these soil nutrients, resulting in farm households becoming locked into a cycle of declining crop yields and poverty (Drechsel *et al*., 2001; Semoka, 2002).

The most limiting nutrients are N and phosphorus (P), and sometimes soil organic matter (Sommer *et al*., 2013). Although other macronutrients are rarely mentioned, Sanchez *et al*. (1997) and Smaling *et al*. (1997) have shown that nutrient mining in the last 30 years in 37 African countries, including Tanzania, averaged 660 kg Nha^{-1}, 75 kg P ha^{-1}, and 450 kg K ha^{-1}on about 200 million ha of cultivated land. The above losses imply that to achieve sustainable crop production one has to consider the disparity between the K removed and the amount added, which is significant. Therefore, net nutrient mining, including of K, has been a cause of agricultural decline in sub-Saharan Africa (Bationo *et al*., 2007).

Country-wide research to establish the variation of major nutrient determinants' for crop production is scanty and possibly not available. There have been broad agro-ecological zone-based fertilizer recommendations in Tanzania, mainly targeting NPK fertilizer (Samki and Harrop, 1981), which have been updated in light of additional agronomic trials (Mowo *et al*., 1993) and localized agronomic research in few areas, where K was found to be a non-limiting factor for soil productivity. For example a study conducted by Amuri *et al*. (2013) reported high K levels that ranged from 0.15-12.53 cmol(+)/kg soil, suggesting variation between low to very high. Exchangeable K deficiency is noted where soil K is less than 2 cmol(+)/kg soils (Anderson, 1973).

In Tanzania, like elsewhere, agricultural productivity is strongly related to the quality of the soil resource-base, among other factors. Deficiency in N and P has been identified as a major problem affecting crop productivity and K is emerging as a potential problem in some parts of the country. Research conducted by Ndakidemi (1992) has singled out K as the most limiting crop nutrient in highland soils. Similar results were given produced by Oikeh *et al*. (2008) who reported K deficiency in some soils of in West Africa, in cereals, particularly rice. The authors recommended three levels for potassium K application: which are 30-60kg K for soils rated to have low K, 15-30 kg K for medium levels; and 0-15 kg K for soils rated to have high levels of K. Other studies in Asia and Africa show that application of NPK results in higher yields than application of NP alone (Thilakarathna and Raizada, 2015).

The available literature shows that exchangeable soil K is important for optimal crop production. However, in Tanzania, data reveals that there is variability of exchangeable K in agricultural soils, and that the levels are inadequate. Therefore there is a need to examine the distribution of variability and status of exchangeable K using legacy data. This study hypothesizes that exchangeable K levels are not variable in Tanzania's major agricultural soils.

This paper reviews exchangeable K levels in Tanzania using previous surveys, memoirs, data generated from agronomic trials, geographical information system (GIS) databases, to assess if the levels are very low, low, medium or high. The objective is to establish the distribution of exchangeable K variability and its deficiencies in relation to locations and land use types, in order to facilitate the formulation of future strategies on integrated nutrient management research in the country.

Methodology

A review was carried out for various individual studies collected in different parts of the country (from over 30 years ago to the present) that examined topsoil (about 0.2 to 0.5 m from the surface). Figure 1 presents the locations of reviewed studies in Tanzania. A total of 18 regions were reviewed, covering major land uses, landforms, geologies and parent materials, which are all attributes that have been reported to influence exchangeable K soil levels.

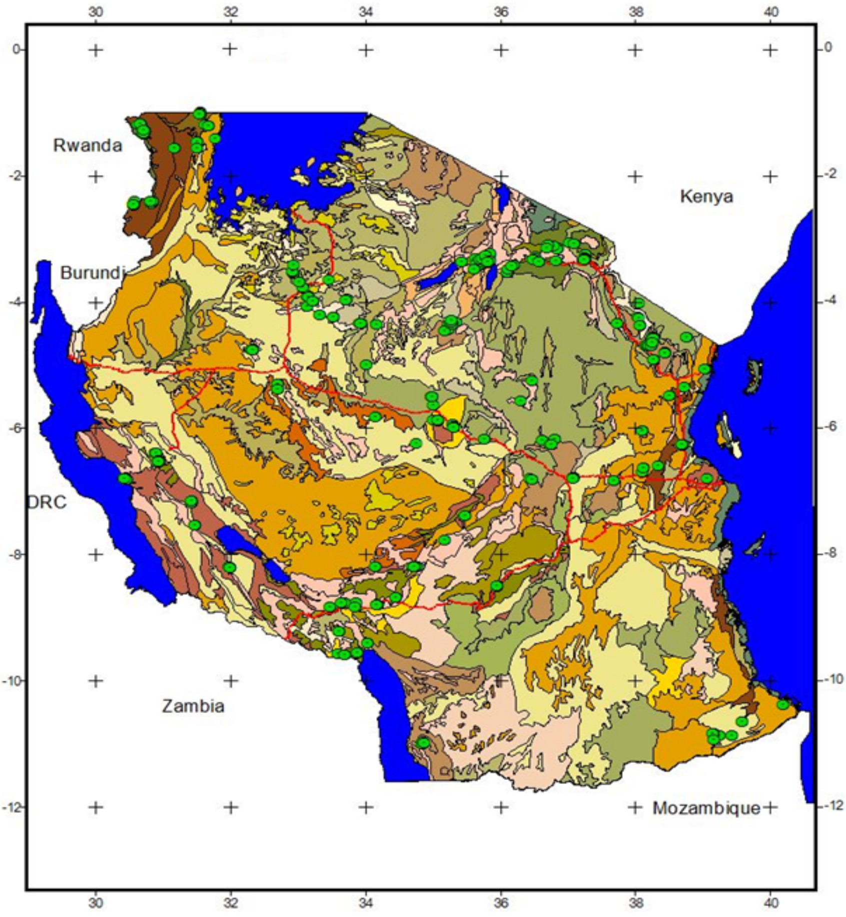

Fig. 1. Distribution of studies (in green dots) reviewed to assess exchangeable K in Tanzanian soils

Among reviewed reports were the *Soil Survey Report of Geita and Sengerema Districts* (FAO, 1982), *Soil Survey Report of Dodoma Capital City District* (FAO, 1983), *Soil Survey Report of Ulyankulu Refugee Settlement* (FAO, 1981), *Soil Survey Report of Mishamo Refugee Settlement* (FAO, 1981) and the *Northern Corridor Wheat Farms Soil Survey Reports* (1980's). Soil testing has been reported to be the most commonly used diagnostic tool to assess plant K availability in soils, but this has proven to be a difficult task due to the complexity of the dynamic equilibrium among the various forms of soil K (Barbagelata, 2006).

Findings and conclusions of reviewed reports were assessed and analytical data were re-analyzed statistically, first using descriptive statistics to study trends and patterns, while box plot and whiskers and histograms were used to complement each other to compare exchangeable soil K between locations (regions and districts) and land use types. Qualitative ranking of low, medium or high was established using guidelines for critical levels by Landon (1991), Euroconsult (1989) and Baize (1993).

Results and Discussions

Variation of exchangeable soil K between locations (districts, regions)

Figure 2 and Figure 3 summarize the degree of exchangeable soil K variability in Tanzania. Measures of variability (range, interquartile range (IQR), standard deviation and variance) show great variations. The observed results are attributed to various factors including parent rock/materials from which the soils were developed, soil types and land use which are different across areas where soil samples were collected. Variability is also shown by kurtosis and skewness which depict the direction of variation of data sets. Results show that exchangeable soil K ranges from very low (<0.02 cmol(+)/kg soils) to very high (>2 cmol(+)/kg soils) (Landon, 1991; Baize, 1993). Except for sandy soils, the median (showing more than 50% of sites) values of 0.48 indicate most soils have medium exchangeable K. However the 1st quartile with an exchangeable K value of 0.22 cmol(+)/kg soil indicate that one-quarter of sampled sites had low exchangeable K values (Euroconsult, 1989) which may be a limiting factor for crop production. Figures 2 and 3, and Table1 reveal variability and distribution by locations (regions and districts) and also soil types, where there are possibilities for exchangeable K deficiency.

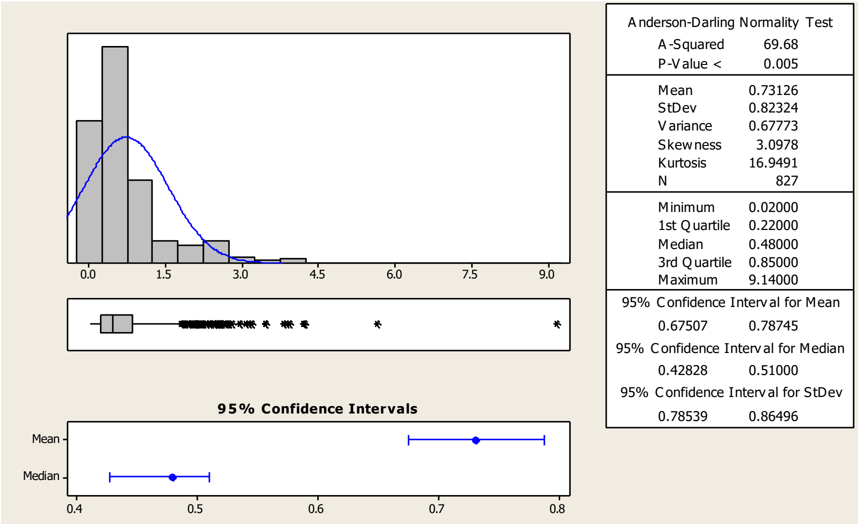

Fig. 2. Variability of exchangeable soil K variation in Tanzanian soils.

The data show that soils developed from volcanic rocks (Arusha, Arumeru, Monduli, Ketesh, Mbuli and Mbeya) and fresh flood deposits (central flood plains of Bahi, Manyoni) have high levels of exchangeable soil K (Figure 3). It is also evident that soils developed from sedimentary rocks (Mishamo) have low exchangeable soil K. These results are in line with reports by Malavolta (1985) and Wopereis *et al.* (2009) which showed that different rocks and soils types exhibited different K contents. Malavolta (1985) further reported that igneous rocks from the earth's crust have higher K contents than sedimentary rocks, while igneous rocks, granites and syenites contain 46-54g K kg^{-1}, basalts 7g K kg^{-1}, and peridotites 2.0 g K kg^{-1}. Among the sedimentary rocks, clayey shales contain 30g K kg^{-1}, whereas limestones have an average of only 6 g K kg^{-1}. This probably explains why the soils developed in sedimentary rocks (Mishamo) have low exchangeable soil K. In addition, Bertsch and Thomas (1985) reported that total K content in soils ranges from 3,000-100,000 kg ha^{-1} in the topsoil, 0.2 cm from the soil surface, of which 98% is fixed in the mineral form and only 2% exists in the soil solution and is exchangeable.

Reviewed data shows variation of exchangeable soil K between locations (district and regions) that relate to parent rocks and hence soil types (Figure 3). The data reveals high exchangeable soil K levels in volcanic rocks (Arusha, Arumeru, Katesh, Mbulu and Mbeya) and flood plain areas such as Kyela (Tenende valley), Bahi plain and Wami River plain. These are in agreement with research from Wopereis *et al.* (2009) and Sparks and Huang (1985) which show that K levels in soils vary with parent rocks, parent materials and soil types.

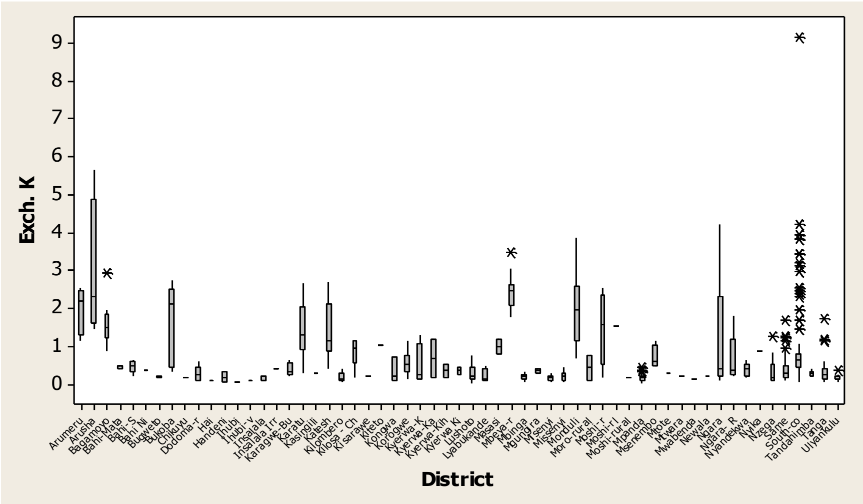

Fig. 3. Variation of exchangeable soil K between locations under different parent rocks in Tanzania.

NB: Exch.K stands for exchangeable K

Table 1. Variability of exchangeable soil K with locations.

District	Sample size n	Mean	SE Mean	StDev	Coefficient of variation (%)	Minimum	Median	Maximum	Range
Arumeru	8	1.973	0.207	0.585	29.67	1.13	2.18	2.56	1.43
Bagamoyo	12	1.553	0.157	0.544	35.05	0.88	1.475	2.94	2.06
Bahi-South	6	0.46	0.0629	0.154	33.48	0.22	0.475	0.65	0.43
Bukoba	7	1.624	0.4	1.059	65.17	0.32	2.13	2.74	2.42
Dodoma-Rural	14	0.2714	0.0485	0.1816	66.89	0.1	0.25	0.6	0.5
Hai	8	0.1125	0.0125	0.0354	31.43	0.1	0.1	0.2	0.1
Insalala	5	0.136	0.0279	0.0623	45.8	0.09	0.1	0.23	0.14
Karatu	35	1.377	0.103	0.611	44.36	0.28	1.28	2.66	2.38
Katesh	26	1.359	0.14	0.713	52.49	0.4	1.135	2.7	2.3
Kilombero	15	0.1787	0.0313	0.1213	67.89	0.05	0.15	0.4	0.35
Kilosa-Chini	8	0.852	0.127	0.36	42.22	0.16	0.94	1.15	0.99
Kongwa	8	0.35	0.105	0.298	85.03	0.1	0.2	0.7	0.6
Korogwe	159	0.54	0.0215	0.271	50.18	0.12	0.51	1.15	1.03
Lushoto	20	0.3025	0.0492	0.2201	72.77	0.03	0.22	0.75	0.72
Mbeya-Rural	11	2.489	0.141	0.469	18.85	1.76	2.46	3.46	1.7
Mbinga	9	0.1911	0.028	0.084	43.97	0.06	0.2	0.33	0.27
Misenyi	6	0.1633	0.03	0.0734	44.94	0.06	0.155	0.28	0.22
Missenyi	7	0.2086	0.0518	0.137	65.71	0.06	0.23	0.46	0.4
Monduli	18	1.971	0.209	0.886	44.96	0.67	1.95	3.87	3.2
Moshi-Rural	9	1.442	0.3	0.9	62.43	0.19	1.57	2.53	2.34
Mpanda	24	0.1733	0.0208	0.1019	58.78	0.02	0.16	0.45	0.43
Msenembo	4	0.713	0.152	0.305	42.76	0.49	0.605	1.15	0.66
Ngara	11	1.209	0.414	1.372	113.49	0.1	0.4	4.2	4.1
Ngara-Rural	8	0.678	0.211	0.597	88.16	0.2	0.37	1.8	1.6
Nyandekwa	7	0.3914	0.0625	0.1654	42.25	0.19	0.4	0.65	0.46
Nzega	21	0.339	0.0688	0.3152	92.97	0.08	0.17	1.25	1.17
Same	68	0.4021	0.0404	0.3332	82.86	0.08	0.285	1.67	1.59
South-co	179	0.9446	0.083	1.1109	117.61	0.04	0.62	9.14	9.1
Tandahimba	6	0.2833	0.0307	0.0753	26.57	0.2	0.3	0.4	0.2
Tanga	40	0.3555	0.0555	0.3507	98.65	0.07	0.25	1.72	1.65
Ulyankulu	13	0.1631	0.0218	0.0786	48.18	0.07	0.13	0.36	0.29

Coefficient of variation (%) - low variation 0-15%; medium variation 15-30%, high variation 30-50%; very high variation > 50%.

Variation of exchangeable soil K within sampling sites

Figure 4 and Figure 5 present exchangeable K across sampling sites and land use types. Individual site analysis reveals areas with low levels of K, which are likely to be a limiting factor in sites with low exchangeable soil K (< 0.02 cmol(+)K/kg soils). According to Landon (1991), and Baize (1993), low levels of K are 0.4 cmol(+)K/kg soil for clayey soils; 0.25 cmol(+)K/kg soil for loamy soils and 0.10 cmol(+)K/kg soil for sandy soils. This implies that whatever the texture of the studied soil, locations with exchangeable soil K below 0.02 cmol(+)K/kg soil are likely to be K deficient.

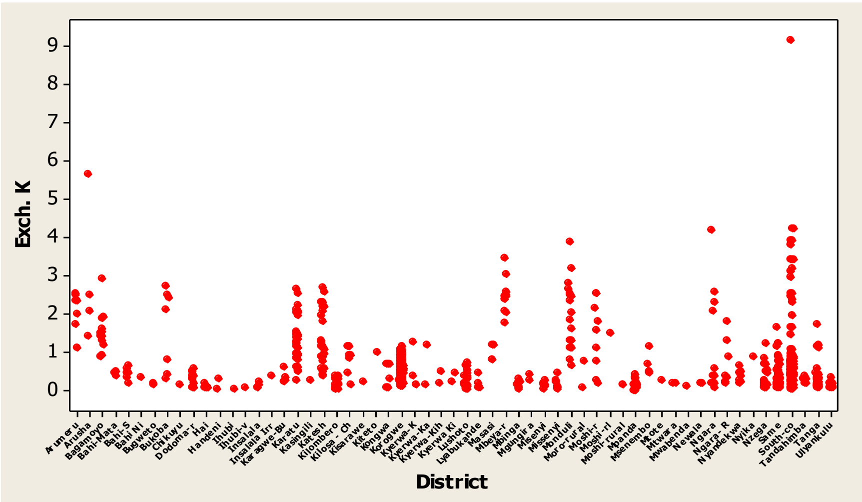

Fig. 4. Variation of exchangeable soil K within individual sampling sites in Tanzania.

Observed variability could be explained by the existence of different forms and variability of texture (Fotyma, 2007) and clay minerals (Sharpley, 1989; Raheb and Heidari, 2011). Clay minerals are known to be a major source of plant nutrients in soil as their specific surface characteristics determine the release pattern of important nutrients, like K. Three forms of K – unavailable, slowly available and readily available – exist in equilibrium in the soil system (Sparks and Huang, 1985; Sharpley, 1989; Bhonsle *et al.*, 1992).

Variability of exchangeable soil K across land use practices

Figure 5 presents variability of exchangeable soil K across land use practices. The data indicate that grassland and coffee plantations have higher levels of exchangeable soil K. This implies that some land use practices encourage release of bound K into solution and exchangeable form. These results are in line with studies by Tittonell *et al*. (2007) and Wang and Huang (2001). Tittonell *et al*. (2007) reported that soil fertility (and therefore of exchangeable K) in the Tropics is strongly influenced by farmers' past soil and crop management practices. Wang and Huang (2001) indicated that soil organic matter considerably promotes the initial fast rate of K adsorption, and become more easily accessible adsorption sites for K compared with mineral constituents of the soils. The data revealed that land which is continuously cultivated had lower levels of exchangeable soil K compared to grassland and in areas under perennial crops such as coffee and banana. There were, however, some exceptions because natural Miombo woodlands with soils developed under sandstones parent materials had low exchangeable soil K.

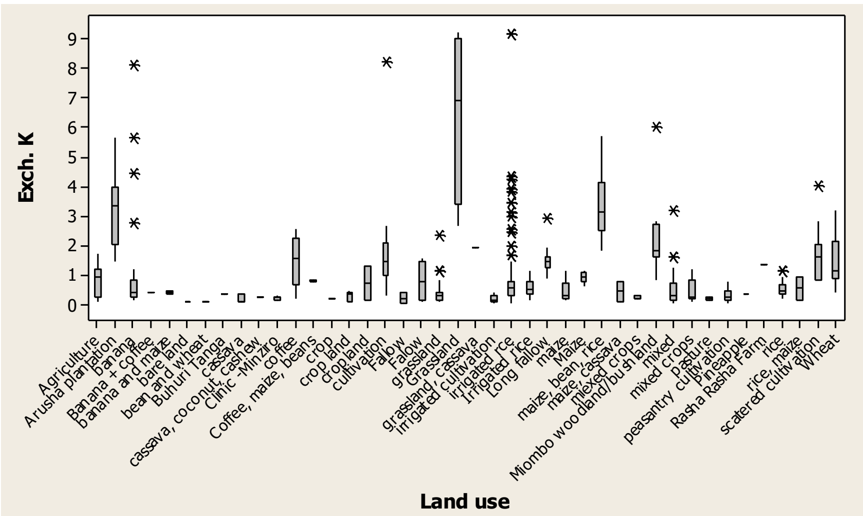

Fig. 5. Variation of exchangeable soil K across land use types in Tanzania

Land use practices also show variability because different plants remove different amounts of exchangeable K. Elsewhere, data generated by Duguma *et al*. (2010) revealed that land uses had caused changes to different parameters including organic matter, N, cation exchange capacity (CEC), and exchangeable bases including exchangeable soil K. Kosmas *et al*. (2000) studied land use changes in selected sites on a variety of parent materials including volcanic lava, pyroclastics, ignimbrite, schist-marble, and shale to explore soil properties changes. Kosmas *et al*. (2000) reported that soil pH, and CEC were slightly affected after abandoning land compared to cultivated soils, while the levels of exchangeable sodium and K were higher on cultivated soils. Therefore regardless of the influence of parent materials, land use equally influences soil properties, including the dynamics of exchangeable soil K. Similar results were reported by Gol (2009) and Abad *et al*. (2014) who studied the effects of land use changes on soil properties in Turkey and Iran, respectively. Research findings elsewhere enable us to infer observed variability of exchangeable soil K to be attributed to existing land use types. It is important to note that exchangeable soil K exists in a mineral form and that daily K requirements by plants are slightly affected by organic associated K, except for exchangeable K adsorbed from soil organic matter (Mengel and Kirkby, 1987; McDonagh *et al*., 2001).

Correlation of exchangeable soil K with selected soil chemical properties

Table 2 present results of correlation study of exchangeable soil K with selected soil properties. The exchangeable K had weaker but significantly and positively correlated with pH_{water} ($r = 0.16$, $p<0.05$), CEC ($r=0.219$, $p<0.05$), and Calcium ($r=0.129$, $p<0.05$). The observed results show that exchangeable soil K is not mainly depended on other basic cations and or even soil organic matter but rather other environmental factors that are not included in this study.

Table 2: Pearson's correlation of exchangeable soil K and selected chemical soil properties, Tanzania

	pHw	**TN%**	**CEC**	**Exch. Ca**	**Exc. Mg**
TN%	-0.011				
p-value	0.755				
CEC	0.505	-0.005			
	0.000	0.901			
Exch. Ca	0.407	-0.013	0.852		
	0.000	0.707	0.000		
Exc. Mg	0.154	0.002	0.692	0.547	
	0.000	0.966	0.000	0.000	
Exch. K	0.16	-0.032	0.219	0.129	0.064
	0.000	0.364	0.000	0.000	0.064

Conclusions and recommendations

This review adds understanding to soil fertility variability in Tanzania as indicated by variation in exchangeable soil K. It is an inherent determinant for smallholder farmers of yields levels they obtain and the extent of food security they can attain. Exchangeable soil K varies within and between locations, hence farmers located just few kilometers apart can experience very different levels of soil fertility. This calls for a thorough exploration of which soil nutrients are limiting for corrections by applying relevant and appropriate rates before one concludes which soil management options to consider.

Conclusions

- Exchangeable soil K is widely variable in Tanzania, but there are areas with deficiencies which may limit sustainable crop production.
- Variability appears to be influenced by multiple factors, including parent materials and land use types.
- Grasslands, perennials, volcanic rocks, and flood plains have had higher levels of exchangeable K than continuously cultivated areas.

Recommendations

- Carry out verification trials in areas that have shown to have low soil K using different crops.
- Examine areas with extremely high levels of K for possible nutrient imbalances or salinity.

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Appendix 1. Statistical soil analytical data for exchangeable K of 18 regions.

Statistics	Same	Setchet Katesh	Oldeani-Karatu	West Kilimanjaro	Katesh-Basotu	Monduli-Arumeru-Arusha	Kilombero Chita	Shinyanga	Igunga-Nzega	Kilosa	Kagera region	Bagamoyo-Coastal region	Ki'ngwa-Coastal-Plain	Ulyankulu	Katavi	Dodoma rural
Mean	0.3313	1.3938	1.3774	3.3375	2.2588	2.9227	0.1473	0.229	0.3395	0.8521	0.3117	0.2309	1.1775	0.1564	0.18	0.9757
SE	0.0275	0.1529	0.1033	0.4123	0.3179	0.4172	0.0343	0.049	0.0689	0.1276	0.0323	0.0381	0.1586	0.0212	0.0196	0.3949
Median	0.2614	1.135	1.28	3.6	2.2	2.36	0.1	0.167	0.1673	0.9410	0.25	0.1223	1.2686	0.13	0.16	0.3
Standard Deviation	0.2149	0.7797	0.6110	1.1661	1.3106	2.2849	0.1138	0.203	0.3157	0.3608	0.2352	0.2350	0.6727	0.0795	0.1037	2.4021
Kurtosis	1.3021	-0.4782	-0.6931	-1.3433	2.7124	1.9181	1.2282	6.260	2.1096	0.7382	7.9291	1.2781	1.4550	2.1590	1.1782	27.9269
Skewness	1.4091	0.7225	0.3403	-0.5687	1.6684	1.6200	1.3742	2.322	1.5431	-1.2609	2.5192	1.4464	0.7844	1.2622	1.1467	5.0710
Range	0.8573	2.8	2.38	2.9	4.7	8.56	0.35	0.815	1.1710	0.9932	1.22	0.8967	2.7512	0.29	0.43	14.2
Minimum	0.0836	0.4	0.28	1.7	0.7	0.67	0.05	0.063	0.0836	0.1568	0.06	0.0204	0.1936	0.07	0.02	0.1
Maximum	0.9410	3.2	2.66	4.6	5.4	9.23	0.4	0.878	1.2546	1.1501	1.28	0.9171	2.9449	0.36	0.45	14.3
n	61	26	35	8	17	30	11	17	21	8	53	38	18	14	28	37
CI(95.0%)	0.05502	0.31493	0.20987	0.974895	0.67382	0.853179	0.07648	0.10442	0.1437	0.30162	0.06489	0.0773	0.334531	0.04589	0.040	0.800

Key: Cl - clay content correlations with exchangeable K

7. Potassium deficiencies limit common bean (*Phaseolus vulgaris* L.) production in West Usambara, northern Tanzania

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Abstract

Common bean (*Phaseolus vulgaris* L.) is the most important grain legume crop in Tanzania's West Usambara Mountains, but its yield remains below potential largely due to nutrient deficiencies in the soil. To identify nutrients limiting bean production, on-farm diagnostic trials were carried out at nine farmer fields around Lushoto town in the short rainy season (*vuli*) from November 2013 until February 2014, through soil and leaf sample analyses. Bean leaf samples were analyzed for macro- and micronutrients, and the Diagnosis and Recommendation Integrated System (DRIS) was applied to rank nutrients according to their degree of limitation to bean production. The combination of different analyses indicated potassium (K) and phosphorus (P) deficiency as a major constraint for bean production in the West Usambara Mountains. Soil analysis indicated deficiencies of the nutrients K and P and some deficiencies of nitrogen (N), calcium (Ca) and magnesium (Mg). Bean growth and yield results revealed positive responses to P and K fertilizers. Analysis of bean leaf tissue indicated deficient nutrient concentrations levels for P, K and N when compared with critical nutrient concentration ranges. Application of P and K (and partially N) fertilizers increased leaf concentrations of the respective elements but depressed the concentrations of Ca, Mg and copper (Cu). Ranking the leaf nutrient concentrations with the DRIS approach showed consistent results for nutrient deficiencies of P and K. Severe K deficiency also became visible at some fields through chlorotic and necrotic leaf symptoms. More work is required to establish the right combinations of deficient nutrients including establishing new fertilizer blends and appropriate application rates.

Keywords: potash, phosphate, nitrogen, calcium, magnesium, *Phaseolus vulgaris* L., West Usambara

Introduction

Common bean is Tanzania's most important grain legume, providing dietary protein and cash in come to smallholder farmers (Hillocks *et al.,* 2006) and contributing to the nitrogen (N) economy of the soil through biological nitrogen fixation (Graham and Vance, 2003; Giller, 2001). Despite these benefits, its productivity is low and yields are far below potential (Baijukya, 2014). According to statistics from the Food and Agriculture Organization of the United Nations (FAOSTAT, 2013), common bean yields in Tanzania range between 600-900 kg ha^{-1}, compared to potential yields of 1,500-3,000 kg ha^{-1} (Hillocks *et al*., 2006). Nutrient limitations and low soil fertility are among the most important constraints for bean production (Graham and Vance, 2003; Hillocks *et al*., 2006; Ndakidemi *et al*., 2006).

In the West Usambara Mountains of northern Tanzania, nutrient limitations in bean production have been studied (Giller *et al*.,1989; Smithson *et al*.,1993; Amijee and Giller,1998; Ndakidemi and Semoka,2006). Smithson *et al*. (1993) observed leaf chlorosis symptoms, referred to as 'Usambara mottle', as an expression of K deficiency. They also pointed at the substantial benefits of phosphorus (P) and potassium (K) fertilizers on yield of common bean and the use of N fertilizer as a relatively small starter dose to stimulate initial growth. The results from Smithson *et al*. (1993) suggested the need for rigorous on-farm experiments in the area to specify nutrient limitations for common bean in order to support sustainable soil fertility management in the future.

Beginning the short rainy season (*vuli*) in November 2013, N2Africa project (www.n2africa.org) initiated studies to find out which specific nutrients were most limiting bean production in the West Usambara Mountains and in which order they were constraining bean growth, which is also the focus of this paper. More experiments have been conducted to explore possible interactions between nutrient deficiencies, soil properties, and other biotic constraints in different agro-ecological zones of West Usambara Mountains.

Methodology

Site selection and characterization

Field experiments were conducted in nine farmer fields representing major field types in the area, range of soil types, altitudes and slopes (Table 1). The fields occur within a radius of 20 km from the district capital Lushoto in the villages of Mabughai, Jaegertal, Lushoto, Kikurunge, Mshizii, Kwemsanga, Ngulwi and Mbuzii (I and II). Each field was considered as one experimental site, on which two or even three replicate blocks were implemented depending on the field size available, which ranged from 150-225 m^2. Next to each experimental field, ten neighboring fields, cultivated with beans, were included in the research. At those fields no experimental plots were laid out and only soils and leaf samples were taken in order to get an indication of local soil fertility status and bean production for comparison with the results obtained from the experimental fields.

Table 1. Field characteristics of nine selected experimental sites in the West Usambara Mountains.

Location	Altitude (m)	Slope (%)	Position on the hill
Mabughai	1,667	0-5	Foot slope
Jaegertal	1,415	0	Foot slope - valley bottom
Lushoto	1,444	0	Uphill slope
Kikurunge	1,340	25-30	Uphill slope
Mshizii	1,256	10-15	Foot slope - valley bottom
Kwemsanga	1,253	20-25	Slope
Ngulwi	1,423	10-15	Slope
Mbuzii I	1,218	5-10	Foot slope
Mbuzii II	1,286	10-15	Uphill slope

The experimental design was a complete randomized block in a factorial arrangement (2^3) with P and K fertilizers and rhizobia inoculationas the main factors. Phosphorus (26 kg P ha^{-1} as triple superphosphate), K (25 kg K ha^{-1} as muriate of potash) and rhizobia inoculant (containing a *rhizobium* strain CIAT-899 manufactured by Legume Technology, UK with 10^9cells $g^{-1}$of rhizobium bacteria on a peat carrier) was used. Nitrogen (25 kg N ha^{-1} as calcium ammonium nitrate) was used in one additional treatment together with P and K to analyze the effect of N fertilizer without inoculation (i.e. the need for inoculation).

Soil information

Prior to seeding, soils at the experimental sites (Table 2) and selected neighboring fields managed by farmers (data not reported) were sampled and chemically analyzed. Per site, 20 soil samples were randomly taken at a depth of 0-20 cm, bulked, air-dried and a subsample of about 500 g taken for chemical analysis at Crop Nutrition Laboratory Services Ltd (Nairobi, Kenya). The following soil properties with corresponding methods were measured: pH (H_2O), available P (Olsen), cation exchange capacity (CEC) (extraction with ammonium acetate), cations (K, calcium (Ca), sodium (Na) and magnesium (Mg) content) (atomic absorption spectrophotometry), electrical conductivity (EC) and soil particle size (Bouyoucos). The results were compared with critical levels obtained from the literature.

Plant growth assessment, leaf sampling and analysis

Plant growth was assessed, scoring plant crop vigor by visual overview and scoring from one (poor growth) to five (healthy and good growth). Recently matured leaf samples were taken from the uppermost fully expanded trifoliolate leaf on the main stem, harvested at the time of 50% flowering (Wortmann *et al.*, 1992). Furthermore, 20 bean leaves were sampled from ten additionally selected farmer fields, planted with common bean by farmers in Mshizii (2), Kwemsanga (2), Ngulwi (3), Mbuzii I (1) and Mbuzii II (2).

Table 2. Soil chemical properties of experimental fields.

Field	pH	Organic carbon (%)	Total N (%)	Available P (mg/kg)	Exchangeable bases (cmol/kg soil)					EC (mS/cm)
					CEC	Ca	Mg	K	Na	
Mabughai	5.3	2.6	0.3	16.3	17.6	3.9	0.8	0.1	0.2	1.1.
Jeagerstal	5.6	2.4	0.3	34.6	21.7	5.6	1.4	0.3	0.2	2.7
Lushoto	5.2	2.5	0.3	37.8	12.5	2.4	0.7	0.2	0.2	1.2
Kikurunge	6.9	2.3	0.2	25.7	24.2	8.0	3.1	0.1	0.3	0.3
Mshizii	6.6	2.0	0.1	47.9	15.7	5.0	1.8	0.3	0.2	0.7
Kwemsanga	6.4	1.4	0.1	55.2	16.8	5.4	1.6	0.2	0.2	0.2
Ngulwi	6.0	2.5	0.2	46.2	16.7	5.2	1.3	0.2	0.2	0.7
Mbuzii 1	6.1	2	0.2	45.3	21.5	6.3	2.2	0.2	0.3	0.8
Mbuzii 2	6.1	2.4	0.2	35.9	18.7	5.4	2.0	0.3	0.3	1.2

Samples were carefully washed with distilled water, dried and subsequently fine grinded and analyzed for Carbon-Hydrogen-Nitrogen (CHN) using a CHN EA-1110 analyzer, following methods described by Jimenez and Ladha(1993). Samples were also analyzed for P, K, Ca, iron (Fe), Mg, manganese (Mn), copper (Cu) and zinc (Zn) using inductively coupled plasma optical emission spectrometry (ICP-OES), following methods described in Nölte (2003). The nutrient concentration data from the leaf samples was used to apply the Diagnosis and Recommendation Integrated System (DRIS) (Beaufils, 1973; Beverly, 1992) to generate nutrient indices. DRIS indices are calculated based on ratios of each nutrient, relative to all other nutrients using the equations below provided by Walworth and Summer (1987). Consider the hypothetical nutrients A through N:

$$Aindex = \frac{f(A/B) + f(A/C) + f(A/D) + \cdots f(A/N)}{z}$$

$$Bindex = \frac{-f(A/B) + f(B/C) + f(B/D) + \cdots f(B/N)}{z}$$

$$Nindex = \frac{-f(A/_N) - f(B/_N) - f(C/_N) - \cdots f(M/N)}{z}$$

Where

$$f\left(\frac{A}{B}\right) = |\, 1 - (a/b)/(A/B) \,| \frac{1000}{CV}$$

Where A/B is the value of the ratio of the two elements in the tissue of the bean plant being diagnosed, a/b is the optimum value or norm for that ratio, CV is the coefficient of variation associated with the norm, and z is the number of functions comprising the nutrient index (Walworth and Summer, 1987). In this study the indices for N, P, K, Ca, Mg, Mn, and Zn were calculated and compared to the norms for dry bean, determined by Wortmann *et al*. (1992).

Plant harvesting to determine yield

The harvest area consisted of the inner three rows, giving a net harvest area of 1.5 m x 2.2 m. The number of plants harvested per plot was counted, the pods separated from the stems and the remaining leaf material and soil particles removed. Thereafter both pods and stems were weighed separately to determine fresh weight. In the laboratory the pods were threshed to separate the husks from the seeds and the number of seeds were counted. Stems, husks and seeds were oven dried at 65°C for 24 hours and weighed to determine dry matter. From these measurements the final yield components were derived: percentage of plants which reached maturity, average number of seeds per pod, 100-seed weight (g), dry stem yield (kg ha^{-1}), dry grain yield per plant (g $plant^{-1}$) and dry grain yield ha^{-1} (kg ha^{-1}).

Statistical analysis

Treatment effects on agronomic indicators were analyzed through an analysis of variance (ANOVA) using the F-test. Treatment effects were analyzed while accounting for Block and Field effects. Where Block and Field were used as blocking factors, subsequent Least Significant Difference (LSD tests were performed ($\alpha = 0.05$). Treatment one to nine were analyzed for possible effects and interactions. The addition of N fertilizer (treatment ten) was analyzed separately by comparing to treatment six and nine. To look for possible site effect, treatment effects were also analyzed for each location separately, with Block as a blocking factor. All analyses were carried out with the use of the statistical software ©Rversion 3.0.3.

Results

Soil analysis

Soil analysis results (Table 3) indicated that Mabughai, Jaegertal and Lushoto had soils with pH levels below the optimal range for bean production, which is 5.8-6.5 (Lunze *et al.*, 2012). Available P was also below the critical level of 15mg kg^{-1} at most sites. Exchangeable K ranged from 0.11-0.25 cmol(+)kg^{-1}, with six out of nine locations scoring lower than the recommended value of 0.20 cmol(+)kg^{-1} for adequate crop growth (Anderson, 1973).Three locations had low levels for Ca, when compared with the critical level of 5.0 cmol(+)kg^{-1} (Lunze *et al*., 2012). Magnesium levels were below the critical level of 2 cmol(+)kg^{-1} (Ndakidemi and Semoka, 2006) at seven out of nine field sites. Soil analysis in the nine farmer fields (data not shown) indicated high pH levels, with an average pH of 6.5, but revealed extremely low P and K levels in six out of the nine locations. The values for Mg and Ca fluctuated around the critical deficiency level.

Crop vigor

Application of P and K fertilizer ($p < 0.001$) gave a significant increase in crop vigor in comparison with the control and inoculation treatment (Figure 1). Also, a significant and positive interaction effect of K, P and the rhizobia inoculant (I) was found ($p < 0.05$). However, addition of N fertilizer to 'K+P' treatment had a positive significant effect on crop vigor ($p < 0.001$) (Figure 1). The addition of rhizobia inoculant to P and K fertilizer however, had no significant effect.

Bean yield

Only bean yield across all fields is reported here as the trend seemed to be the same at all sites. Grain yields were significantly increased by the application of both P and K fertilizer ($p < 0.001$ and $p < 0.01$ respectively). There was no significant effect of inoculation and none of the interactions among treatments were significant. A separate analysis indicated that addition of neither N fertilizer nor inoculation significantly affected bean grain yield relative to the 'K+P' treatment. Largest bean grain yields were obtained within the 'K+P', 'K+P+I' and 'N+P+K' treatments, whereas smallest bean grain yields were found in the control and inoculation plots (Figure 4). Differences in bean grain yield reflected differences in pod number m^{-2} (Figure 2). The application of both P and K fertilizer led to a significant increase of pods m^{-2} ($p < 0.001$ and $p < 0.01$ respectively).

Table3. Chemical soil properties from experimental farmer field locations in the West Usambara Mountains collected during the *vuli* season of 2013-2014.

Location	pH (H_2O)	P-Olsen Available P (mg/kg^{-1})	CEC ($cmol/kg^{-1}$)	Exchangeable bases ($cmol/kg^{-1}$)				EC ($mScm^{-1}$)	Particle size analysis Texture			
				K	Ca	Mg	Na		Clay (%)	Silt (%)	Sand (%)	Class name
Mabughai	5.4	6.1	17.6	0.11	3.92	0.84	0.24	1.13	24	18	58	Sandy clay soil
Jaegertal	5.5	1.5	21.7	0.18	5.56	1.42	0.22	2.69	36	23	40	Clay loam
Lushoto	5.3	10.9	12.5	0.20	2.40	0.70	0.19	1.21	28	20	52	Sandy clay loam
Kikurunge	6.3	2.6	24.2	0.13	8.00	3.07	0.29	0.67	44	18	42	Clay
Mshizi	6.3	5.7	15.7	0.18	4.96	1.79	0.33	0.67	46	16	38	Sandy clay
Kwemsanga	6.3	2.3	16.8	0.17	5.36	1.58	0.23	0.70	42	12	46	Sandy clay
Ngulwi	6.2	2.5	16.7	0.20	5.16	1.30	0.16	0.69	40	18	42	Clay (loam)
Mbuzii I	6.0	2.7	21.5	0.19	6.26	2.23	0.30	0.78	32	18	50	Sandy clay loam
Mbuzii II	6.1	1.6	18.7	0.25	5.36	1.99	0.32	1.24	50	12	38	Clay

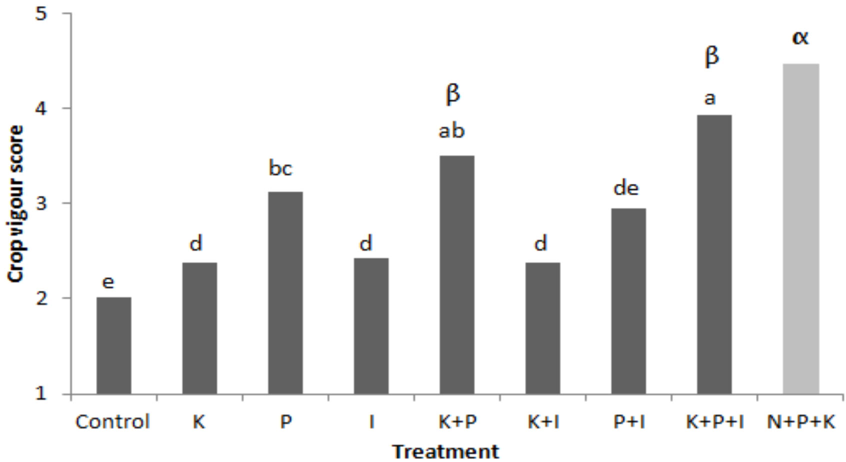

Fig. 1. Crop vigor, ranging from one (poorest growth) to five (best growth) as affected by treatments.

Data are summarized across sites. I = Inoculant.

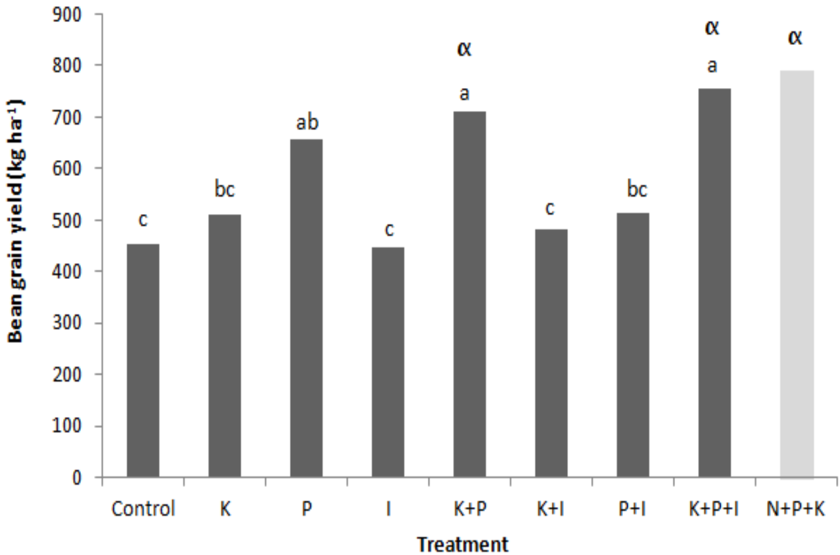

Fig. 2. Bean grain yield (kg/ha^{-1}) against treatment as observed across the experimental sites, I= rhizobia inoculant.

Leaf nutrient analysis

Leaf nutrient concentrations

Leaf nutrient concentrations of the macronutrients N, P, K, Ca, Mg and micronutrients Cu, Zn and Mn were compared to the critical deficiency concentrations (CDC) for bean, obtained from Reuter and Robinson (1997). Treatment effects were largest for leaf K concentration: 84.8% of all observations were below adequate K concentration range of 1.5-3.5%. Application of K fertilizer significantly increased overall leaf K concentration ($p < 0.0001$). The N concentrations ranged from a minimum value of 2.89% at Kikurunge to a maximum value of 7.83% at Jaegertal in which 89.2% of the total observations were below the adequate range of 5.2-5.5% (Reuter and Robinson, 1997). Both P and K fertilizers significantly increased leaf N concentration ($p < 0.05$). In the case of P, 94.9% of total observations were below the adequate P concentration range of 0.4-0.6% (Reuter and Robinson, 1997), with the smallest concentration of 0.1% measured at Mbuzii II and the largest concentration of 0.52% at Lushoto. P fertilizer had an overall significant effect on leaf P concentration ($p < 0.01$). Leaf nutrient concentrations for Ca, Mg, Cu and Mn fell within adequate ranges for almost all plots (Table 4). Measured leaf Zn concentrations, however, were less than the adequate range of 35-100 mg/kg^{-1}(Reuter and Robinson, 1997) in 99.2% of the total measurements. Leaf nutrient concentrations measured at ten additional farmer fields located in the region, which did not receive any treatment (data not reported), indicated overall deficiencies for K, P and Zn (partly N) relative to the CDCs.

Relationship between grain yield and leaf nutrient concentrations

Bean leaf nutrient concentrations (N, P, K, Ca, Mg, Zn and Mn) were compared with grain yield (Figure 3) to study the relationship between plant growth and nutrient concentration in shoots. Leaf N concentrations varied from 3-6.5% within the low grain yield section (below 750). However, a slight increase in leaf N concentration was observed in the relatively higher grain yield section, consisting of yields obtained at Mabughai, Jaegertal and Lushoto. The relationship between leaf P concentration and grain yield showed a similar pattern, with a broad nutrient range at the base, after which growth increases with only small changes in leaf P concentration. A more linear relationship was found for leaf K concentration, but a broad nutrient range was still observed within the relatively low yield section. Clear C-shaped curves were found when comparing grain yield with the leaf concentrations for Ca and Mg and partly for Cu and Zn (x-axis). However, relationships between grain yield and leaf nutrient concentrations differed between sites, where treatment effects became more clear for Mabughai and Jaegertal, which made up the major part of obtained yields above

750 kg ha^{-1}, and for Ngulwi. Highly significant effects of K were found for leaf K concentrations when comparing treatments at all three locations.

At Jaegertal, leaf N concentration was significantly increased by P fertilizer application ($p < 0.05$ and $p < 0.01$ respectively) and highest N concentrations were measured when P fertilizer was combined with K or I at Mabughai and with K+I and K+N at Jaegertal. However, leaf N concentration measured at Ngulwi was significantly decreased by K ($p < 0.005$). P significantly increased leaf P concentration at Jaegertal ($p < 0.001$) and Ngulwi ($p < 0.01$). Whereas K gave a significant increase in leaf P concentration at Jaegertal ($p < 0.05$) and a significant decrease at Ngulwi ($p < 0.001$). Leaf nutrient concentrations of Ca, Mg, Cu and Zn (which were not part of the fertilizer treatments) were generally lower after the application of P, K and/or N fertilizer, most likely due to dilution. At Mabughai, K significantly decreased leaf Mg ($p <0.0001$), Ca ($p < 0.01$), Cu and Zn concentrations ($p < 0.05$), while P had a significant effect on leaf Cu and Zn concentrations ($p < 0.05$). However, I significantly increased leaf Mg concentration ($p < 0.05$). When looking for significant treatment effects on those nutrients at Jaegertal, only Zn was significantly decreased by K ($p < 0.05$). At Ngulwi leaf Ca, Mg, Cu and Zn concentrations were significantly lower when K fertilizer was applied ($p < 0.05$, $p < 0.001$, $p < 0.001$ and $p < 0.01$ respectively). The same was true after addition of P fertilizer for leaf nutrient concentrations of Cu ($p < 0.05$) and Zn ($p < 0.001$).

The indicated relationships were also compared with CDCs for bean production obtained from literature (Reuter and Robinson, 1997) (Figure 4). Leaf N, P and Zn concentrations were all below the proposed CDC. However, this did not agree with the relationships between grain yield and leaf nutrient concentration (Figure 4). Leaf nutrient concentrations of Ca, Mg and partly K, gave a clear increase in grain yield above the proposed CDC.

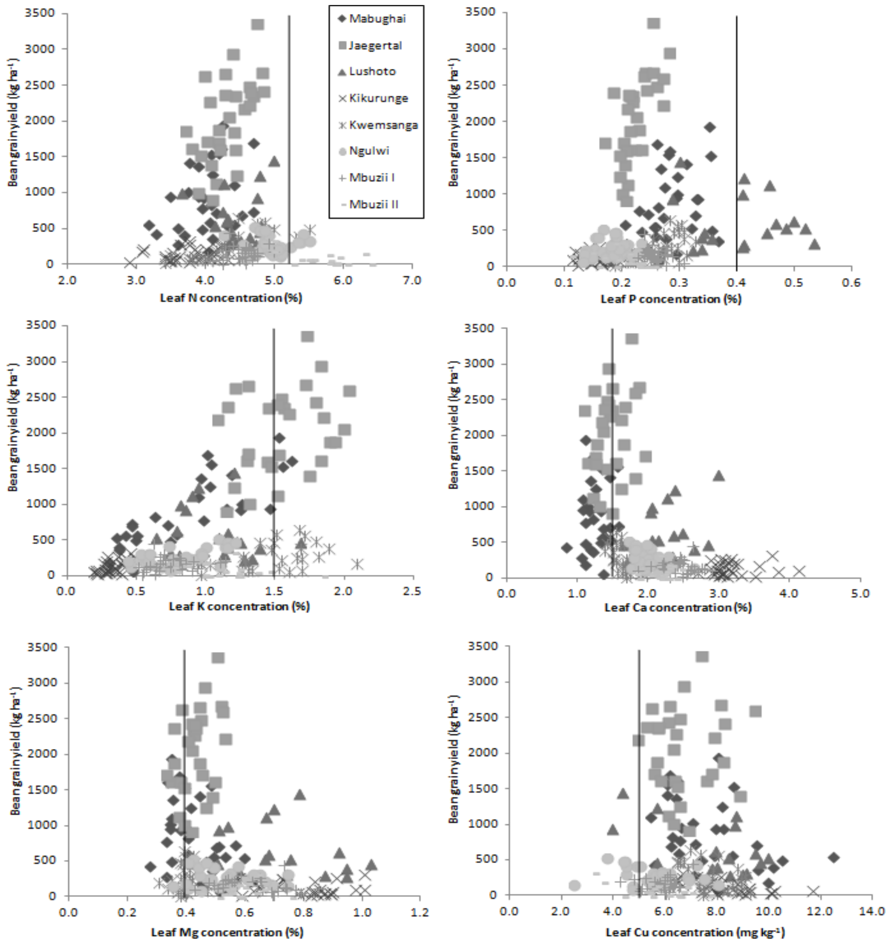

Fig. 3. Bean grain yield as a function of determined leaf nutrient concentration, for the nutrients N,P, K, Ca, Mg and Cu.

DRIS indices

DRIS indices were calculated for all plots used in the field trial as well as for the ten additional farmer fields (data not reported). After ranking the nutrients, it became clear that K, followed by P and N respectively, had the lowest DRIS indices overall, indicating the relatively high importance of those nutrients in limiting yield. Some differences were observed between different locations, but the K-index ranked lowest for almost all locations.

When comparing the DRIS indices with obtained grain yields, a clear and positive relationship was found between K-index and grain yield, but indices remained below zero, even for the highest yields obtained (Figure 4). A similar but weaker relationship was found for the P-index, where positive values were obtained at Lushoto and Mabughai. A negative response was found for Ca, Mg and Mn indices, where grain yield decreased with increasing index values. Those nutrients were not applied as fertilizers within the experiments. The N-index showed intermediate results and for the Zn-index no clear relationship with grain yield could be found, with all observations scoring index values well above zero (Figure 4).

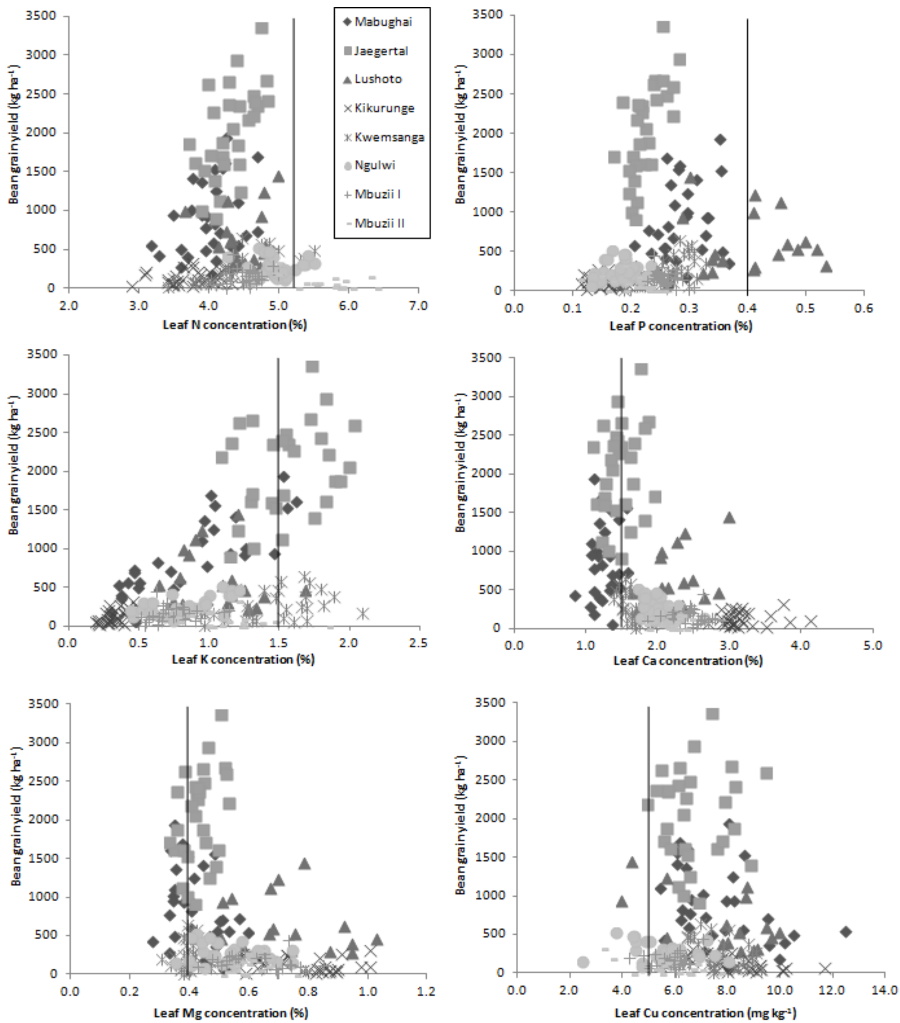

Fig. 4. Bean grain yield as a function of calculated DRIS indices for the nutrients N, P, K, Ca, Mg and Cu.

Discussion and Conclusion

In this study, soil analyses revealed soils with poor levels of P and K, limiting bean growth and productivity. Growth and yield results indicated differences in treatment responses, however effects were not that clear at all nine experimental fields. Sites where nutrients were clearly limiting revealed responses to P and K fertilizers, accompanied by more pods and increased number of seeds per pod. Analysis of bean leaf tissue indicated deficient nutrient concentrations levels for P, K, N and Zn when compared with CDCs (Reuter and Robinson, 1997). At some sites application of P and K (and partially N) fertilizers increased leaf concentrations of the respective elements but depressed the concentrations of Ca, Mg, Cu and Zn. Improved plant growth, initiated by the addition of K, P and/or N fertilizer(s), could be attributed to a dilution in the leaf tissue of the other major and minor nutrients not included in the experimental trials. Measured leaf Ca, Mg and partially N concentration in relation to bean grain yield showed a C-shaped response curve, which could be referred to as the 'Piper-Steenbjerg' effect (Bates, 1971). Ranking the obtained leaf nutrient concentrations with the DRIS approach showed consistent results for nutrient deficiencies of P and K (partly N), with K as the most limiting nutrient followed by P and N respectively (Figure 3 and Figure 4).

Besides quantitative results, possible nutrient deficiencies were also visually analyzed during the experiments where severe K deficiency became visible at some fields through chlorotic and necrotic leaf symptoms, earlier referred to as 'Usambara mottle' in beans by Smithson *et al*. (1993). K is the nutrient required in the largest amount by plants and when K is deficient growth is retarded, enhancing net transport of K^+ from mature leaves and stems (Marschner and Cakmak, 1989). Leaf senescence is induced by K deficiency (Armengaud *et al*., 2004) and in the form of leaf chlorosis of source leaves; it can readily be induced by high light intensity combined with K, Mg and/or Zn deficiency (Marschner and Cakmak, 1989).

Results obtained within the experimental study, in combination with farmer interviews, indicated some implications for N2Africa's research within this region in the future. There is a need to increase the use of animal manure and/or fertilizers based on K and P deficiencies in the West Usambara Mountains to be able to increase soil fertility and to maintain agricultural production. Fertilizers already used in the region are mostly based on N and P, so there is need for more research on the application of K fertilizers, including determining proper and economical application rates.

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8. Nutritional requirements of potassium for crop production: the case of sisal production in Tanzania

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Abstract

Since the introduction of sisal (*Agave spp.*) in the country in 1893, the crop has been an important foreign exchange earner, becoming the top earner in the mid-1960s. Despite competition between natural fiber and synthetic products in the global market, sisal has continued to play a key role in Tanzania's social and economic development. Soil fertility decline has been the main sisal production constraint in the country, which has been attributed to the tradition of continuously growing the crop in the same land area without fertilizer application. This practice has resulted in reduction of crop yield and frequent outbreaks of nutritional diseases, mainly due to soil potassium (K) deficiency (Banding disease). This disease is characterized by brownish spots which develop into necrotic tissues, causing leaves to collapse at the neck. Depending on the spread and severity of the disease, it may cause up to 100% economic loss to the sisal farmer per annum. The disease mostly affects leaves with lower critical nutrient concentration from 0.5-0.6% of K. Despite the economic impact of the disease, limited research on the nutritional requirements of K for sustainable sisal production in Tanzania has been reported. In sisal, K is known to play significant roles in promoting transport of assimilates, controlling stomata opening, enzyme activation, nitrogen (N) utilization, stimulation of early growth, disease resistance, and product quality. The main objective of this paper was therefore to review previous work on the nutritional requirements of K in selected sisal estates in Tanzania. In general the review was based on the status of soil K in relation to sisal fiber yield, soil K uptake by sisal and an overview of different sisal cropping practices on major soil types and K availability for sisal production. Research gaps were later identified and proposed for improving sisal production in the country. The research areas proposed include establishment of soil N/K ratio in major soil types in relation to banding disease development, establishment of critical levels of K for high-yielding fertilizer-demanding sisal hybrids, and establishment of critical deficiency levels of N for disease development.

Keywords: *Agave spp*., potash, nitrogen

Introduction

Sisal (*Agave spp*.) is a tropical crop from which fiber is extracted from its leaves. The fiber accounts for 5% of sisal leaves and is used for making ropes, agricultural twine, mats, bags, motor vehicle spare parts and paper (CFC, 2005; Hartermink, 1995). The sisal (*Agave sisalana Perrine*) crop was introduced in Tanzania in 1893 by the German agronomist Dr. Richard Hindolf. About 62 sisal bulbils from Mexico were planted at Kikogwe near Pangani in Tanga Region. These plants were the foundation of the sisal industry in East Africa (Lock, 1962).

In 1934, the Sisal Research Station was established to breed improved sisal varieties and develop agronomic practices for sisal production in Tanzania. Among the achievements of the Sisal Research Station include the release of a high yielding sisal variety called Hybrid 11648, and the development of improved sisal production technologies. These achievements enabled the sisal industry to attain the highest global production of 230,000 tons in the 1960s, whereby at that time sisal became the first foreign exchange earner for Tanzania (TSGA, 1965). Despite the fall of sisal prices, followed by the nationalization of sisal estates in the 1970s, the crop continued to play a key role in social and economic development in Tanzania.

Since the early 1990s, sisal has been continuously grown on the same land without fertilizer applications. This practice has resulted in the decline of soil fertility which has resulted in frequent outbreaks of nutritional diseases like banding disease caused by soil potassium (K) deficiency, chlorosis caused by nitrogen (N) deficiency, and purple leaf tip roll caused by calcium (Ca) deficiency.

Banding disease occurs in a variety of soils, but not in soils that have high mica content or soils of volcanic origin (Lock, 1962). Banding disease is sometimes known as leaf base disease. The disease is characterized by brownish spots which develop to necrotic tissues. Necrotic lesions spread and enlarge to form dead shrunken tissues which causes leaves to collapse at the neck. The disease affects mostly the lower leaves. Damaged leaves however cannot be cured. Other effects of the disease include stunted growth. The plant is also unable to pole. The disease signifies that leaves are starved of K and that remedial measures should be undertaken.

It is therefore important that the levels of soil K and contents of K in plants are established in order to be able to recommend management options for sustainable sisal production.

Potassium is the third plant macronutrient after N and phosphorus (P) and is therefore indispensable for every plant species (Lock, 1962; Mengel, 1978; Oosterhuis *et al*., 2014). In sisal, K plays significant roles in promoting transport of assimilates, controlling stomata opening, enzyme activation, N utilization, stimulation of early growth, and disease resistance (Lauchli and Pfluger, 1979; Rehm and Schmitt, 2002; Yawson *et al*., 2011; Lakudzala, 2013). The nutrient is therefore necessary for increased growth, vigor, crop yield formation and product quality (Rehm and Schmitt, 2002).

Potassium is one of the most abundant elements in soil but its low availability limits plant growth and productivity of ecosystems (Garcia and Zimmermann, 2014). In soils with K deficiency, problems of banding disease have been reported (Lock 1962; Mowo *et al*., 1993; Hartemink, 1995). Depending on the spread and severity of the disease, it may cause up to 100% economic loss to the sisal farmer per annum. Despite the economic importance of the disease, limited research on the nutritional requirements of K for sustainable sisal production in Tanzania has been carried out.

Previous studies on K requirements of sisal by the Tanzania Sisal Growers Association (1965) and Mowo *et al*. (1993) recommended application of 200-250 kg K ha^{-1} $cycle^{-1}$ in loamy and clay soils with low soil K and where banding disease occurs. This recommendation rate has to be applied in five splits of 40-50 kg K ha^{-1} $year^{-1}$. In sandy soils with exchangeable K levels of 1.5-2.9 cmol (+) kg^{-1} of soil, the recommended application is 20 kg K ha^{-1}.

It is therefore important that more research should be conducted to determine the dynamics of K in different soil types and its interactions with other soil nutrients for sustainable sisal production.

This paper provides a review of existing work on K status in selected sisal estates in Tanzania. Specifically, it examines different sisal cropping practices on soil types and availability for sisal production, evaluates different sisal varieties on K uptake, analyses the impact of K status on sisal fiber yield, and critically review previous work and identify research gaps.

Materials and methods

Guidelines for K content in sisal leaves and other chemical characteristics related to soil K for optimal sisal growth and production were obtained from Lock (1962), Hartemink (1995) and Mowo *et al*. (1993). to determine uptake of K from the soil by sisal crops, the content of K from sisal leaves and fiber yield were also compiled from previous experiments. Literature was reviewed to determine the status of K and its impact on sisal production in Tanzania and identify research gaps to improve crop productivity.

Overview of different sisal cropping practices on major soil types and K availability for sisal production

With continuous sisal cultivation on a Ferralsol at Bamba estate (Table 1), there was a decrease in pH (H_2O) from 5.5-5. Calcium levels also decreased from 19-6 cmol/kg while K levels were almost exhausted in 25 years of sisal cultivation. The same trend was exhibited in Kwafungo estate; except for K levels which were not altered because they were initially low in 1958.

Table 1. Soil fertility (0-20cm) status in continuously cultivated sisal fields at different sampling times.

Major soil groupings	Plantation	Sampling year	pH (H_2O)	Exchangeable cations (cmol kg^{-1})		
				Ca	Mg	K
Ferralsol	Bamba	1966	5.5	19	11	4
		1990	5.0	6	3	1
	Kwafungo	1959	5.7	32	Na	1
		1989	4.8	13	12	1
	Kwamdulu	1958	5.6	15	17	2
		1987	4.5	8	7	1
Acrisol	Bamba	1966	6.9	75	28	5
		1990	5.9	41	17	3
	Kwamdulu	1966	6.7	49	13	2
		1987	5.0	25	13	1
Luvisol	Mwera	1960	6.5	41	9	2
		1987	6.6	44	12	2
Phaeozem		1959	8.0	311	26	9
		1987	7.8	229	36	1
Leptosol	Mwera	1959	7.0	190	18	5
		1987	7.9	196	62	2

Source: National Soil Service (1995), Agricultural Research Institute Mlingano, Tanga

Top soil K in Acrisols at Bamba decreased from 5 cmol kg^{-1} in 1966 to 3 cmolkg^{-1} in 1990, while at Kwamdulu estates, K levels slightly changed. The decline of K levels was more severe in Ferralsols than in Acrisols in Bamba. The difference in the two soil groupings can be explained by higher initial fertility and possibly because of more weatherable minerals in Ferralsols than Acrisols.

The levels of soil K in Luvisols remained low in both 1960 and 1987. In Phaeozems and Leptosols, there was a decrease in levels of soil K from 9-1 mmol kg^{-1} in Phaeozem and from 5-2 cmol kg^{-1}. Taking into account the heterogeneity of the soils in Tanzania, there is a need to cover all major soil types in the country in evaluating soil K so that soil types/areas prone to K deficiency in sisal can be established.

Status of soil K in relation to sisal fiber yield

The soil chemical data on Ferralsols are linked with sisal yield (Table2). The data indicate that the highest yield of 2.3 tons $ha^{-1}yr^{-1}$ was obtained in the field with the highest soil pH, exchangeable Ca and K. The nutrients therefore need particular attention to ensure that the needs of the crop under consideration are met.

Soil K uptake by sisal

Sisal nutrient requirements, like any other crop, may be ascertained reasonably well by determining the composition of their tissue. Studies conducted by Lock (1962) and Malavolta (1992) to determine sisal uptake of nutrients grown in red Ferralsols indicated that macronutrient concentration in mature sisal leaf were 0.8% N, 0.13% P, 2.1% K, 1% magnesium (Mg), 1.8% Ca, and 0.1% sulfur (S). Similar studies were also conducted to determine nutrient removal from1ton of line fiber. The results for macronutrients were 31kg N, 5kg P, 79 kg K, 66kg Ca, and 38 kg Mg.

Table 2. Status of soil K in relation to sisal fiber yield in three sisal fields (Ferralsols) at Mlingano.

Reference yield (t ha^{-1})	**2.3**		**1.8**		**1.5**	
Sampled depth (cm)	0-20	30-50	0-20	30-50	0-20	30-50
pH (H_2O) 1:2.5	6.5	5.3	5.4	5.2	5.0	4.9
Total N (%)	0.11	0.05	0.16	0.17	1.5	0.5
C/N	15	16	12	9	0.12	0.04
Available P (Bray 1)	5	1	4	< 0.5	3	1
CEC (NH_4OAc pH 7) mmol/kg	93	73	111	70	64	50
Exchangeable Ca (mmol/kg)	46	22	19	12	6	6
Exchangeable K (mmol/kg)	7	4	2	1	1	< 0.5
Exchangeable Mg (mmol/kg)	17	9	6	3	3	2

Source: NSS Mlingano (1993)

Key: t ha^{-1} - tones per hectare, cm - centimeter, pH - potential of hydrogen, N - nitrogen, C/N - carbon to nitrogen ratio, P - phosphorus, CEC - cation exchange capacity, NH_4OAc - ammonium acetate, mmol/kg - milimol per kilogram, Ca - calcium, K - potassium

Table 3. Mean uptake of macro nutrients by sisal at Agricultural Research Institute (ARI) Mlingano.

	N	P	K	Ca	Mg
Mean	1.42	0.18	4.10	0.95	0.93
Max	2.01	0.27	5.36	1.44	1.09
Min	0.93	0.12	3.36	0.66	0.82
SD +_	0.37	0.06	0.54	0.23	0.1

Source: Masuki and Shabani (2004)

Previous work conducted by Masuki and Shabani (2004) on Ferralsol at Mlingano (Table 3) indicated high K uptake with a range of 3.36-5.36% and a mean of 4.1%. These data seem to be slightly above the ranges of 2.1-2.5% reported by Lock (1962) and Malavolta (1992). Differences in nutrient removal are also reported by Osborne (1967) (Table 4). The variation could be attributed to the growing condition (temperature, moisture and the climate of the area) and the genetic potential of sisal varieties. However these studies imply that sisal takes up more K than any other macronutrient. It is therefore important that K removed from the soil is replenished through K fertilizer application to attain optimal sisal yields.

It is believed that in the 1960s, most researchers used *Agave sisalana* in evaluating the uptake of soil K by sisal. The critical nutrient concentration in the sisal leaf which was earlier reported by Lock (1962) in *Agave sisalana* leaves ranged from 0.5-0.6% of K. At the moment Kenya has three commercial sisal varieties, namely H.1300, *Agave hildana* and Hybrid 11648. These varieties are also available in Tanzania. There is therefore a need to carry out more research to determine the critical K levels of these new varieties in various soils in Tanzania.

Future research required

Limited research has been conducted on nutritional requirements of K for sisal production in Tanzania. However, the data provide useful information on the status and need for K fertilizer-based application in the sisal industry. In general K requirement is increasingly becoming important for sisal production due to:

- Declining fertile virgin land, as a result of continuous cultivation of sisal plantations coupled with occurrence of banding diseases.
- Introduction of high-yielding varieties which are high fertilizer demanding sisal hybrids.
- Attractive global market prices due to growing demand for sisal fiber.

It is believed that these factors will continue to demand more research on K nutrition if sustainable sisal production is to be achieved.

It has been established that banding disease is accelerated by application of N fertilizer on soils with low soil K content. There is also therefore a need to establish critical levels of N for disease development.

Other studies report that some soil types which have low N and K do not show banding disease. It is therefore important that more research be conducted to establish disease development in relation to soil N/K ratio.

Table 4. Nutrient removal by sisal crop (kg ton^{-1} fibre).

Source	**Plant**	**Nutrient**				
		N	**P**	**K**	**Ca**	**Mg**
Osborne (1967)	*Agave sisalana*	27	7	69	70	34
Osborne (1967)	Hybrid 11648	26	3.5	44	82	31
Berger (1969)	Not specified	27-33	5-7	59-69	42-66	30-34
Lock (1969)	Not specified	31±9	5±3	79±22	66±25	38±15
IPI‡ (1978)	Hybrid 11648	22-25	3-4	30-40	79-83	na
IPI‡ (1978)	*Agave sisalana*	27-33	5-7	59-69	42-66	na
Finck (1982)	not specified	35	6.5	65	na	30
Rehm and Epsig (1991)	Not specified	30	5	80	65	40
IFA(1992)	Not specified	20	23	33	54	20
Range of values:	All data	20-50	2-23	30-101	41-159	20-53
	Agave sisalana	27-33	5-7	59-69	42-70	34
	Hybrid11648	22-26	3-4	30-44	79-83	na

Sources: Osborne (1967) and Berger (1969)

Key: IPI – International Potash Institute, IFA – International Fertilizer Industry Association

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9. Potential for response to potash application: the case of maize and rice production in Tanzania

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Abstract

Maize and rice are the two most consumed cereals in Tanzania. The bulk of these crops are produced by smallholder farmers without adequate plant nutrition or land management practices. For a long time now, nitrogen (N) and phosphorus (P) have remained the most emphasized and applied nutrients for these crops, while potassium (K) has been assumed to be sufficient in soils across Tanzania. This paper was prepared with the objective of examining levels of soil exchangeable K in selected areas known for maize and rice production, and determining the potential response or non-response of selected sites towards K application. Soils from 13 rice irrigation schemes (n = 113) and smallholder maize fields (n = 382) covering 14 districts were analyzed for K status and critically assessed for their sufficiency in providing K to maize and rice. In total, soils from the 495 locations were sampled and tested for exchangeable K. Standard laboratory procedures were applied to analyze the soils while crop yield levels for maize and rice were based on literature and resource persons in the sampled locations. Results indicate that availability of K in irrigated rice schemes is not critical and yields of rice across the studied schemes showed no significant response to the inherent exchangeable K in their soils. Potassium levels in smallholder maize fields, however, need attention because the study found that nearly 40% of the studied fields had K levels below critical values. Further, yields of maize in the studied fields showed a significant ($p < 0.03$) correlation with levels of exchangeable K in the soils as well as K: Magnesium (Mg) ratio ($p < 0.01$) across the schemes. The study also finds significant differences ($p < 0.00$) regarding levels of K across the selected research zones. The study concludes that the addition of K-fertilizers in irrigated rice schemes is unlikely to stimulate an agronomic response from the paddy established in those schemes. For smallholder maize fields however, the application of K fertilizers is likely to benefit maize production. This later finding implies that specific K recommendations may need to be generated for each of the selected zones. Though influence of other soil nutrients (N, P) cannot overlooked, these results provide a useful insight into the plight of potash nutrition for maize and rice in Tanzania.

Keywords: maize, rice, potassium, Tanzania

Introduction

Potassium (K) is among the most utilized essential nutrient after nitrogen (N) and phosphorus (P) in crops. Potassium is required for many important functions in a plant including crop vigor, development of root systems, resistance towards pests and diseases, and prevention of crop plants from lodging (Chianu et al., 2012). Almost all K in the soil is involved in the structural component of soil minerals. Therefore, the amount supplied by soils varies, which translates to variations in the amount of K fertilizer applications needed across soil types.

For maize and rice, K is associated with the movement of water, nutrients, and carbohydrates within the plant. Potassium stimulates early growth, increases protein production, and improves the efficiency of water use and resistance to diseases and insects (Rehm and Schmitt, 2002). Plants with insufficient K have difficulty absorbing water and N from the soil and may be slower at closing their stomata which makes them more vulnerable to drought stress. In addition, K deficient plants may have trouble making energy via photosynthesis. Adequate K levels are important to maximize maize and rice yield potential. Peak absorption of K occurs from flowering through early pod development. A shortage of K during this period can result in yield loss without obvious foliar symptoms.

The study of K's role in plant nutrition in Tanzania has not received much attention in the past, partly because it was taken for granted that the level of K was not limiting (Acland, 1971). Studies conducted in rice fields in Lake zone in Tanzania (Meertens, 2003) found that K levels were medium (0.25 meq K/100 g of soil). Another study which covered eight rice growing areas from Mbeya, Coast and Morogoro regions (Semoka and Mnguu, 2000) also found that extracted K values were higher than critical values. When K levels are higher than critical levels, response towards K fertilizer application becomes reduced.

In Tanzania, most of the maize and rice is grown in smallholder fields. Application of nutrients, especially for maize, has long been reported as being insufficient. Whenever nutrient applications are made, it is often N and P which are given priority. For this reason, knowledge on the K situation in both rice and maize production across Tanzania is not adequately understood and therefore knowledge of potential areas where response of rice and maize can be expected is long overdue. Studies from other regions have indicated response of K maize and rice. This paper therefore examines status of exchangeable K in smallholder fields across selected areas in Tanzania, and critically looks at their sufficiency for potential response to K fertilizer applications. The paper specifically examines levels of soil exchangeable K in selected areas known for maize and rice production and determines the potential for response or non-response of these sites towards K application.

Materials and methods

Locations from which soils were collected are shown in Figure 1. For rice growing areas, 13 rice irrigation schemes (Table 1) were chosen for this study. For maize, soils from farmers across 14 districts (Table 2) were collected and analyzed. All sites were selected on the basis of importance for rice or maize, access, and availability of crop yield information. In each district, smallholder maize farms were also selected based on experience of the extension personnel in the area. Collection of soils from each field were based on standard soil sampling techniques of representation of the site and were collected as composite soil samples from the top 0-30 cm of the soil depth. Soils from these sites were collected, air dried ground and sieved through a 2 mm sieve. Analysis of soil particle size distribution was carried out using the hydrometer method (Gee and Bauder, 1986) after dispersing the soil using calgon. For chemical properties, the soils were analyzed for soil pH (McLean, 1982), organic carbon (C) (Nelson and Sommers, 1982), total N (Bremner and Mulvaney, 1982), bases (Thomas, 1982) and available P using the Bray-Kurtz 1 (Olsen and Sommers, 1982).

For crop data, average yields for maize and rice in the respective sites were obtained from farmers, agricultural extension offices, resource persons, and recently published literature. Management of fields varied across the schemes and fields, hence only average yields were calculated and reported. Yields given in terms of bags (90 kg bags per acre) were converted into tons per hectare through calculations. Data collected from all locations were stored in Excel spreadsheets. For statistical analyses on the relationship between yield data and soil properties, Develve Version 2.5 statistical software was used to explore the associations. Sufficiency or inadequacy of exchangeable K in the soils from each location were based on their estimation for tropical soils (Landon, 1991; Baize, 1993).

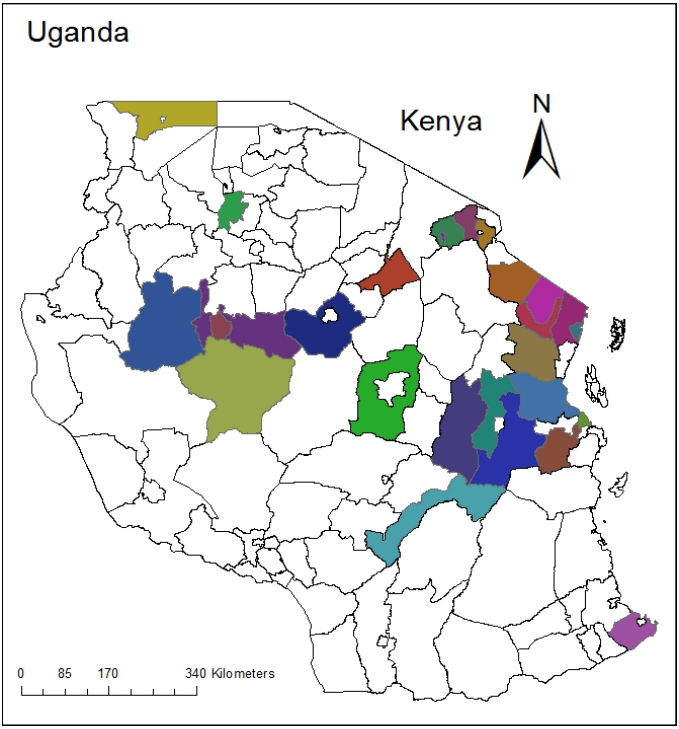

Fig. 1. Location of study sites.

Results and discussion

Potassium in rice fields

For rice growing areas, the physical and chemical properties of soils from irrigated rice schemes are shown in Table 1. Percent clay was highest in the Europryma Irrigation Scheme (mean 69.4%: coefficient of variation (CV) 17.8%) and lowest in the Lekitatu Irrigation Scheme (mean 24%: CV 6.8%). These two schemes are located in the Mt. Kilimanjaro-Meru zone where the geomorphology and landscape is greatly influenced by volcanism of these two mountains. Therefore, the variation in their soil clay content is probably associated with their local positions in the general landscape.

There was a significant variation ($p < 0.03$) of the soil pH across the studied schemes which was probably caused by the type of soils from which these schemes were located. Soil pH was lowest in Europryima Irrigation Scheme in

Arusha district (mean 6.1; CV 7.8%) and highest in Kitivo Irrigation Scheme (mean 7.9; CV 12.3%). Apart from the soil types on which the schemes were located, the variation in the soil pH was also probably associated with the level of precipitation and drainage conditions. The Europryima Irrigation Scheme in Arusha is within an area not reported to have salinity problems. The irrigation scheme in Kitivo however, is in an area receiving 650 mm yr^{-1} and is known to have soil salinity problems (Kashenge-Killenga et al., 2013). These two conditions probably contribute to the differences in the soil pH of the two schemes.

Generally, all 13 irrigation schemes had higher levels of exchangeable K above the critical level of 0.3 meq K $100g^{-1}$ (Landon, 1991; Baize, 1993) for tropical soils. The highest amount of exchangeable K was observed in the Itigi Irrigation Scheme (mean 5.54 meq K $100g^{-1}$; CV 14.7%) located in the Central Tanzanian region of Singida. The lowest level of exchangeable K was observed in the Dakawa Irrigation Scheme (mean 0.39 meq K $100g^{-1}$; CV 52%) in Mvomero district.

Table 1. Soil conditions in selected rice growing areas in Tanzania.

Irrigation Scheme	Sampled locations	Clay	Sand	pH	Organic C	Total Nitrogen	Available Phosphorus	Calcium (Ca)	Magnesium (Mg)	K	K:Mg	Sodium (Na)	Rice yields
	(No.)	(%)	(%)	(H_2O)	(%)	(%)	(mg/kg)	(meq/100g)	(meq/100g)	(meq/100g)	(ratio)	(meq/100g)	(ton/ha)
Bahi-Dodoma	7	48	34.8	7.3	0.74	0.076	3.84	14.02	4.08	0.68	0.16	2.66	3.6 (b)
Dakawa-Mvomero	11	39.1	49.6	7.84	0.89	0.06	4.54	18.94	5.39	0.39	0.07	0.74	3.5 (b)
Europryima-Arusha	13	69.3	10.6	6.1	1.26	0.13	9.51	1.75	16.33	3.23	0.19	1.75	4.3 (d)
Ilonga-Kilosa	20	36.3	46.6	7.3	1.21	0.13	38.85	8.59	2.75	1.27	0.46	0.09	4.9 (c)
Itigi-Singida	6	50	32.3	7.85	1.18	0.13	5.2	1.89	3.23	5.54	1.71	0.44	4.3 (d)
Kitivo-Korogwe	5	34	54	7.86	17.57	0.21	7.655	29.76	1.31	1.15	0.87	0.51	5.1 (c)
Kivulini-Moshi rural	3	40	33	7.03	1.37	0.12	18.68	26.81	15.61	3.73	0.23	0.93	3.8 (a)
Lekitatu-Arumeru	3	24	48	7.1	1.3	0.08	13.93	19.43	4.94	1.49	0.30	1.62	4.2 (a)
Lower Moshi-Moshi urban	3	28	42	6.5	0.84	0.05	40.72	11.01	4.39	2.42	0.55	0.74	3.2 (c)
Lukenge-Mvomero	8	44.5	40.75	6.33	1.15	0.11	4.665	25.93	4.56	0.735	0.16	1.18	3.6 (b)
Mombo-Korogwe	13	42	38	7.35	1.76	0.2	27.87	21.2	3.98	0.78	0.19	1.26	3.9 (a)
Ndungu-Same	16	42	39	6.59	1.39	0.12	3.24	14.24	5.16	0.67	0.13	9	4.3 (c)
Ruvu-Same	8	32.3	39.5	6.75	1.16	0.16	7.9	13.3	59.2	4.9	0.08	1.64	4.8 (d)

Sources: (a) Mkojera, 2009; (b) Tusekelege *et al*., 2014; (c) Kiishweko, 2013; (d) Personal communication with extension personnel and farmers in the area levels of K showed no significant correlation with rice yields across the studied schemes. This was in contrast to organic C (%) and total N (%) which had a significant ($p < 0.04$; $p < 0$) correlation to rice yields respectively (Table 2).

Table 2. Correlation between rice yields and physical-chemical conditions in selected rice irrigation schemes, Tanzania.

Parameter	Pearson r-correlation	p-value (n= 116)
Clay (%)	-0.04	0.90
Sand (%)	0.13	0.68
pH (water)	0.21	0.48
Soil Organic Carbon (%)	0.53	0.06
Total Nitrogen (%)	0.69	0.01
Available Phosphorus (mg/kg soil)	-0.09	0.77
Calcium (meq/100g soil)	-0.08	0.78
Mg (meq/100g soil)	0.29	0.33
K (meq/100g soil)	0.23	0.44
K:Mg ratio	0.27	0.38
Na (meq/100g soil)	0.01	0.96

A number of studies have also reported a non-significant relationship between extractable K and rice yields. For example, a study across eight rice growing areas in Tanzania (Semoka and Mnguu, 2000) and another in Iran (Bahmaniar and Ranjbar, 2007) also reported non-significant relationships between extractable K and rice yields. It seems logical therefore to attribute lack of response of paddy to K in these schemes to the already high levels of exchangeable K in their soils. Globally, most rice growing schemes, like those covered in this study, are located in landform positions which make them final recipients of sediments and other products of erosion which enriches their soils with plant nutrients (Roberts *et al.*, 2010). For this reason it seems that addition of K fertilizers in the studied irrigated rice schemes is unlikely to bring any significant agronomic benefits or response from the paddy. There are other studies however, which reported a positive response of paddy to application of K. In China (Quampah *et al.*, 2011), application of K resulted in increased grain yields and water productivity to paddy. The authors however attributed this readiness of response to the highly weathered stage (kaolinitic phase) of the soils on which the experiments were laid.

Despite this uncertainty, another study (Bahmanyar and Mashaee, 2012) also reported a positive response of rice yields to K application. In Tanzania, K application at 50 kg K ha^{-1} enhanced yield and yield components of rice varieties under saturation soil moisture level and drought conditions. Grain yield was significantly and positively correlated with number of grains per panicle and proportion of fertile spikelets (Ndwasinde, 2013). It is worth noting however, that studies reporting a positive trend between K application and rice yields deliberately applied K as a treatment to the paddy, unlike our study which only considered inherent levels of exchangeable K in the soils against reported yields by farmers. For this reason more research will be required to generate more informed decisions.

When these schemes are considered in terms of the zones – Northern ($n = 5$), Eastern ($n = 6$), and Central ($n = 2$) – from where they originated, results showed that the three zones had comparable levels of exchangeable K. They had, however, significant differences in percent organic C ($p < 0.0024$), total N ($p < 0.0003$), soil pH ($p < 0.0112$), K:Mg ratio ($p < 0.0343$) and rice yields ($p < 0.0025$). Though the level of exchangeable K was comparable across the three zones, the significant ($p < 0.0343$) difference in K:Mg ratio is an area which needs to be addressed. A high K:Mg ratio implies there is a higher occurrence of exchangeable K to that of exchangeable Mg in the soil. High K:Mg ratios have been reported to induce severe Mg deficiency. Therefore, differences in K:Mg ratio across the studied zones deserves attention. For potential response of rice towards potash nutrition across Tanzania it can be concluded that the level of exchangeable K in rice growing schemes is beyond the critical level and therefore does not pose immediate risk to paddy production. This status however, may change in view of the adoption of rice hybrid varieties which extract more soil nutrients, including K.

Potassium in maize fields

For maize production, soil conditions and maize yields across different smallholder fields in Tanzania are shown in Table 3. Level of clay was highest in fields around Babati-Arusha (mean 56.1%; CV 27.4%) and lowest in Naliendele-Mtwara (mean 10.6%, CV 12.5%). The variation was probably caused by the parent material from which the soils of the two locations were formed. Babati is on an area whose soil parent material is derived from the Rift Valley formation and volcanism at an altitude varying from 1,635-2,200 m.a.s.l. (Kihara et al., 2014) while Naliendele is on a coastal plain (120 m.a.s.l.) with sandstone parent material which has weathered to form coarse textured Ferralic Arenosols soils (Majule, 2006). These two parent materials give rise to two different textured soils and could be the reason for the differences observed in the level of clay between the two locations.

Soil pH was highest in the Moshi-Kilimanjaro Agricultural Training Centre (KATC) area (mean 7.84; CV 3.8%) and lowest in Mahenge district, Lupiro village (mean 5.2; CV 8.7%). The KATC area is located on the plains of Mount Kilimanjaro where low level of precipitation and high temperatures have resulted in soil salinity problems and hence high soil pH (Vaje *et al*., 2000). On the other hand, the Lupiro area is located in the Kilombero Valley which is an area with more precipitation (Hamisi *et al*., 2012) and coarser textured soils (Table 3), hence leaching of soil nutrients in the area is probably the main reason for the significantly different pH levels in the soils from these areas.

Soil organic matter was highest in fields located around Soni-Lushoto area but lowest in and around Naliendele in Mtwara. The Soni area is a cooler and high altitude location at 1,200 m.a.s.l., while Naliendele is a hot and humid lowland (120 m.a.s.l.) coastal area with coarse textured soils. A study in the Soni-Lushoto area had already attributed accumulation of soil organic matter to the relatively low temperatures in the area which allowed organic matter to accumulate from reduced rates of oxidative processes (Wickama *et al*., 2014). Daily temperatures of locations are known to influence accumulation of organic matter in soils (Li *et al*., 2006) and this is probably the major reason why Naliendele has lower organic matter accumulation in its soils.

Table 3. Soil Conditions in selected maize growing areas in Tanzania.

Maize fields	Sampled locations	Clay	pH	Organic C	Av. P	K	Locations with K < critical level	Percent < critical level	Maize yields
Smallholders	n	%	(w)	%	(mg/kg)	(meq/100g)	n		tons/ha
Arusha rural	29	35.1	5.5	1.55	6.75	1.85	12	41.38	1.62
Soni-Lushoto	31	40	6.1	2.3	2.48	0.82	14	45.16	1.23
Babati	71	56	6.5	1.26	32.1	1.1	10	14.08	2.50
Muheza	9	47.7	6.2	1.11	6.04	0.52	3	33.33	1.48
KATC Moshi	31	31.4	7.8	0.81	2.92	1.24	0	0	1.42
Korogwe rural	47	38.2	6.6	1.29	10.9	2.03	3	6.38	1.56
Tabora rural	79	14.9	5.4	0.67	15	0.13	77	97.47	0.81
Lupiro-Mahenge	10	21.6	5.2	1.25	4.9	0.37	5	50	1.02
Singida rural	3	42	6.9	0.86	2.9	0.11	3	100	1.33
Dodoma rural	16	16.2	5.9	0.79	4.9	0.39	9	56.25	1.25
Kilosa rural	14	28.4	6.8	1.51	31.9	1.21	0	0	1.54
Naliendele-Mtwara	9	10.6	5.5	0.45	3.69	0.11	9	100	0.92
Ruvu village	2	42	5.4	0.87	0.33	0.27	2	100	1.20
Kilindi rural	30	27.7	6.6	1.77	18.7	0.98	2	6.67	1.65

The level of K in maize fields varied from 0.11 cmol K kg^{-1} soil in Singida rural and Mtwara (Naliendele) to 2.03 cmol K kg^{-1} soil in Korogwe rural. However, for maize fields, it is worth noting that proportion of locations with levels of K below the critical level was highest in Tabora, Singida and Mtwara and lowest in Moshi (KATC) and Kilosa (Table 2). Overall, there was a significant ($p < 0$) correlation between level of sand and remaining exchangeable K across the studied locations. These results represent a potential for K deficiency risk of 39% across maize fields. The correlation of maize yields to other variables across smallholder fields is presented in Table 4. Maize yields significantly ($p < 0.02$) correlated with the zone from which the maize was established; the proportion of clay in the fields ($p < 0$); available P ($p < 0.01$); exchangeable K ($p < 0.02$) and magnitude of area with K below critical levels.

Table 4. Correlation between maize yields and selected variables in smallholder maize fields, Tanzania.

Parameter	Pearson r-correlation	p-value (n= 381)
Clay (%)	0.71	0.00
pH (water)	0.46	0.10
K (meq/100g soil)	0.58	0.03
Available Phosphorus (mg/kg soil)	0.62	0.02
Organic Carbon (%)	0.36	0.21

These observations imply that unlike rice schemes, response to K application can be expected for maize. These observations are supported by earlier research reports from West and East Africa (Kumwenda *et al*., 1996; Tittonell *et al*., 2005) where application of K based fertilizers was observed to cause positive responses of maize yields.

When locations for irrigated rice schemes (n = 116) were compared with those from maize fields (n = 381), then significant differences between the two areas were also observed in their percent clay ($p < 0.0007$), sand ($p < 0$), soil pH ($p < 0$), and all exchangeable bases ($p < 0$). These observations imply there is less risk of rice schemes becoming deficient of nutrient bases compared to maize fields. This supports earlier reports that on a landscape scale, plant nutrients migrate from uplands to lowlands through erosion and floods (Abegaz and van Keulen, 2009). In our case, we suspect a net movement of nutrient materials from agricultural lands used for maize and other crops to rice cultivating areas through surface floods and soil erosion processes. This assumption seems logical if we consider and compare soil conditions in the Mombo Irrigation Scheme at

600 m.a.s.l. (Table 1) to those of smallholder fields in Soni-Lushoto area located on the West Usambara highlands at 1,200-1,400 m.a.s.l. (Table 2). Studies from the Soni area estimated soil losses from smallholder farmers to be in the range of 1-60 tons ha^{-1} depending on field management (Wickama *et al*., 2014). The hydrology pattern in the area is such that most products of soil erosion end up in the Mkuzu-Soni River which irrigates the Mombo Irrigation Scheme. Therefore, the natural enrichment of soil conditions in the Mombo Irrigation Scheme can only occur at the expense of eroded fields on the West Usambara highlands, particularly the Soni area.

Discussions

This study has shown that availability of exchangeable K in rice growing schemes across Tanzania does not pose immediate risk to K application in paddy production. What is at stake though, is to sustain soil quality in these schemes. In the studied rice schemes, problems of soil salinity are reported to be growing (Kashenge-Killenga *et al*., 2013). Further, as farmers are adopting superior rice hybrids then more pressure on extracting K from the fields can be expected. In China, although the adoption of high yielding hybrid rice varieties increased rice production, it also increased extraction of K from the soil to the point where new fertilizer recommendations had to be developed (Zhang *et al*., 2011). Further, though it is acknowledged that increased application of NP fertilizers in rice schemes has increased rice yields in Tanzania, and that in places like Kilimanjaro region rice yields have more than doubled to over 6 tons ha^{-1} following adoption of improved seeds and agronomic practices for rice (Kiishweko, 2013), their effect on K status has not been studied adequately. For this reason, the comfort period of adequate K levels in irrigated rice schemes across Tanzania may be short-lived. Results from maize fields, however, reflect potential risks of K deficiency across the country. Globally, maize fields are more at risk of K deficiency than rice fields. Maize grown on soils with K concentrations below 0.21 cmol per litre showed significant response in growth and grain yields to K fertilizer application (Heckman and Kamprath, 1992). For this reason, maize fields in places with widespread K deficient areas (Table 2) need critical K application efforts. Findings from this study indicate that priority areas for K fertilizer testing and utilization include Ruvu area in the Pangani river basin, the coastal plains of Mtwara region, Singida, Tabora and Dodoma regions, and Mahenge and Lushoto districts.

Conclusions

Despite limited availability of tests and experimentation, it is safe to conclude that there are no immediate dangers of K deficiency in most irrigated rice schemes across Tanzania. However, this will likely change in view of growing adoption of high yielding rice varieties and hybrids. Further, conditions of K adequacy in maize fields are less encouraging with nearly 40% of smallholder fields having K levels below critical levels. For this reason, fertilizer utilization efforts should consider application of K in fields planted with maize.

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10. The role of potash for sustainable crop production: The case of flue-cured tobacco

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Abstract

Most fertilizer research on tobacco in Tanzania has concentrated on the rates of nitrogen (N) fertilizers. Nitrogen was considered to be the most critical nutrient for tobacco production. Phosphorus (P) and potassium (K) were considered to only be needed to replenish amounts taken up by plants. However, recent research has shown K to be one of the major nutrients required by plants, including tobacco. These studies have shown that K deficiency leads to reduced yields and impaired growth. Tobacco is grown in areas that are mainly sandy in texture and of relatively low fertility, thus requiring large amounts of NPK fertilizers. Tobacco leaf yield and quality depends, among many other factors, on the nutrients taken up by the plant. Potassium improves fire holding (combustion) capacity of tobacco leaves. Other quality parameters include the content of nicotine and reducing sugars. Potassium plays a role in these quality parameters as a catalyst in many physiological processes. This paper gives a brief review of tobacco soils in relation to K, and the role of K in tobacco leaf yield and quality. Detailed macro and micronutrient studies are required to develop fertilizer technologies suitable to Tanzania's environment.

Keywords: potassium, flue-cured tobacco, tobacco soils, leaf yield, leaf quality.

Introduction

Tobacco research in Tanzania began in 1954 at Tabora when Tumbi Research Station was handed over to the British American Tobacco (BAT) company from Nyanza Cooperative Union. At that time the objective was to improve tobacco yield by testing new technologies developed elsewhere, mostly at Kutsaga Research Station in Zimbabwe where tobacco research was more advanced.

For many years tobacco research on fertilizers in Tanzania mainly concentrated on nitrogen (N) because it was considered to be the most critical nutrient for tobacco production. Phosphorus (P) and potassium (K) were considered to be needed only to replenish the amounts taken up by plants. In fact it was thought that soils had enough K for many crops, including tobacco. However, recent analysis of soils taken by the Association of Tanzania Tobacco Traders (ATTT) from the major tobacco growing areas of Tanzania showed that K levels were low to medium (Table 1).

Flue-cured tobacco is grown primarily on sandy and sandy loam soils. These soils are relatively low in inherent fertility, which means large quantities of fertilizers have to be used in the production of tobacco (Woltz, *et al.*, 1949). Similarly, soils in tobacco growing areas of Tabora have low nutrient levels and farmers need to apply large quantities of fertilizer to achieve high yields.

Importance of K to the growth of tobacco plants

Certain chemical constituents of cured tobacco leaf are known to influence its value for cigarette purposes. Two of these are reducing sugars and nicotine (Woltz, *et al.*, 1949). K and P play a key role in controlling sugar and alkaloid (nicotine) contents (Marchand, 2010). The role of K on leaf nicotine content is related to its function as a carrier in the absorption of nitrates.

Potassium is an element that plays a key role in plant development and reproduction. It is absolutely essential to plant growth and cannot be entirely replaced by any other element. Potassium has a specific and important role of catalyzing the synthesis of carbohydrates (starch, sugar and cellulose). Without K there would be no photosynthesis, and green plants could not exist in the absence of the simple carbon-containing foods (products of photosynthesis), from which all the organs of the plant largely are elaborated.

Potassium increases resistance to lodging and improves disease resistance, and is closely connected with the quality of the crop. Potassium is essential for the vigorous growth of the tobacco plants and is one of the nutrients required in large amounts (macronutrients). It is more important than any other element in producing good combustion of the dried leaf and choice aroma (Day, 1940). Therefore application of adequate amounts of K is necessary for profitable tobacco production (TORITA, 2012).

There is also considerable evidence that K has a catalytic function in the synthesis of proteins. Cell division (mitosis) does not occur in the absence of K. In addition to its specific function as a catalyst, K serves as a carrier in the absorption of nitrates and other anions through the root hairs and in their translocation throughout the plant. An adequate supply of K makes the tobacco plant more resistant to drought (Anderson *et al*., 1932).

Effects of K deficiency on tobacco plants

Nutrient deficiency or excess causes non-parasitic diseases or nutritional disorders. Their major symptoms are frequently observed as yellowing to different degrees on different plant parts. The major physiological functions disrupted by lack of K are the osmotic regulation of the plant and the ionic balance of cells (pH). This affects the opening of stomata and activation of many enzymes. Deficiency of K causes a decrease in layer thickness as well as disease and stress resistance (Blancard, 2013).

When K levels are not adequate the plant will develop cankers of dead tissue on the plant body, and the tips of the leaves will turn a brownish color. Chlorosis (often referred to as 'firing') is more or less marked at the leaf tips and sometimes at margins, accompanied by necrotic spots. With chlorosis the lower leaves are curved towards the underside of lamina surface (Blancard, 2013).

Potassium deficiency is common worldwide and leads to crop growth inhibition and output reduction (Lu *et al.*, 2015). Deficiency of K and N causes yield loss and reduction of leaf quality. Furthermore both P and K play a key role in controlling important quality parameters such as leaf color, texture, hygroscopic properties and combustibility, sugar and alkaloid contents (Marchand, 2010). Therefore deficiency of these nutrients leads to reduction in yield and quality of tobacco leaves.

Potassium content in tobacco growing soils

Like many crops, tobacco needs various minerals for growth and formation of good quality leaves. Its growth and fertilization is quite complex because it is particularly affected by the amount and balance of soil nutrients, type of tobacco grown, the variety chosen, planting density and environmental factors such as rainfall amount, intensity and distribution.

It has long been assumed that K occurs in sufficient quantities in the soils of Tanzania. However, literature shows that soils vary in their supply of available K, depending upon the parent material, previous fertilization, and cropping history. Sub soils in tobacco fields may contain substantial amounts of K and other leachable nutrients that are seldom measured by soil tests because only top soils are usually sampled. When considering what an appropriate K rate is for a specific field, the residual soil K content, soil texture, and depth to clay layer should be considered (North Carolina State University, 2014).

Table 1 and Table 2 present levels of K from sites growing flue-cured tobacco. The levels of extractable K in most soils in the flue-cured tobacco growing areas of Tanzania are low to medium (according to Sokoine University of Agriculture guidelines of soil fertility rating).

Table 1. Number of soil samples in relation to K levels of some sites growing flue-cured tobacco.

Area	Very low	Low	Medium	High	Very high
Kahama	0	3	92	15	0
Tabora South	1	11	40	3	1
Tabora	0	38	84	15	0
Urambo	3	22	88	6	0
Chunya	0	3	27	1	0
Mpanda	0	12	21	0	1
Total	4	89	352	40	2
Contribution (%)	0.82	18.28	72.28	8.21	0.41

Source: Shenkalwa *et al*. (1997), unpublished

Table 2. Percent coverage of soils in relation to levels of K content.

Area	Very low	Low	Medium	High	Very high
Kahama	0	2.7	83.6	13.6	0
Tabora South	1.8	19.6	71.4	5.4	1.8
Tabora	0	27.7	61.3	10.9	0
Urambo	2.5	18.5	73.9	5.0	0
Chunya	0	9.7	87.1	3.2	0
Mpanda	0	35.3	61.8	0	2.9
Mean	0.7	18.9	73.2	6.4	0.8

Source: Shenkalwa *et al.* (1997), unpublished

At Agricultural Research Institute (ARI) Tumbi, where the main tobacco research institute is located, tobacco is grown in two main soil types, locally known as Isenga and Kikungu types. Kikungu is the local name for Ferralic Cambisol, which is the major soil type in Tabora region. Kikungu soils are well drained and medium textured. Isenga soils are mainly Arenosols, which are sandy, well drained soils whose texture is sandy loam or coarser within 100 cm of the surface (Acres *et al.*, 1984). Table 3 presents the average nutrient contents of the top soils (0-30 cm) for the two soil types (Shenkalwa *et al.,* 1999, unpublished).

The differences in nutrient content between these two soils are not spectacular, but there is a considerable difference in the tobacco leaf yields from control plots (unfertilized plots) in the two soils (Table 3). The levels of N and K were very low where yields were lower (Isenga soil) and low where yields were slightly higher (Kikungu soil). As the difference in total N is almost negligible, it would be interesting to investigate whether exchangeable K had any contribution to the observed higher yield in Kikungu soil.

Potassium fertilizer trials on tobacco

To determine the effects of K on different tobacco parameters in a fertilizer trial, the levels of major nutrients would have to be kept constant so that only the K levels varied, but such a trial has not been carried out in Tanzania. Fertilizer trials for tobacco in Tanzania have always considered NPK compounds or mixtures of NPK. Potassium treatment variations therefore depended mostly on variations of N, which is still considered to be the most limiting nutrient in tobacco production. In such trials it is not possible to separate the individual effects of the different nutrients contained in the compound. Yield results from a trial to test different NPK formulations showed no evidence that reducing K content in the formulations affected yield in any way (TORITA, 2012).

It has been established experimentally that a good tobacco crop removes about 100.8 $kgha^{-1}$ as K_2O. Therefore application of the recommended rates of 90-110 kg K_2Oha^{-1} per growing cycle is necessary for optimum tobacco production (Shenkalwa *et al*., unpublished).

Table 3. Average nutrient content of the top 30 cm of Isenga and Kikungu soil types.

Soil type	Texture	Total N	Bray-1 P	K	Ca	Mg	Leaf yield
		%	mg/kg	cmol/kg	cmol/kg	cmol/kg	kg/ha
Isenga	Sandy Loam	0.10 Very low	4.5 Low	0.09 Very low	1.83 Low	0.33 Low	297
Kikungu	Sand Clay Loam	0.11 Low	3.5 Low	0.17 Low	1.96 Low	0.34 Low	408

Source: Shenkalwa *et al*. (1999), unpublished

Leaf nicotine and reducing sugars levels

The quality of tobacco leaves is judged by leaf blenders according to their nicotine content and the content of reducing sugars. The preferred nicotine content is 2%.

Nicotine concentration is closely correlated with the amount of N supplied, since N is 17.3% of the molecular weight of nicotine (Sabeti, *et al.*, 2013).

The role of K on leaf nicotine content is related to its function as a carrier in the absorption of nitrates. According to Bing (2013), the amount of nicotine in different parts of the tobacco plant can be reduced by the application of K fertilizer at different times of growth (Bing, 2013). Higher content of reducing sugars in flue-cured tobacco is undesirable as it imparts an acidic character to the smoke. Lower contents impart alkalinity to smoke due to high nitrogenous constituents (CTRI, 2015). The optimal value of reducing sugars is 22.09% (Butorac *et al.*, 2004).

Leaf grade indices also serve as a measure of leaf quality. In an on-farm trial at Mtanila in Chunya to compare two formulations (N:P:K 10:18:24 and N:P:K 12:20:20), there was an increase in the average grade index from $US 1.25-1.85 kg^{-1} for the formulation with reduced K but increased N and P contents (N:P:K 12:20:20) (TORITA, 2012). This shows that appropriate nutrient ratios for optimum leaf quality need to be determined.

Conclusions

Tanzania's environment in terms of soils and climate differs from many other countries where potash research on flue-cured tobacco has been undertaken. The behavior of different nutrients and the response of tobacco plants to the nutrients may therefore differ as well. It is evident that we need to undertake detailed studies on the role of K and other nutrients in tobacco production with respect to the Tanzanian environment. One particular aspect would be how to reduce the large amounts of chemical fertilizers used while maintaining high yield and quality levels.

Optimum proportions of different macro- and micro-nutrients in applied fertilizers for different soils and rainfall regimes need to be established, and must take current climate change trends into consideration.

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11. Trends of potassium levels in soils under sisal, maize, rice and cassava-based production systems in Tanzania

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Abstract

Potassium (K) is one of the essential nutrients removed from the soil by plants in large quantities and yet the nutrient is not replenished through application of fertilizers by most farmers in Tanzania. Levels of K were considered sufficient in most soils, but with continuous cultivation the nutrient is becoming deficient in some soils. This paper reviewed the trends of K levels in soils under sisal, maize, rice and cassava-based production systems with the objective of understanding the rate at which exchangeable K is depleted through cultivation, to come up with recommendations regarding the incorporation of potash containing fertilizers in cropping systems. Data were collected from research reports conducted at the National Soils Laboratory at Mlingano, journal papers, and unpublished reports from different sources. The results indicate that there are limited studies on sisal, maize, cassava and rice which have been carried out to monitor soil K changes with continuous cultivation in Tanzania. Under sisal plantations between 1959 and 1990, levels of K decreased from 0.4-0.1 cmol(+)kg^{-1} in Ferralsols, 0.5-0.3 cmol(+)kg^{-1} in Acrisols, 0.5-0.2 cmol(+)kg^{-1} in Leptosols, and 0.9-0.1 cmol(+)kg^{-1} in Phaeozems. Under maize production between 1981 and 1988 along the Mlingano catena, K decreased from 0.42-0.35 cmol(+)kg^{-1} in Ferralsols, 0.77-0.46 cmol(+)kg^{-1} in Luvisols, and 1.04-0.66 cmol(+)kg^{-1} in Ferralsol Luvisol intergrade. Under cassava-based cropping systems K decreased from high in 1999 to medium in 2010 on most farmers' fields. In upland rice K was low, whereas in irrigated schemes the levels ware adequate to high. Assessment of soils data analyzed at Mlingano National Soils Laboratory indicated low to very low K levels in most samples. It was concluded that potash-containing fertilizers need to be recommended for use in crop production to increase yields and quality, and avoid further depletion of the nutrient which would lead to low crop yields.

Keywords: potassium levels, soils, sisal maize, cassava, rice

Introduction

Sustainable soil productivity depends, among other factors, on adequate supplies of essential plant nutrients for crop establishments. Potassium (K) is among the major essential nutrients which is required in relatively large quantities. Maize varieties yielding 9.5 t ha^{-1} for example, take about 120 kg K_2O from the soil, whereas cassava yielding 30 t ha^{-1} of fresh tubers remove between 140-160 kg K_2O from the soil (IPI, 2001; IPI, 2010). Therefore, continuous cultivation removes large quantities of K from the soil which needs to be replenished by fertilizer application to avoid it becoming deficient (Howeler, 2002; IPI, 2010).

Potassium may be present in large quantities in soils without adverse effects on crops. Adequate levels of K in soils differ depending on the textural class. For example in clayey textured soil, exchangeable K below 0.4 cmol(+)kg^{-1} is low and above 1.2 cmol(+)kg^{-1} is high. The corresponding levels for loamy soils are 0.25 and 0.80cmol(+)kg^{-1}, whereas for sandy soils the levels are 0.10 and 0.40 cmol(+)kg^{-1}, respectively (Landon, 1991).

Most crops remove more K than any other nutrient (IPI, 2001), which is why it is important to manage crop residues to avoid further K depletion. Studies to compare K contents of fields under sisal cultivation with virgin land adjacent these fields, for example, showed that the percentage decrease in K was 75% on limestone in the coastal plains of Tanga and 89% on limestone in the coastal plains of Lindi (Kimaro *et al*., 1994). In these sisal estates K was being mined from the soils without replenishment through fertilization or returning residues to fields.

Several studies were conducted in Tanzania to assess soil fertility status, including K levels in research sites and on farmers' fields (Mowo *et al*., 1993; Semoka and Mnguu, 2000; Makoi and Ndakidemi, 2008; Shekiffu, 2011; Mbogoni *et al*., 2013). These studies reported adequate K levels for crop production for many soils. For example, Semoka and Mnguu (2000) assessed the fertility status of 10 important rice growing areas in Mbeya, Morogoro and Coast regions, and found that extractable K levels were high in all the sites, with nitrogen (N) and phosphorus (P) being the only constraint in rice production. Similarly, Makoi and Ndakidemi (2008) reported that exchangeable K levels in 22 traditional irrigation schemes in Mbulu district ranged from 0.2-7.9 cmol(+)kg^{-1}, with 95% of the sites having K values >0.4cmol(+)kg^{-1} and were rated as medium or high to very high K contents. On the other hand, Nyambilila *et al*. (2013) found that K levels in 13 rice growing villages in Eastern and Northern zones ranged from 0.15-4.90 cmol(+)kg^{-1}, whereas in 17 maize growing villages it ranged from 0.18-12.53 cmol(+)kg^{-1} out of which 26% of the sites had low K contents. Similarly, in several sisal estates in Tanzania levels of exchangeable K were reported to be low or very low (Van Kekem and Kimaro, 1986; Kimaro and Van Kekem, 1987; Mbogoni *et al*., 1989; and Ngaillo *et a1*., 1990).

Although some studies showed that levels of K were adequate in some sites, continued cultivation without application of K fertilizers could result different findings due to continued mining of soil K.

This paper reviewed the research work done to assess exchangeable K levels and their trends in selected soils under sisal, rice, maize and cassava-based production systems in Tanzania to come up with recommendations for incorporating potash containing fertilizers in cropping systems.

Materials and methods

A review of K levels in selected soils in Tanzania was carried out to understand how exchangeable K has been fluctuating with time. Data was collected from:

- Gray literature, specifically two field experiments conducted at Mlingano between 1981 and 1991.
- Data published in journals, books, site evaluation reports, proceedings and thesis.
- Data from Mlingano analytical soil laboratory records.

Field experiments

a) Soils under maize production systems: Long term experiments were conducted at Agricultural Research Institute (ARI) Mlingano in Tanga region between 1981 and 1988 (NSS, 1989b). The experiment was designed to investigate response of maize to the application of different levels of N fertilizer (sulfate of ammonia) and P fertilizer (triple superphosphate, TSP) and their effects on soil chemical properties. The experiments took place in Mlingano, specifically on three soil profiles: crest with Rhodic Ferralsols, mid slope with intergrades, and lower slope with Chomic Luvisols. The area is characterized by bimodal rainfall pattern with long rains from March to June and short rains between October and December. The experiments were conducted during long rains, and during short rains the plots were left fallow. Data were collected from the control plots which were not fertilized. Soils were sampled using an auger from 0-20 cm depth before planting maize each year at six points in a $5m^2$ plot size. Soil samples from four replications were thoroughly mixed before sub-sampled for laboratory analysis. Results of exchangeable K from the control plots are reported.

b) Soils under maize production systems: An agroforestry field experiment was conducted at ARI Mlingano between 1986 and 1991. The trial investigated the effects of intercropping maize with *Leucaena leucocephala* on maize grain yield and soil properties. The research was comprised of the *Leucaena* established at three spacing (3m x3m; 4m x 4m and 6m x 6m) in a plot size of 6m x 12m. Prunings from the trees were used as green manure for the maize crop on top of 50 kg N (applied as sulfate of ammonia) and 17.6 kg P ha^{-1} (applied as TSP). A monocrop maize treatment was included which received 50 kg N and 17.6 kg P ha^{-1} from the above sources. Soil was sampled at nine points before the maize was planted each season. Composite samples from four replications were analyzed for physical and chemical properties. Results of soil exchangeable K from the maize monocrop plots and that from *Leucaena* maize intercrop at spacing of 6m x 6m are presented.

Data published in different sources

a) Soils under sisal production: Soil fertility evaluations were carried out on several sisal estates in Tanga between 1959 and 1990. These estates were under continuous sisal cultivation without application of fertilizers for more than 25 years. Decline in sisal production necessitated the estates' management to request soil fertility evaluation. Most of the work was carried out by Mlingano researchers and some from other organizations. Top soil (0-20 cm) was sampled based on dominant soil groups (Hartemink, 1997). The levels of exchangeable K from the fertility evaluation studies are presented to indicate trends of K in sisal plantations resulting from continuous sisal cultivation.

b) Soils under cassava-based production systems: Collaborative Study of Cassava in Africa (COSCA) conducted research to assess fertility status of soils under cassava production systems in the Lake, Southern and Eastern zones of Tanzania (Asadu and Nweke, 1999). Top soil samples from the Eastern zone were collected in farmers' fields from 29 villages located in the Coast region and analyzed for physical and chemical properties. In 2010, other studies were conducted in the same production systems in 21 farmers' fields in the Coast region to assess soil fertility status and to determine optimum and economic P and K rates (Shekiffu, 2011). Top soil was sampled in the fields and analyzed for physical and chemical properties. Potassium contents in 1999 and 2010 are reported to show K trends.

c) Soils under upland rice production: A study was conducted in 14 upland rice fields in Korogwe and Muheza districts in Tanga region in 2014 to assess fertility status of these fields (Senkoro *et al*., 2014). In Muheza district the villages selected were Masimba and Kwemsala whereas in Korogwe district, Mnyuzi and Lusanga villages were selected. In each village, three to five representative upland rice fields were selected based on dominant soil types in the village, topography, cropping systems and crop management practices.

Soil samples from the top 0-20 cm were taken diagonally at representative points in each field and thoroughly mixed and sub-sampled for laboratory analysis. The K contents of these samples are reported to represent K status in upland rice fields.

Data from soil laboratory records

a) Soil from rice irrigation schemes: Soil analytical results from evaluations of soil fertility status in Mombo, Kitivo and Ruvu irrigation schemes have been reviewed. These samples were analyzed between 2010 and 2013. The exchangeable K of these samples was reported to represent the current status of the nutrient in irrigated rice fields.

b) Soils from different cropping systems in Tanzania: Soil analytical data of samples analyzed between 2013 and 2015 at the National Soils Laboratory in Mlingano were randomly picked to assess levels of K. A total of 319 samples were picked from different places in Tanzania for such an assessment. Samples originated from Makurunge in Bagamoyo district (40), Ngomeni in Muheza district (11), Ngara district (28), Karagwe district (4), Misenyi district (13), Bukoba district (8), Kagera River Basin (13), Kilombero district (32), Naliendele in Mtwara (35), Dodoma (14), Morogoro rural River Basin (23) and Lushoto district (23). The Kcontents of these samples were classified according to Landon (1991).

Results and discussions

Trends of K levels in selected soils under maize production systems

Results of soil exchangeable K from long-term N and P fertilizer experiments conducted at ARI Mlingano on three positions along the catena are presented in Figure 1. At the beginning of the experiment, the levels of exchangeable K were 0.42, 1.94 and 0.77 cmol(+)kg^{-1} for the Ferralsol, intergrade and Luvisol, respectively. These levels are above the critical value of 0.4 cmol(+)kg^{-1} above which response to application of K fertilizers is not likely. These sites were cleared from secondary bush hence exchangeable K was medium to high. After eight years of continuous maize cultivation without application of fertilizers, the levels of K decreased by 17%, 36% and 40% of the initial values for the Ferralsol, intergrade and Luvisol, respectively. The mean maize yields over the eight years were 615 kg ha^{-1}, 1,595 kg ha^{-1} and 3,400 kg ha^{-1}, respectively. Except for the Ferralsol at the crest position of the catena, results show that the levels of K in soils at the intergrade and Luvisol could support maize requirement without application of K fertilizer.

Figure 2 presents the trend of exchangeable K from soil sampled from the agroforestry experiment conducted at Mlingano on Rhodic Ferralsol. Throughout the six years of sampling, the exchangeable K values from the sole maize treatments were above the maize *Leucaena* intercrop treatment. The K values at the start of the experiment for both treatments were above the critical value of 0.4cmol(+)kg^{-1}, suggesting that application of K fertilizer was not necessary for optimum maize crop production. The levels of K decreased with the same pattern in both treatments, reaching levels below the critical value in the sixth season of cultivation. Similar declines in the levels of exchangeable K was reported after six years of maize cultivation on Ferralsol (NSS, 1989a). These results suggest that there is a need to apply K fertilizer if optimum maize production on such soil is intended. Addition of K in the soil from the *Leucaena* green manure was not enough to sustain the K requirement of the cropping system.

Trends of K levels in soils under sisal production systems

Figure 3 presents K levels resulting from research carried out tostudy the trends of soil fertility in four sisal estates in Tanga region (Hartemink, 1997). When the study was initiated, Ferralsols had an exchangeable K value of 0.40 cmol(+)kg^{-1} which is considered as a critical level below which the nutrient is considered deficient. Other soil types (Acrisol, Phaeozem and Leptosol) had exchangeable K values above the critical level, suggesting that the plantations could support sisal production without application of potash fertilizers. After between 21 and 28 years of sisal cultivation without application of potash fertilizers, the levels of exchangeable K had decreased between 40-89% of the initial sampling with all soil groups having very low values. Such declining trends call for interventions to increase these levels which does not currently occur. The most common practice is to harvest the leaves and not to add fertilizers or residues to the fields. This has resulted in K decline as reported in other sisal plantations in Tanzania (Van Kekem and Kimaro, 1986; Kimaro and Van Kekem, 1987; Mbogoni *et al*., 1989).

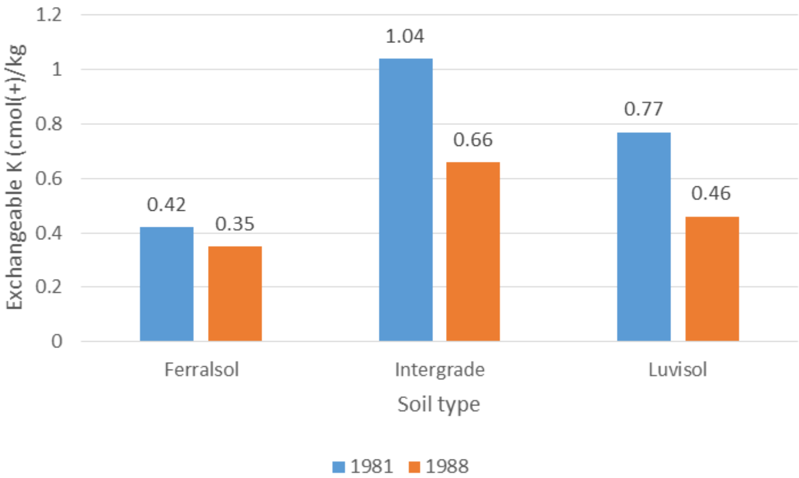

Fig. 1. Effect of eight years of maize cultivation on exchangeable K on Mlingano catena.

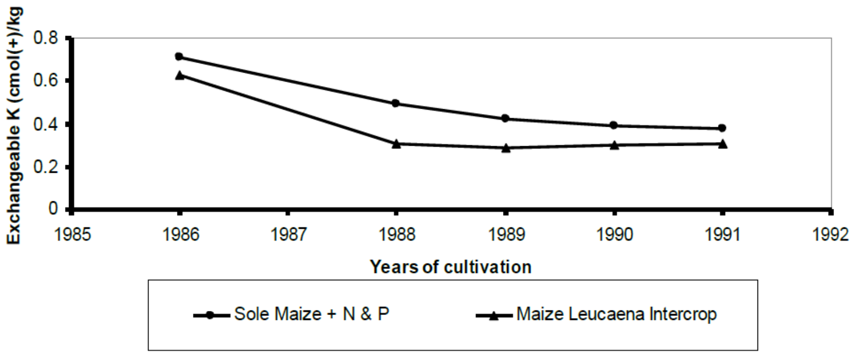

Fig. 2. Trend of exchangeable K from agro-forestry experiment on Rhodic Ferralsol.

Source: REFM (unpublished)

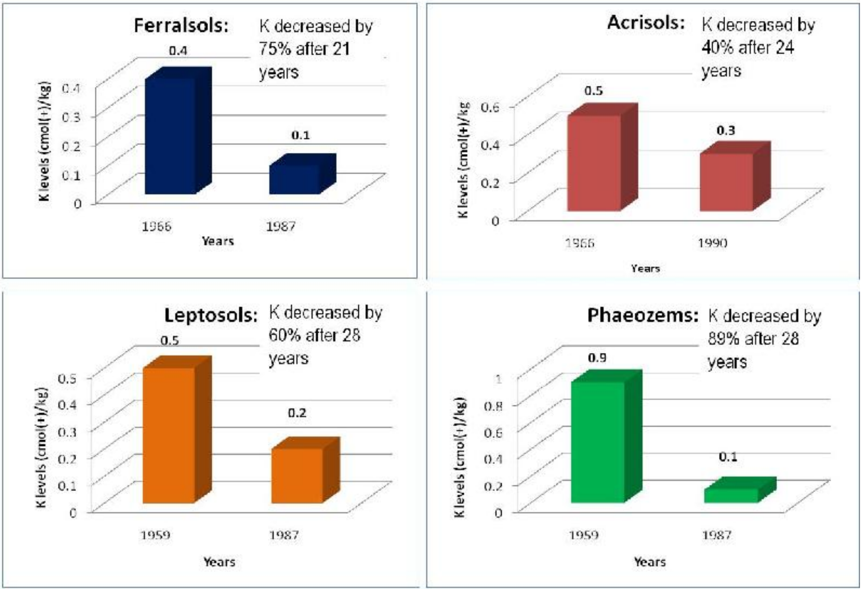

Fig. 3. Trend of K levels over years of cultivation on four soil groups in sisal estates in Tanga (*Source*: Hartemink, 1997).

Trends of K status in selected soils under cassava-based production systems

Figure 4 indicates the trend of exchangeable K status in selected soils under cassava-based production systems. In 1991, 28% of the study sites had low levels of exchangeable K whereas 72% had adequate levels. In 2010, out of 21 farmers' fields assessed, 33% had low levels of exchangeable K, and 67% had medium levels. None of the assessed fields had soils with adequate exchangeable K levels for the crops (cassava, maize and cowpea) grown.

These findings generally showed that soils under cassava-based production systems are gradually becoming depleted of K, and with time many fields may require regular inputs of potash to enhance and sustain cassava production. Currently, most farmers (97.5%) in the Coast region of Tanzania don't use fertilizers in cassava-based production systems (Shekiffu, 2011).

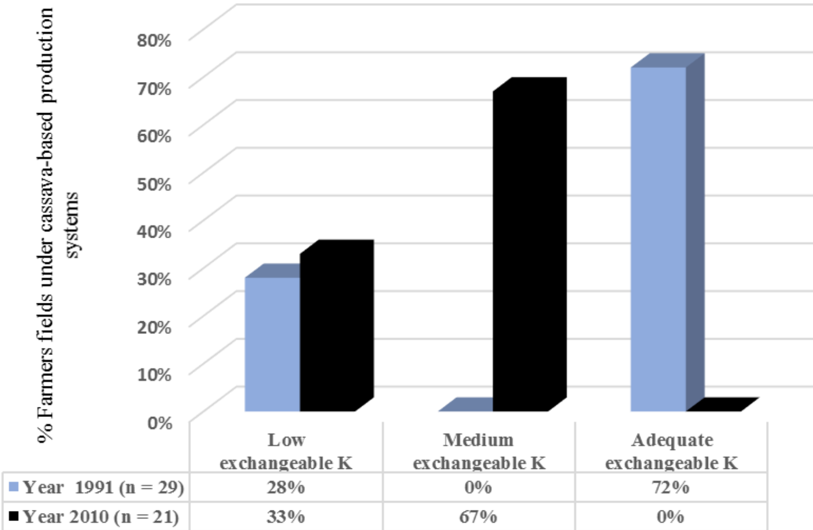

Fig. 4. Trends of K levels in farmers' fields under cassava-based production systems in the Coast region (*Source*: Shekiffu, 2011).

Soils under rice production

Figure 5 presents results of soil fertility with respect to exchangeable K in 14 farmers' fields in Korogwe and Muheza districts. Of these, 64% had low exchangeable K for upland rice production (Sanchez *et al*., 2003). In these fields symptoms of K deficiency have been observed which contributed to reduction in reported rice yields. Application of potash fertilizers is therefore necessary to increase and sustain rice production in upland rice production ecosystems.

The status of K in rice irrigated schemes is presented in Figure 6. Unlike upland rice, levels of exchangeable K were high in the three schemes assessed. This could be attributed to input of K by irrigation water. The levels of K could currently support rice production without addition of potash fertilizers. Adequate K levels in other irrigation schemes in Tanzania have also been reported (Semoka and Mnguu, 2000; Makoi and Ndakidemi, 2008).

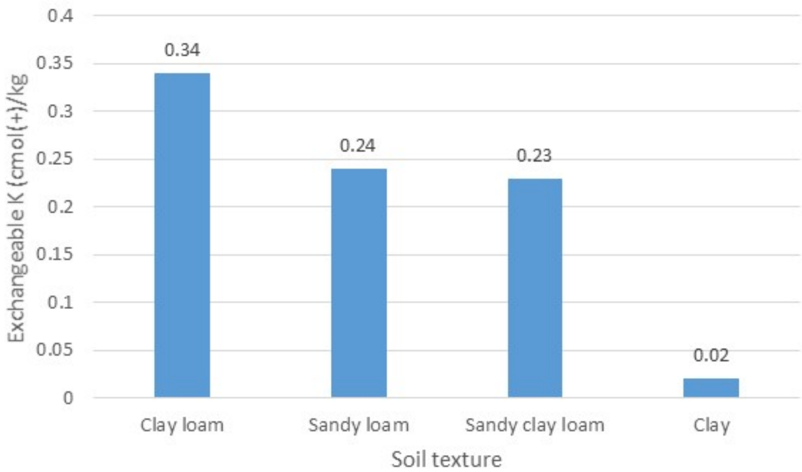

Fig. 5. Exchangeable K in soils of some villages in Tanga region.

Source: Senkoro *et al*., 2014

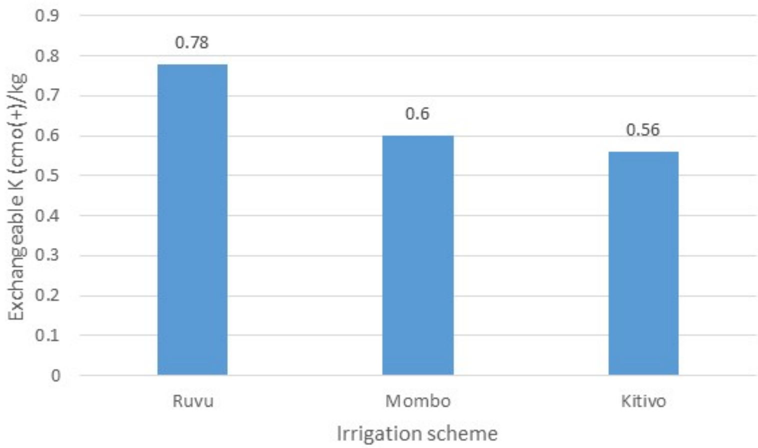

Fig. 6. Potassium levels in irrigation schemes in Tanzania.

Source: Mlingano, National Soils Laboratory, 2015

Data from soil laboratory records

Results of categorization of the 319 soil samples analyzed at Mlingano National Soils Laboratory (Figure 7) reveal that 40% of the soil samples have very low K content. The other categories of low, medium, high and very high have about 27%, 26%, 2% and 5% of K content, respectively.

These data are a clear indication that the level of K in Tanzania's soils has declined to the extent that use of potash fertilizers is inevitable if crop yields are to be optimized. The data also shows the clear indication of K deficiency as observed on various crops in farmers' fields.

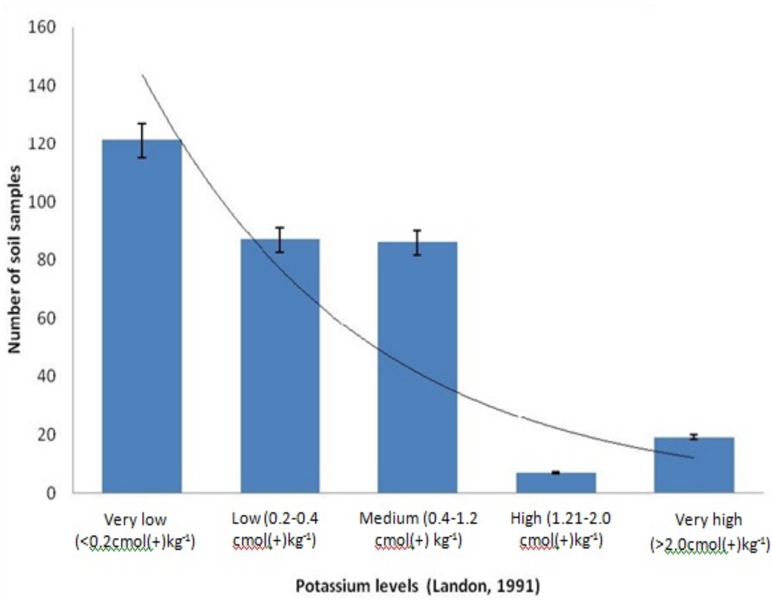

Fig. 7. Potassium levels in some Tanzanian soils.

Source: Mlingano, National Soils Laboratory, 2015

Conclusions and recommendations

Potassium fertilizers have not been included in fertilizer recommendations as soils had sufficient levels. Continuous K mining through cultivation has reduced K levels in some fields to the extent that potash containing fertilizers are required to increase and sustain quantity and quality of crop yields. It is therefore necessary to develop K recommendations for deficient soils and maintenance for soils with medium K levels. This should be considered together with regular monitoring of K trends in cultivated fields.

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12. The law of the minimum: Linking potash fertilizer utilization, farm level production productivity, and economic losses in Tanzania

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Abstract

In recent years utilization of in-organic fertilizers in Tanzania has more than doubled due to many factors including government subsidies through the National Input Voucher Scheme (NAIVS). However the increase is more pronounced on use of Urea, Di-Ammonium Phosphate (DAP) and Calcium Ammonium Nitrate (CAN) which accounts for more that 60% while Potash fertilizer through NPK and other compound fertilizers account for the rest. Using the "Law of Minimum", this paper analyse and model the missing opportunity for maximizing crop productivity and associated economic losses due dismal levels of Potash fertilizer utilization the country. The paper suggest for a strategic fertilizer blending programmes to increase use of potash utilization to avoid the trap evidenced by the Law of Minimum.

Keywords: Fertilizer, Potash, Crop productivity, Law of minimum, Tanzania

1. Introduction

Improving agricultural productivity and production in African smallholder agriculture is widely recognized as a critical outcome in the pathway to growth and poverty alleviation. Increased productivity, especially of major staple crops allows farmers to take advantage of growing market opportunities for these crops, while increasing household food and nutrition security.

Agriculture is the dominant sector in Tanzania’s economy similar to many developing countries. It employs 76% of Tanzanians with 88.2% of population living in rural areas (NBS, 2014). It is a source of food and nutritional security, accounting for 24% of GDP and about 30% of exports (URT, 2014). Agriculture sector is also related to other sectors as it is a source of raw material to industries and utilize industrial outputs, thus its growth can move the country out of poverty.

In Tanzania agriculture, it mostly dominated by crops, which accounts for more than 72% of the Agriculture Gross Domestic Product (AGDP)[1], followed by livestock (15%), hunting and forestry (8%) and fishing (6%). Hence any strategies to increase impact on poverty alleviation strategies should be focused on agriculture more so in crop production. A key ingredient to increased agricultural productivity and production is farmer access to inputs, particularly fertilizer and quality seed of superior varieties. The importance of enhancing smallholder farmers' access to fertilizer and the role this can play in raising productivity of Tanzania agriculture is highlighted in various policy and strategy documents such as the National Agricultural Policy (NAP, 2013), the Agricultural Sector Development Program (ASDP), the Kilimo Kwanza national declaration of 2009 and Big Result Now (BRN) initiatives of 2012

Despite the important role played by agriculture, the sector faces numerous challenges and constraints. The main constraints facing agriculture in Tanzania is low productivity coupled with declining soil fertility, weather uncertainty, poor application of production technologies and market problems (Kamuhabwa, 2014; Hella *et al*, 2015; and NBS, 2014). Poor productivity does not cope with food needs for population growth of 2.8% (NBS, 2014). In the last for years, Tanzania agricultural growth recorded 4.2% below Comprehensive African Agriculture Development Programme (CAADP) target of 6-7% annual growth of agricultural sector GDP. Thus yield increasing technologies such as improved production inputs linked with value added and functioning markets are inevitable in agriculture production especially when additional land for cultivation is becoming increasingly limited and climate change adversely affecting crop production.

Nevertheless, high cost of production inputs such as fertilizers limits smallholder farmers, mainly in low income bracket and marginalized groups, to apply required fertilizer rates to boost crop production. That's why the government intervention such as input subsidy provision to smallholder farmers was thought to be a rational approach to boosting agricultural productivity in the short run (Yawson *et al.*, 2010, Meertens, 2000). Studies in many places show that subsidy is linked to reduction.

[1]Food crops account for 65% of agriculture gross domestic product (AGDP) (NAP, 2013)

2. The problem and Theoretical framework

2.1 The problems

It is generally accepted that breakthrough in poverty alleviation strategies in sub-Saharan Africa in general and Tanzania in particular should be though agriculture since this is the sectors where majority of the poorest are employed. In attempt to decrease poverty, in early 2000, many African countries resumed fertilizer subsidy (Chibwana *et al.,* 2010, Danning *et al.,* 2009). The new system of subsidy was considered market "Smart" and concurrent with Abuja declaration (Wiggins and Brooks, 2010, Danning *et al*., 2009,). The need for subsidies was further intensified following the Abuja Declaration on African Green Revolution. The declaration African Union (AU) member states was as to rise fertilizer use to an average of 50kg/ha by 2015 (Yawson *et al.,* 2010) through elimination barriers on fertilizer access such as tariffs on fertilizers and fertilizer raw materials in order to increase food supply, reduce food insecurity and poverty levels. Further, the Comprehensive Africa Agriculture Development Programme (CAADP) pillar III called African Union countries to increase agriculture growth by 6% and increase government budget on agriculture by 10% (URT, 2012, Hella *et al.,* 2015) with emphasis on increasing fertilizer use as it is reported that, no region of the world has managed to increase agriculture growth and reduce hunger without increase in fertilizer use (NEPAD, 2009).

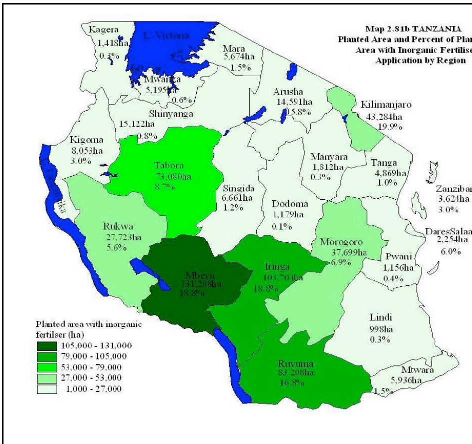
New subsidy scheme was considered to be "market smart" as it had specific targeting, measurable impacts, achievable goals, results orientation and timely duration of implementation (Aloice, 2015). The new scheme originated from Malawi as a small starter pack in 1998 revealing significant increase in fertilizer use and high crop productivity (Dorward and Chirwa, 2011). Tanzania and other African countries such as Nigeria, Zambia, Kenya, and Ghana adopted the initiative at different time.

However for Tanzania, the programme has not reached into the forethought expectations. Ten years post CAADP it recorded little progress in crop productivity compared to other study countries[2] (Hella *et al*., 2015). The average yields of major staple food crops such as maize and rice have changed little over the last 20 years. This reflects both the continuing expansion of planted area and the relative poverty of domestic farming systems. Estimates of input adoption rates vary across the country. According to the 2007/08 Census Survey of Agriculture, less than 8% of all smallholder farmers used improved seed, and less than 3% used inorganic fertilizer, when the NAIVS was initiated in 2002/03 growing season. Much of this utilization was concentrated in the southern

[2]Ethiopia, Rwanda, Burkina Faso, Ghana, Nigeria Sierra Leone, and Mali

highlands (Mbeya and Iringa) and northern highlands area (Kilimanjaro) where population densities and rainfall are higher (Figure 2).

In comparison, the 2008 National Panel Survey estimates that 20 percent of smallholder farmers used improved seed and roughly 12% used chemical fertilizer (National Bureau of Statistics, 2010. Tanzania National Panel Survey Report, Round 1, 2008-09). The average levels of use of chemical fertilizer were estimated to be only around 9 kilograms per hectare (kg/ha), compared with 27 kg/ha in Malawi and 365 kg/ha in Vietnam (Msambichaka *et al*., 2010). Correspondingly, average grain yields achieved by smallholders were only 20 to 30 percent of their potential (World Bank, 2009).



Intensity (%) of fertilizer use by regions

1) Mbeya 15% ★
2) Iringa 14% ★
3) Tabora 12%
4) Ruvuma 10% ★
5) Morogoro 8% ★
6) Rukwa 8% ★
7) Kigoma 6% ★
8) Kilimanjaro 6% ★
9) Arussha……4% ★
10) Manyara 3% ★

Account 85% of fertilizer used in Tanzania

★ **AFAP** target regions

(**72%** fertlizer used in Tanzania)

Statistics of top 10 regions in fertilizer use

Fig. 1. Intensity and statistics of fertilizer use in Tanzania.

Source: NBS (2012) and Hella (2015)

It is from this background that there has been an emergency of Non-State Actors (NSA) and Non-Governmental Organisations (NGOs) such as African Fertilizer Agribusiness Programme (AFAP) in Tanzania for the purpose of spearheading fertilizer use among many resources poor farms in remote areas in the country

2.2 Theoretical framework and the Law of minimum

2.2.1 Law of minimum and potash fertilizer use

The Law of minimum is based on historical aspects of plant nutrition by Liebig in 1840. The Law states that the crop on the field diminishes or increases extract proportion to the diminution or increase of the nutrient substances conveyed to it in manure (inorganic fertilizer). The law of minimum is explained in Figure 2 and Figure 3. Figure 2 entails that even though you apply optimal amounts of N, P or both. Deficiencies of all nutrients must be corrected to achieve maximum benefits of all nutrients.

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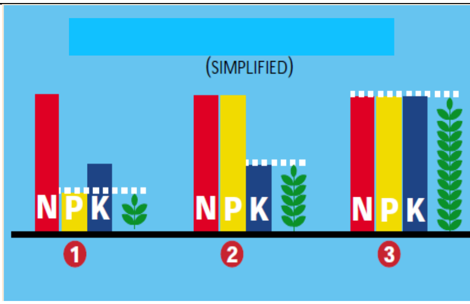

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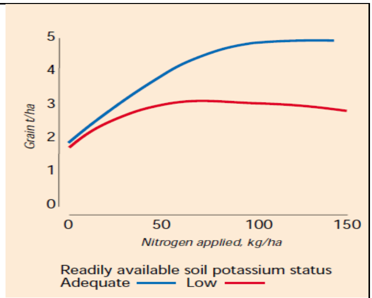

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<td>Figure 2a:</td>
<td>Figure 2b:</td>
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<td>Limited potash fertilizer application (1) & (2) would cause yield performance not beyond 50% despite the level of N & P nutrients used (2). Full yield potential can be attained only if P is also applied</td>
<td>-With too little available potassium is justifiable to apply only 50kg N/ha (diminishing return sets in)

-With adequate Potassium 100 kg N/ha give optimal yields</td>
</tr>
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Fig. 2. Influence of Potash fertilizer on yield depicting the law of the minimum

Source: Johnston (2003)

2.2.2 Economics of fertilizer use

The economics of fertilizer use in centred on the core objective of profit maximization. As indicated in equation (1) below, profit is the difference between total revenue and total cost (i.e. variable and fixed costs). In this analysis, short run time period is considered hence short run time period is considered hence only the variable costs will be taken into consideration. Also assuming all other variable costs except cost of fertilizer are held constant, the profit is explained by the difference between total revenue ($Q_y.P_y$) and cost of fertilizer ($P_x.Q_x$) (Equation 2)

- Profit (π) = Revenue – Cost …………………………………… (1)
- Profit (π) = $Q_y.P_y - P_x.Q_x$ ....…………………………….......... (2)

Taking equation 2 in consideration, revenue for the profit equation (2) can be expressed as a function fertilizer which supply three macro-nutrients viz: Nitrogen (N), Phosphorus (P) and Potassium (K) (equation 3)

- Quantity of output: Q_y. = f (N, P, K) …………..………………… (3)

Based on the Law of minimum, the yield levels (Qy) even id recommended rates of N and P are used. Non use of potash fertilizer has additional implications of the price of the produce (P_y) which is an important factor is price of the commodity through as outlined in equation (4) below

- Price of output: P_y = f (quality, colour, shelf life, appearance, less diseases) .... (4)

Furthermore, looking at the Law of minimum from fertilizer cost point of view while holding other production cost *ceteris peribus*, it entails that despite increased use of N and P fertilizers, in absence of K, yield response due to fertilizer use is low.

3. Methodology

3.1 Location of the study

This paper is based on data secondary data collected in Tanzania. The United Republic of Tanzania is largely an agriculture-based economy, accounting for more than a quarter of GDP (Figure 3) and remains an important contributor to economic growth (Figure 4). More than 73 percent of the population is rural and about two-thirds of the employed population works in the agricultural sector making this sector extremely important for poverty reduction and food security (Table 1.1). Although per capita income has grown continuously for the past 2 decades, the 2010 per capita income in Tanzania of 399 thousands TZS (473 constant 2000 USD) places it among world's poorest countries. According to the World Bank figures, almost 88 percent of the population lives on less than 2 dollars-a-day and almost 68 percent is estimated to live on less than 1.25 dollar-a-day, a level that defines extreme poverty. Further, about 39 percent of the population is estimated to be undernourished, i.e. living with chronic hunger.

Table 1. Agriculture and Poverty indices in Tanzania, 2011.

Agriculture, % GDP	27.1
Employment in agriculture (%)[a]	76.5
GDP per capita (constant 2000, 000 TZS)	399
GDP per capita (constant 2000 USD)	473
GDP per capita (PPP 2005 USD)	1334
Poverty headcount ratio - USD PPP 1.25 a day (% of population)[b]	67.9
Poverty headcount ratio - USD PPP 2 a day (% of population)[b]	87.9
Prevalence of undernourishment (% of population)[c]	38.8
Rural population (% of total population)	73.3
Population (million)	44.8

Notes: a. 2006 estimate; b. 2007 estimate; c. 2010-12 estimate.
Source: World Bank (2012)

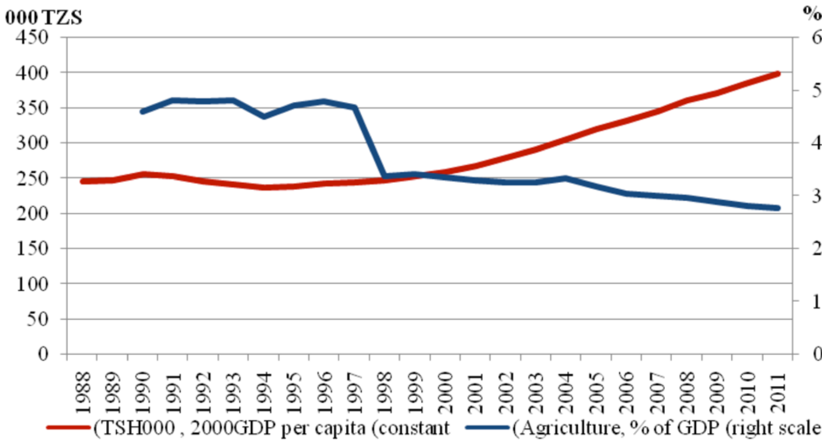

Fig. 3. Share of Agriculture in GDP and GDP per capita in Tanzania.

Source: World Bank (2012)

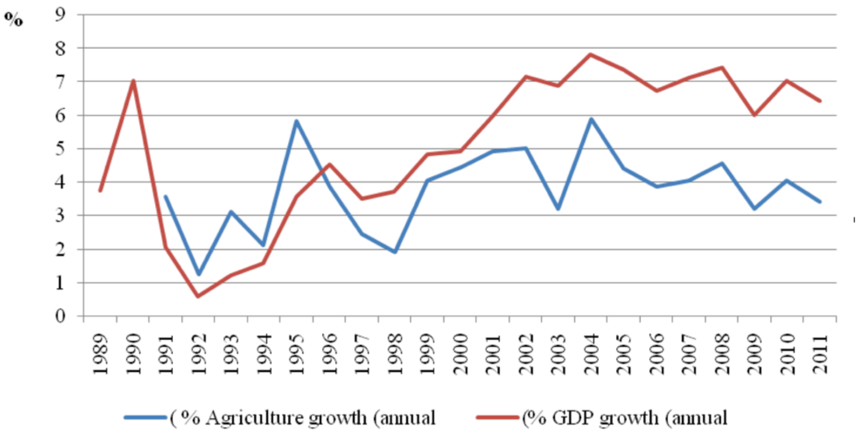

Fig. 4. Agriculture and GDP Growth Rates in Tanzania.

Source: World Bank (2012)

Agricultural growth has been only 1.5 percent higher than population growth (2.7 percent). Production of the major staple food crops (maize, rice, cassava, and beans) grew at an average rate of 3.5%, compared to 5.4 percent for cash crops.

Tanzania's agriculture is dominated by low productivity smallholder farms. Because agriculture in Tanzania depends almost entirely on rainfall, it is highly susceptible to climatic shocks, particularly in the semiarid areas of central and northern Tanzania. Farmers' yields are only 20–30 percent of potential yields (World Bank, 2009). Moreover, improved agricultural technologies have been adopted at extremely low rates in Tanzania. Figure 1.3 shows the percentage of farmers using fertilizer in Tanzania by districts. As shown in the figure, fertilizer utilization rate in Tanzania has generally been low. Between 2002 and 2003 less that 5 percent of farmers in approximately 50 percent of the districts in Tanzania used fertilizer. On average, Tanzanian farmers use approximately 9 kg/ha of fertilizer as compared to Malawi that uses 27 kg/ha, and Vietnam that uses 365 kg/ha (Msambichaka *et al*., 2010). This paper explores the use of Potash in Tanzania and tries to establish the linkage between economic gain/loses based on the famous Law of minimum.

3.2 Data type, sources and methods of analysis

Amount of fertiliser use and output level of major crops (mainly maize) were main type data for this study. Desk research, and key informant interviews work were the main data collection methods as discussed below. Desk review was the principal method used in collecting data for this report. Various reports from Agriculture sector lead Ministries (ASLM) especially those related to government sponsored input voucher schemes were reviewed. Other sources included reports from NGO (e.g. AFAP), government institutions (e.g. ARI Mlingano), fertilizer companies (YARA, TFA, & ETG) and crop bodies (e.g. Tobacco, sugarcane, and tea). Collected were analysed by using descriptive statistics (mean, variance, chi-square supported by figure and graphs).

4. Results and Discussion

4.1 Trend of fertilizer use by type and crops

There are different soil conditions obtaining around the country, a situation which dictates what crops can grow where and in the same manner this also influences whether and what fertilizers should be applied. The list of top ten fertilizer types used in Tanzania include

(i) **Urea:** Up to 120,000 Mt of urea are used annually. The product is of 46% Nitrogen.

(ii) **NPK- 10:18:24; 20:10:10 (tobacco NPK):** Consists of three Nitrogen, Phosphates and Potassium and is also used in different areas. An annual amount of 40,000 MT of NPK 10-18-24 on average is applied mostly by tobacco growers in Tabora, Mpanda, Chunya and Iringa. Around 20,000

MT of 20:10:10 are used by tobacco growers in Ruvuma but also by other crop growers.

(iii) **DAP (Di-Ammonium Phosphate)**:18% Nitrogen and 46% P_2O_5: This is the most commonly used fertilizer for basal application during planting. These are used mainly in areas where soils are deficient in Phosphorus, especially in the Southern Highlands of Iringa, Njombe, Mbeya, Rukwa, Katavi and parts of Kigoma, Kilimanjaro and Arusha. The annual consumption is estimated at 50,000 MT.

(iv) **CAN (Calcium Ammonium Nitrate)**: 26-27% Nitrogen. Annual consumption is around 40,000 MT.

(v) **SA (Sulphate of Ammonia):** 21%Nitrogen. Used extensively for top dressing, especially in Ruvuma region whereby around 10,000 MT are used annually.

(vi) **Minjingu Rock Phosphate**: (MRP) 28 - 30% P_2O_5, Produced locally at Minjingu factory near Arusha. Annual consumption is estimated to be around 20,000 MT and has increased substantially in recent years due to government subsidy.

(vii) **NPK 25: 5: 5 + 5S:** Mainly used in the tea production with annual consumption at 2000 – 3000MT

(viii) **TSP (Triple Super Phosphate**): 46% P_2O_5 - Annual consumption is around 3,000 MT.

(ix) **NPK 17:17:17** Used in sugarcane growing and annual consumption is estimated at 1,000mt other types in very small quantities.

(x) **Others nutrients –** Negligible.

From the list of fertilizers indicated above, it is obvious that use of potash fertilizer is very small. Nitrogenous fertilizers and Phosphates are used in most areas of the country for food crop growing such as maize, rice and other cereals. NPK 10-18-24 is applied mostly by tobacco growers in Tabora, Mpanda, Chunya and Iringa districts while for NPK 20-10-10 an annual amount of 20,000 MT is used by tobacco growers in Ruvuma but also by other crop growers like coffee. NPK 25:5:5+5S is mainly used in the Tea crop growing. Analysis of fertilizers used as subsidies through the input voucher schemes (NAIVS) programme to smallholders maize and rice growers show similar pattern.

According to realizable sources, the main objective of the program is to improve farmers' access to critical agricultural inputs (fertilizer and improved seeds) for maize and rice production, and it has been implemented by the Ministry of Agriculture, Food Security and Cooperatives (MAFC) to provide input vouchers to a total of 2.5 million maize and rice farmers until now. Each eligible farmer receives vouchers for a maximum of three years. Beneficiaries obtain an "input package" consisting of three vouchers[3]: one voucher for a N or nitrogenous fertilizer (1 bag of urea); one voucher for a P or phosphate fertilizer (1 bag of di-ammonium phosphate (DAP), option 1, or 2 bags of Mussoorie Rock Phosphate (MRP), option 2) with nitrogen supplement depending on farmers' choice); and one seed voucher (10 kg hybrid/open pollinated variety (OPV) maize or 16 kilograms of a rice variety) providing inputs for an average of 0.5 hectare of maize/rice cropped area (Table 2).

Table 2. Input packages for maize and rice (for 0.5 ha).

Crops		N source	P source	Seeds
Maize farmer	(Option 1)	1 bag of Urea	1 bag of DAP	10 kg (OPV or hybrid seeds)
	(Option 2)	1 bag of Urea	2 bags of MRP + 10N	10 kg (OPV or hybrid seeds)
Rice farmer	(Option 1)	1 bag of Urea	1 bag of DAP	16 kg OPV seeds
	(Option 2)	Bag of Urea	2 bags of MRP + 10N	16 kg OPV seeds

Source: World Bank (2014)

4.2 Trend of crop yield in Tanzania

In order to understand the influence of fertilizers on crop production, we are presenting yield of two main staple crops in Tanzania, *viz* maize and rice which are also covered by NAIVS. Maize is considered the most important food crop in Tanzania covering 45 %of total arable land and generating close to 50% of rural cash income, an average of 100 USD per maize producing household in 2008 (USAID, 2010). Rice is the third most important food and cash crop after maize; and it's among the major sources of employment, and income for many farming households. According to the Agricultural census of 2004, 17% of all agricultural households grow rice. Rice production in Tanzania covers approximately 681,000 ha, representing 18% of cultivated land. Almost all rice (99%) is grown by smallholder farmers using traditional seed varieties.

[3]Seeds package would cover 0.5 hectare (100 percent) and 0.25 hectare (50 percent) for maize and paddy respectively.

The overall trends in maize as well as paddy production and productivity for the past three decades from 1981/82 to 2009/10 in the NAIVS program area are increasing over time despite the fact that its productivity over the period shows a declining trend. While maize recorded 1.1 million metric tons in 1981/82 and 2.2 million metric tons in 1995/96, a total of 3 million metric tons were produced in 2009/2010. On the other hand, maize productivity was 1.1 tons per ha in 1981/82 and 1.8 metric tons per ha in 1995/96, while in 2009/10 productivity declined to 1.5 metric tons per ha.

For paddy, both production and productivity over the period have been increasing. In 1981/82, 145200 metric tons were produced in the NAIVS project regions with productivity at 1.6 metric tons per ha. In 2009/10 production of paddy was 1.6 million metric tons in the project regions with productivity at 2.4 metric tons per ha. In terms of quantity produced maize has been far better compared to paddy, while in terms of productivity paddy performs slightly better in comparison to maize. This trend in production and particularly productivity of maize and paddy can be explained by the fact that over time paddy becomes a more attractive crop to farmers due to its higher prices in the market compared to maize. In addition, the government has developed a number of projects to promote paddy production through irrigation in the country (Figure 5), which also leads to the good performance of paddy compared to maize which depends mainly on rainfall.

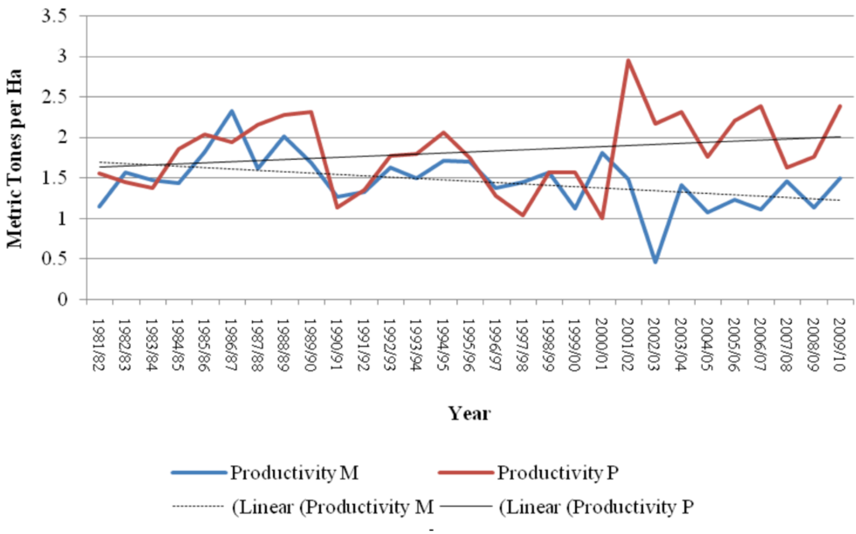

Fig. 5. Productivities of main food staples (maize & rice) in Tanzania.

Source: Constructed using data from MAFC – Agricultural Input Section

As observed in Figure 5, despite investing much in fertilizer use through input voucher scheme programme, productivity of main staples in particular maize (M) show negative linear productivity, denoting declining trend. Many reasons can explain this strange behavior including rainfall variability and other biotic factors such as pests and diseases, but minimum or limited use of Potash fertilizer as depicted by the Law of minimum in Figure 2 cannot be ruled out. The Law requires optimal use of Potash fertilizer for realizing the responses of the use of other fertilizer nutrients such as Nitrogen and Phosphorus.

4.3 Added advantage of potash fertilizer on crop quality

Despite the limited use in Tanzania, Potash fertilizer is used by farmers all over the world due to its unique advantages. It keeps plants healthy by allowing nutrients and sugars to move throughout the plant, helping to keep it stress and disease free. Potash fertilizer is therefore an essential ingredient for producing good crops of vegetables and beautiful flowers. Good quality crop is an important ingredient for price it fetches as the market and hence high profit to the farmers (see derivation in section 2.2.2 above). Using a potash fertilizer helps to increase the use of other nutrients in the plant and promotes root growth. It also helps to cope with drought situations and increases the plant's ability to survive in frosty conditions. This is an important attribute especially in recent years where vagaries of weather caused by climate change have increased in Tanzania (See Figure 6). In agriculture potash fertilizers among other things, help grains and fruits to increase the protein oil and vitamin C in their harvest, and gives food a better color and flavor. It retains its nutritional value for longer period when packed for storage or travelling purposes thus increased shelf life.

(a) Maize crop failure due to drought

(b) Paddy crop seriously attacked by white flies

Fig. 6. Cost for not using Potash fertilizer on major staple in Tanzania.

For a gardener potash is an important ingredient for fighting disease and resisting pests, making plants grow faster and healthier, making plants will produce better flowers, and vegetables. In monetary value, these benefits associated with potash add revenue to the producers through increased price of the produce or decreased cost of inputs such as pesticides.

4.4 Cost implication of limited use of potash on cost due poor response of other fertilizers on crop yield

Cost implication for limited use of Potash fertilizer in Tanzania is huge. As mentioned above, the value of Potash fertilizer on increasing the efficiency of other fertilizers (Nitrogenous & Phosphate) as elaborated in the law of minimum is cost to the producers. First major const is that of using fertilizer without realizing the required level of output. Based on the law of minimum, even when you apply optimal level N and P without K, farmers can realize only 50% of the expected yield. This situation suggests that we in Tanzania incur costs for realized low levels of outputs. For example in 2011/2 reason, the government of Tanzania used 81.2 Tsh to 1,658,888 households as subsidies vouchers for purchasing Phosphorus and Nitrogenous fertilizers (Table 3). The subsequent impact on yield based on the Law of minimum is low (50%) because Potash fertilizer is not used.

Table 3. Number of vouchers distributed to regions in 2011/12 crop season.

Regions	Number of households	Phosphorus Fertilizer		Nitrogenous fertilizer		Total Cost (Tsh '000)
		No of Voucher	Total Cost/ Value (Tsh '000)	No of Voucher	Total Cost/ Value (Tsh '000)	
Iringa	231,000	231,000	6,468,000.0	231,000	4,273,500.0	10,741,500.0
Mbeya	300,000	300,000	8,400,000.0	300,000	6,000,000.0	14,400,000.0
Ruvuma	192,469	192,469	5,389,132.0	192,469	3,849,380.0	9,238,512.0
Rukwa	146,000	146,000	4,380,000.0	146,000	3,212,000.0	7,592,000.0
Morogoro	177,541	177,541	4,971,148.0	177,541	3,284,508.5	8,255,656.5
Kigoma	160,000	160,000	4,800,000.0	160,000	3,520,000.0	8,320,000.0
Dodoma	24,776	24,776	693,728.0	24,776	458,356.0	1,152,084.0
Lindi	21,197	21,197	593,516.0	21,197	392,144.5	985,660.5
Tanga	47,292	47,292	1,324,176.0	47,292	874,902.0	2,199,078.0
Tabora	60,138	60,138	1,804,140.0	60,138	1,323,036.0	3,127,176.0
Shinyanga	53,192	53,192	1,595,760.0	53,192	1,170,224.0	2,765,984.0
Mwanza	54,201	54,201	1,626,030.0	54,201	1,192,422.0	2,818,452.0
Kagera	53,192	53,192	1,595,760.0	53,192	1,170,224.0	2,765,984.0
Mara	63,596	63,596	1,907,880.0	63,596	1,399,112.0	3,306,992.0
Kilimanjaro	74,289	74,289	2,080,092.0	74,289	1,485,780.0	3,565,872.0
TOTAL	1,658,883	1,658,883	47,629,362.0	1,658,883	33,605,589.0	81,234,951.0

Source: World Bank (2014)

Another indirect cost related to not using Potash fertilizer in production in Tanzania the fact that our crops become very prone to diseases, pests and succumbing to drought. For example, in the Table 3 above, Tshs 81.2 billion used as subsidies for nitrogenous and phosphate fertilizers. However since Potash fertilizer was not used it is very likely that farmers who were recipients of input vouchers incurred extra costs for inputs for buying pesticides and fungicides cause by increased incidences of pests and diseases for not using potash fertilizer. Other cost associated with crop failure due to droughts is related to decline in yield which has direct impact on revenue from crops. Putting in a better way, a functional relationship which exists between cost and yield (revenue) is not linear mainly because of limited use of potash fertilizer.

As mentioned earlier, the role of Potash fertilizer on improving the quality of the produce which has direct impact on price, then revenue and hence profit is affected. Linking to the huge cost in Table 3 above, definitely there are several other costs which farmers incur for not using potash fertilizer.

5. Conclusions and Recommendations

The main objective of this paper is to explain how the limited use of potash fertilizer has huge limitation of efficient use of other fertilizer. The fact is very small amount of Potash fertilizer is used for staple crop production in Tanzania. Potash fertilizer is common in tea and tobacco production. Based on the law of minimum, it is evident that even with optimal use of both Nitrogenous and Phosphorus fertilizers, yield potential cannot surpass 50%. Hence the country is incurring double cost, first is that of applying fertilizers (Nitrogen & Phosphorus) which is not translated to optimal yield. Secondly the cost of crop protection due to declining ability of the plants to tolerate vagaries of nature associated to limited use of Potash fertilizer. The importance Potash fertilizer in increasing the quality of the produce which is associated with high price, increased revenue and hence profit to farmers. Unfortunately very few farmers and policy makers know the value of Potash fertilizer in crop production and the associated Law of minimum.

This paper conclude that in a situation of increased cost of production, declining productivity and climate change which has increased incidences of crop failure due to drought, build up pest and disease incidences, use of potash fertilizers is imperative. The government through local authorities should promote use of Potash fertilizer hand in hand with nitrogenous and phosphorus fertilizers. Directives for the purposeful fertilizer blending to include potash fertilizer should be taken communicated to fertilizer companies throughout the country.

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13. African Fertilizer and Agribusiness Partnership (AFAP)

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Background

The African Fertilizer and Agribusiness Partnership (AFAP) is an independent non-profit organization created by a partnership of African development organizations. It builds on the work of the Comprehensive Africa Agriculture Development Programme (CAADP), a framework for achieving ambitious agricultural development goals set in place by African nations and leaders. CAADP was founded in 2003 as part of the New Partnership for Africa's Development (NEPAD). Its purpose was to eliminate hunger and reduce poverty by growing the agricultural sector in Africa.

The CAADP approach places African leadership at the forefront of efforts undertaken by national governments, civil society and development partners. It has become a new model of country-led development that has influenced how donors provide assistance to the African agriculture sector. Among the CAADP priorities is a call for increased use of agricultural inputs, including fertilizers. AFAP sees its work as contribution to CAADP's aim of bolstering fertilizer markets and engaging the private sector in realizing goals set by African leaders.

So far, the Alliance for a Green Revolution in Africa (AGRA) has committed to providing AFAP US$25 million to establish a regional fertilizer and agribusiness development unit, coordinate with partners, and begin direct financial, technical and managerial support to the fertilizer industry in Ghana, Mozambique, and Tanzania. But AFAP is seeking additional support so it can expand its operations, bringing the power of public private partnerships to smallholder farmers Africa.

AFAP was founded to bolster the markets that provided inputs to smallholder farmers and contribute to an African Green Revolution. The independent non-profit works to establish more competitive and sustainable fertilizer markets. But rather than rely on traditional development paradigms, AFAP believes that a united public and private sector can strengthen the marketplace and encourage consistent and responsible fertilizer use.

AFAP unites the expertize and dedication of the public and private sectors to increase agricultural production, reduce food security and support African smallholder farmers. Using an innovative partnership contract, AFAP joins industry and development interest to inspire productivity and prosperity in Africa.

Therefore the goals of AFAP are to increase the number of fertilizer users by 15% and at least double total fertilizer use in the countries where AFAP works. To achieve these goals AFAP works to:

- Introduce new fertilizer suppliers to new markets and provide expansion assistance to those already in business in the countries where AFAP works.
- Add new or improved blending or granulating plants in each country where AFAP works.
- Increase the number of metric tons of capacity available for fertilizer warehousing.
- Develop new and improved retail and cooperative storage facilities that can bolster the number of metric tons of fertilizer storage available.

Organizations that contributed to founding AFAP include:

- NEPAD
- AGRA
- International Fertilizer Development Centre (IFDC)
- African Development Bank (AfDB)
- Agricultural Market Development Trust (AGMARK)

Uniting public and private for sustainable fertilizer markets

To accomplish its goals, AFAP offers private agribusinesses incentives and assistance as they invest in Africa's emerging fertilizer markets. In return for this assistance, private agribusinesses commit to making substantial development contributions that will benefit company bottom lines and African farming communities. AFAP also connects entrepreneurs and business leaders with development organizations that have proven track records in providing African smallholder farmers with the incentive, initiative and capability to source and use fertilizers.

Agribusiness contribution could include making infrastructure improvements, bolstering local farm cooperatives, providing technical assistance to agro-dealer associations or offering trade credit to local retailers.

Agribusiness partnership contracts

The mechanism that allows AFAP to unite the expertize and the public and private sectors is the Agribusiness Partnership Contract (APC). The APC is available to eligible international, regional and local agribusinesses that want financial, technical and logistical assistance as they make inroads into emerging African markets. The contracts are structured to be flexible while providing benefits to businesses and communities.

An APC is an agreement between an agribusiness and AFAP that provides AFAP assistance in return for substantive market development contributions that further the goal of boosting responsible fertilizer use and availability to smallholder farmers in Africa. AFAP assistance can come in the form of credit guarantees or, in limited instances, matching grants. Assistance may also include technical consultations, logistical assistance and training.

APC's are devised to be flexible, allowing AFAP leadership to respond to the changing needs of a region, market, or business. AFAP can creatively offer monetary, technical or logistical support depending on the situation. In particular, AFAP seeks to provide:

- Guarantees to fertilizer distribution for credit to retailers.
- Financing assistance for importers and blenders interested in entering or growing business in an African market.
- Guarantees to new or growing blenders interested building or expanding a facility.
- Financing assistance for fertilizer storage and distribution.
- Technical, logistical and marketing support.
- Training and organizing of local entrepreneurs and farmers.

In return for assistance, AFAP requires participating agribusiness to:

- Engage in development efforts that will increase access, affordability and sustainable use of fertilizer to smallholder farmers.
- Provide contributions to the lives and communities of smallholder farmers and the markets in which they operate above and beyond the services the company offers in its regular course of business.
- Offer a long-term commitment to develop market infrastructure or capacity that bolsters sustainable fertilizer use.

How to apply

The APC application process has two phases. In the first phase, AFAP asks organizations to supply an initial concept note. This is a note that requests assistance for a project that supports AFAP goals. AFAP staff offer guidance to applicants drafting the concept notes. In the second phase AFAP reviews the concept note. If it is approved, AFAP will ask the applicants to submit an official application for funding. The applicant will be asked to supply a detailed final proposal. The information required for this proposal will depend on the complexity and breadth of the project proposed. There are specific requirements but all proposals must include:

- A business plan detailing the cost of the project.
- Detailed of how the money will be spent.
- Applicant's contributions to the project.
- Length of the project.
- Description of the applicant's business including its management and key staff.

AFAP's investment committee sets the condition for APCs including a schedule of payments linked to performance. It also recommends strategies, policies, and priorities for projects and oversees monitoring and evaluation systems. Though it maintains strict oversight, AFAP encourages risk taking. As a result, APCs have been developed to provide flexibility in how the contract is negotiated and executed.

Eligibility

International, regional and local agribusinesses that can:

- Demonstrate that their project will boost access, affordability and usage of fertilizer to smallholder farmers.
- Create projects that will reduce constraints to fertilizer supply and demand.
- Contribute to the lives and communities of smallholder farmers and markets in which they operate.

AFAP is currently seeking innovative and ambitious proposal for bolstering fertilizer availability and responsible use in Africa. To discuss submitting a concept note for AFAP review, please contact Cecilia Khupe, AFAP's director of programs, at info@afap-partnership.org.

Annexes

Annex 1. Way forward/deliberations from the First National Potash Symposium

Issues identified by groups	Research/development activities required	Key players
Output 1: Current status of potassium (K) in Tanzanian soils is established by December 2016		
Research problem 1.1 There is K deficiency in some Tanzanian soils 1.2 Extent and magnitude of K deficiency in soils and crops in Tanzania is not adequately understood	Conduct a diagnostic survey (including a literature review) to establish current K status in soils and crops in selected areas of Tanzania. Analyze available soil samples. Identify research and knowledge gaps with respect to K status in Tanzania. Produce maps which show status of K distribution and hot spots for K deficiency in Tanzania.	Agricultural Research Institute (ARI) Mlingano in collaboration with Sokoine University of Agriculture (SUA), other ARIs and districts councils.
Output 2: K-based fertilizer recommendations for selected crops developed for dissemination by December 2019		
Research problem 2.1 K-based fertilizer recommendations for many crops are not available	Review current knowledge on K fertilizer recommendations for crops in Tanzania. Identify priority crops and geographical areas for K fertilizer experiments. Conduct experiments to generate site/area specific K fertilizer recommendations, effective application methods and management options. Determine the effect of K fertilizer rates on quality of crops with respect to human and livestock health.	ARI Mlingano in collaboration with SUA, other ARIs and districts councils.
Output 3: Extension messages on K utilization are packaged and disseminated by mid-2020		
Research problem 3.1 There is inadequate awareness on K deficiency in Tanzanian soils and its impact on crop production, and human and livestock health 3.2 There is inadequate awareness of appropriate K fertilizer use management in Tanzania	Assess needs and format of knowledge sharing products required for extension personnel and farmers. Sensitize stakeholders on K deficiencies, and its impact on crop production, and human and livestock health. Design, develop and disseminate extension packages on the use and management options of K fertilizers.	ARI Mlingano in collaboration with the Farmers Education and Publicity Unit of the Ministry of Agriculture, televisions channels (TBC, Star TV, ITV, local TV stations), radio stations and private sector organizations.

Output 4: Policy and multi-stakeholder support for K-based fertilizer use and management solicited and obtained by December 2017		
Research problem 4.1 The awareness and support of policy partners and other stakeholders on K-based fertilizer use and management is inadequate	Identify and prioritize areas related to K-based research and development which require policy support. Establish stakeholder platforms from which K-based research and development is supported and promoted. Solicit and create an enabling environment for public private partnerships regarding fertilizer importation, use, availability, distribution and marketing in the country. Solicit international collaboration and participation in the research and development of K fertilizers for sustainable agricultural production. Lobby for an efficient credit and subsidy system for agricultural inputs including fertilizers.	ARI Mlingano in collaboration with AFAP, the Tanzania Fertilizer Regulatory Authority (TFRA), fertilizer companies and the Presidential Delivery Bureau.
Output 5: Efficient validation, registration and enforcement of protocols for fertilizers and fertilizer supplements is promoted, adopted and operational by early 2017		
Research problem 5.1 Validation and registration procedures of fertilizers and fertilizer supplements takes too long, discouraging investors. 5.2 Effectiveness of current fertilizers quality control procedures are not adequately known	Identify areas for improvements to shorten the current validation process of fertilizers and fertilizer supplements. Review and improve current fertilizer registration procedures. Study effectiveness of current fertilizer quality control procedures.	TFRA in collaboration with, fertilizer companies, and ARI Mlingano

Annex 2. Opening statement

Mr. Peniel Lyimo,

Deputy Chief Executive Officer, President's Office, President's Delivery Bureau

Mr. Chairman
Director, International Potash Institute
Symposium organizers
Symposium participants
Distinguished guests
The media

Ladies and gentlemen

First of all, let me acknowledge the honor and privilege given to me by symposium organizers to officially open this 1st National Potash Symposium in Tanzania, which is being held here at Protea Hotel, Courtyard, in Dar-es-Salaam. I thank the Almighty God for giving all of us strength and the opportunity to arrive safely and participate in this important symposium. On behalf of the Government of the United Republic of Tanzania, and on my own behalf, I welcome you all to Dar-es-Salaam. I appreciate the commitment shown by all participants to attend this historic 1st National Potash Symposium. I am informed that this symposium brings together about 80 participants from a broad range of national and international organizations both from within and outside Tanzania. Considering the diversity and depth of the knowledge and experience of the participants attending this symposium, I am confident this 2-day workshop will deliver very useful deliberations that will possibly contribute to addressing agricultural productivity challenges in Tanzania, and the region broadly.

Ladies and gentlemen

Before I take you through the core purpose and process of this symposium, let me provide a brief historical background of fertilizer research in Tanzania. Since independence in 1961, there have been several attempts to develop fertilizer recommendations for various crops. These attempts led to the development of fertilizer recommendations in Tanzania, which are sequentially contained in the publications I am going to list out:

- Samki, J.K. 1975. *Fertilizer Recommendations in Tanzania*. Food and Agriculture Organization of the United Nations (FAO) and Norwegian Agency for Development Cooperation (NORAD) Seminar on Fertilizer use development in Tanzania. FAO, Rome.

- Samki, J.K., J.F. Harrop, H.C. Dewan, and F. Miany. 1982. *Fertilizer Recommendations Related to Ecological Zones in Tanzania*. National Soil Service, Ministry of Agriculture Food Security and Cooperatives (MAFC), Dar-es-Salaam.
- Samki, J.K., and J.F. Harrop. 1984. *Fertilizer Recommendations in Tanzania on District by District Basis: Technical Paper*. National Soil Service, Agriculture Research Institute Mlingano, Tanga.
- Mowo, J.G., J. Floor, F.B.S. Kaihura, and J.P. Magoggo. 1993. *Revised Fertilizer Recommendations for Tanzania*.National Soil Service, Agriculture Research Institute Mlingano, Tanga.
- Marandu, A.E.T, J.D.J. Mbogoni, and G.J. Ley. 2014. *Revised Fertilizer Recommendations for Maize and Rice in the Eastern, Southern Highlands and Lake Zones of Tanzania*. Agriculture Research Institute Mlingano, Tanga.

In all these five publications, the recommendations were mainly for nitrogen (N) and phosphorus (P) containing fertilizers for many crops. Potash as fertilizer was recommended mainly for tea and tobacco, and to a lesser extent to coconut, pineapple and sisal. Potash recommendations for maize and coffee were only recommended for one site. Most of you may be aware, a popular agronomy book entitled *East African Crops* by J.D. Acland (1975) documented that most soils of East Africa (including Tanzania) had sufficient levels of potassium (K) for plant nutrition. However, continuous cultivation without potash fertilizer application has led to nutrient mining, and eventually most soils became K deficient.

It is on this basis that:

- For over five decades, Khas been regarded as sufficient in most soils of Tanzania.
- There has been little research work regarding soil's K status, plant nutrition and fertilizer recommendations which include K.
- There are K blended fertilizer recommendations for a few cash crops like tobacco and tea. Recently, blended recommendations have been made for major food crops like maize and rice. For other crops, blending was made depending on inherent K supply from the soil. This, in general, signals that K levels are gradually declining in Tanzanian soils due to a lack of nutrient replenishing strategies.

Ladies and gentlemen

Declining soil fertility is common in areas where recommended agronomic practices such as use of fertilizers, control of soil erosion, intercropping with legumes, and use of leguminous cover crops are not consistently used. Continuous cultivation over a long period of time with application of N and P containing fertilizers alone accelerates the use of other nutrients, including K, by plants from soils which speed up depletion of nutrients from soil reserves. This is what has been recognized in recent years in some soils in Tanzania. Low levels of K in soils and symptoms of K deficiency are now very common in many agricultural lands and crops. Crops which have shown K deficiencies include maize, cassava, sisal, rice and horticultural crops. With such observed deficiencies, our scientists cannot provide fertilizer recommendations, including K, with certainty.

The government is keen to see that the country is food and nutrition secure by ensuring that agricultural productivity is significantly improved to be able to feed the ever growing population. In this regard, I urge our scientists, particularly soil and natural resource management scientists– in all national research institutions, universities, private organizations, NGOs, and international research centers – to ensure that the sites used for various experiments are properly characterized and the data generated is systematically documented for monitoring of soil characteristics and for appropriate interventions when needed. This strategy will help the nation know the areas with nutrient deficiencies and toxicities and develop remedial measures.

Ladies and gentlemen

Let me use this opportunity to say a few words about overarching programs and initiatives launched to drive our country's agricultural and economic growth.

As you may be aware, Tanzania has set its Development Vision 2025.It is a long-term vision that Tanzanians will have created a substantially developed, people-centered, peaceful, stable and united society with high quality livelihoods by 2025. The economy will have undergone transformation driven by agricultural development that leads the country to a middle income, semi-industrialized, competitive and resilient economy.

The overall agricultural development framework in Tanzania is guided by the Agricultural Sector Development Program (ASDP), which provides a long-term perspective for the transformation of the sector. In order to expedite the implementation of the program, the government has also introduced and number of initiatives.

In 2009, Kilimo Kwanza (Agriculture First) was launched which aimed at modernizing agriculture by lifting agricultural growth from 4% to 10% through public private partnerships. The emphasis was to overhaul the agriculture sector and boost the uptake of agricultural inputs and technologies to increase productivity, strengthen market development and promote exports.

Another initiative is the Southern Agriculture Growth Corridor of Tanzania (SAGCOT). It is a corridor-based development approach to expand multi-stakeholder and inclusive investment in agribusiness, anchored on smallholder farmer's transformation leading to increased income for smallholder farmers and generation of employment. SAGCOT promotes ‘clusters’ of profitable agricultural investments by mobilizing resources from the private sector through public private partnerships. SAGOT focuses on value addition, infrastructure development and agricultural productivity.

Big Results Now (BRN) is a transformative methodology adopted in 2012 to speed up the delivery of results of national priority areas in six sectors – agriculture, energy, education, resource mobilization, transport and water. Business, environment and health were added later. To operationalize BRN, the government established an independent institution under the President’s Office called President’s Delivery Bureau (PDB) which is mandated to play a catalytic role in the planning, implementation and performance management of key national areas.

With regard to agriculture, BRN focuses on delivering 25 inclusive large-scale commercial farming investments (with out-growers), 78 professionally managed rice irrigation schemes and 275 warehouses in SAGCOT areas. Crops prioritized are rice, maize and sugarcane. More than 400,000 people will be impacted by the agriculture initiative.

To increase agricultural productivity, PDB, in collaboration with Africa Soil Information Services (AfSIS) and the newly established Tanzania Soil Information Services (TanSIS) in the Ministry of Agriculture, Food Security and Cooperatives (MAFC), has initiated soil mapping and analysis in the BRN/SAGCOT regions, which is currently in the planning process. This initiative is intended to establish soil nutrient requirements and inform fertilizer companies to produce and distribute fertilizer blends in BRN regions, which covers eight regions and 19 maize and rice growing districts. After we learn from the BRN region, MAFC through TanSIS will scale up to the entire country. I believe this initiative will have strong linkages with the objective of this symposium and I encourage AFAP and other key stakeholders to collaborate with AfSIS and TanSIS for potential synergy and coordination.

Mr. Chairman

Consumption of fertilizers in sub-Saharan Africa is generally very low, with the main fertilizers applied being N and P fertilizers. Just like in Tanzania, potash containing fertilizers, blended as NPKs, are mainly applied to coffee, tea, tobacco and to some extent to vegetable crops like tomato. The remaining staples, including maize and rice, which are major sources of carbohydrates, are not considered to require potash fertilizers in most sub-Saharan Africa countries. Africa as a continent also consumes very low amounts of fertilizers compared to other continents. Available data for the period of 2005 to 2010 indicate that average fertilizer consumption in Africa was about 3.2 million MT per year, while in Asia, Americas and Europe, average consumption was 74.1, 19.5 and 13.0

million MT per year, respectively. Globally the consumption of potash fertilizers has steadily increased over the last five decades (from 1961 to 2010) by only 203% compared to consumption of N and P fertilizers which increased by 775% and 271%, respectively. Such increases of fertilizer consumption in the last 50 years has contributed to yield increases ranging from as low as 60% for root and tuber crops to 554% for oil crops. In general, Africa is using very little amounts of fertilizers and it is unlikely that we will be able to put enough food on the table if this trend is not corrected as soon as possible.

Ladies and gentlemen

The theme of this symposium is ‘Potassium for Sustainable Crop Production, Food Security and Poverty Reduction’. This theme is appropriate and timely as the nation is currently struggling to increase agricultural productivity to feed the population of about 50 million, by intensifying productivity on small pieces of land by using improved agronomic practices. Agricultural intensification is inevitable, now more than ever before, because of the challenges of population growth and climate change. Tanzania had a population of approximately 9 million at independence in 1961, which increased to about 50 million in 2015, but the land size has remained the same (940 million m^2). One of the most important agronomic practices to increase productivity in an environmentally friendly way is the use of compound fertilizers containing all limiting nutrients, including K. Use of such fertilizers will ensure that our crops are provided with balanced nutrients. By lacking adequate data of K status in soils, crop performance with potash fertilizers, short/long-term effects of potash on soils, and economics of fertilizer use, it is difficult to develop cost-effective fertilizer recommendations, including of potash.

This symposium is aiming at increasing agricultural productivity sustainably by inclusion of Kin fertilizer recommendations for various crops. This important objective will be achieved by obtaining baseline information of K research conducted in Tanzania, which has to be systematically synthesized by the participants in this 2-day symposium. This symposium is also expected to identify information gaps and then establish a K research agenda. To achieve the objective, there will be a number of presentations and discussions, keynote addresses and research papers from eminent scientists attending this symposium. Let me urge all presenters to present their ideas and innovations as clearly as possible to achieve symposium objectives and inform future decisions.

Mr. Chairman

Allow me to elucidate briefly the importance of K to plants and human beings. Potassium as a nutrient element is essential for vigorous growth, disease resistance, fruit and vegetable flavor and development, and for general plant function. Deficiency symptoms, for instance in maize, include yellowing of areas along leaf veins and leaf margins, and in other plants the leaves crinkle and roll-up, and produce dead twigs. Fruit trees may develop fruit with poor flavor or less developed fruits. Potassium is also very important mineral for the human body, as it is involved in various biochemical reactions. Some of the notable K deficiency symptoms in human beings include increased blood pressure, excessive sweating, fatigue, and muscle weaknesses. All foods contain K, with meats and many vegetables and fruits being good sources of K. It is therefore evident that our soils should contain adequate amounts of K that can be available for plant uptake and enter the food web. Developed countries have recommended dietary daily intake of K based on age (infants, children/ adolescents and adults). As a nation, we should develop recommended dietary daily intake of K, at least for infants and children. This 2-day symposium provides a great opportunity for researchers in Tanzania, as it will help scientists establish the basis of research on potash, develop the K research agenda and start long-term research to achieve soil K maps and fertilizer recommendations with potash for various crops.

Ladies and gentlemen

This gathering of eminent scientists, government officials, business community representatives, and the media from Tanzania and beyond could not be possible without the financial support of the International Potash Institute (IPI) based in Horgen, Switzerland, and the symposium organizing committee composed of members from AFAP and scientists from Agricultural Research Institute (ARI) Mlingano. On behalf of the Government of the United Republic of Tanzania, let me sincerely thank the management of IPI for financial support for this important initiative and symposium. I also thank the symposium organizers for their tireless efforts to make this symposium a reality.

Ladies and gentlemen

On behalf of the organizing committee and on my own behalf, let me welcome you once again. After these brief remarks, it is my pleasure to declare that the 1st National Potash Symposium is officially open, and I wish you very fruitful deliberations.

Thank you all.

Annex 3. Closing remarks

Prof. Semoka, J.M.R.

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Mr. Chairman
Director, International Potash Institute
Symposium organizers
Symposium participants
Distinguished guests
The media
Dear ladies and gentlemen

Good afternoon!

At last we are approaching the end of this 2-day symposium here at Protea Hotel, Courtyard, in Dar-es-Salaam. Let me first of all take this opportunity to thank the symposium organizers for inviting me to come and officiate the closing ceremony of this 1st National Potash Symposium in Tanzania. Before discussing what was covered in the symposium, let me thank the invited keynote speakers, researchers who presented papers, chairpersons of various sessions, rapporteurs, and of course you, the participants, for your excellent contributions in this symposium. From the enthusiasm I witnessed, I can comfortably conclude that the symposium was very successful and that we can look forward to attaining sustainable crop production and food security through the judicious use of fertilizers, including potassium (K).

Mr. Chairman

With your permission, allow me to briefly air my views about the papers presented in this symposium. Both invited keynote speakers and researchers who presented papers deserve very special acknowledgments for developing very informative papers. On the coverage of potash topics, the papers presented covered a wide range of the most important aspects of potash. To mention just a few: K status of major soil groups of Tanzania, the role of K on human and livestock health, K in sustaining crop productivity in Tanzania, and K in soils and crop nutrition. Knowledge contained in the papers is educative but more importantly has generated a lot of unknown knowledge on K for the scientific community. During the symposium we have had the opportunity to share experiences, listen to committed voices, and feel that the problems that concern soil K nutrition can be addressed by collective action of relevant stakeholders, including researchers, fertilizer manufacturers, and policymakers.

Ladies and gentlemen

The contributions of participants through discussions of the papers and the views of all participants summarized in group presentations were very useful outputs of the symposium. It is clearly evident that the symposium has been an occasion and opportunity to strengthen collaboration among stakeholders to address the problems of soil fertility in relation to K nutrition. I am confident that most of our expectations were met.

The presentations not only reviewed and evaluated what we have done in the past but also provided opportunities to exchange ideas and mutually stimulate research through both formal and informal discussions. In addition, the quality of presentations has given fresh directions to the active stakeholders for future research areas of K nutrition and fertilizer use.

Ladies and gentlemen

I am informed that the papers presented produced baseline information on K research conducted in Tanzania, and identified research gaps which will be used to generate a K research agenda in Tanzania. The main conclusion from this synthesis is that addressing K fertilizer demand in Tanzania is very relevant and timely.

I understand that we shall have a symposium proceeding but the key question now is what's next? This matter was probably raised during the 2days in this symposium. I think it should be our reflection now – what's next? We talked a lot, we discussed a lot and reached to five outputs. Some of these outputs should immediately be followed up when we go back to our respective areas and disseminate the updates that we shared here with all stakeholders.

Ladies and gentlemen

Once again, I want to thank all of you for making this a successful symposium. Your enthusiasm, dedication, devotion to improving soil fertility in general and K nutrition in particular, is the engine of all that has been achieved in this symposium. Before the formal closing of the symposium, I would like to join hands with all participants and extend our sincere thanks and congratulations to the International Potash Institute (IPI) for financing this 2-day symposium. It is my expectation that the findings generated in this symposium will lay down the foundation and form the beginning of long-term K research in Tanzania.

I would also like to sincerely thank the symposium organizing committee, composed of members from the African Fertilizer and Agribusiness Partnership

(AFAP) and scientists from the Agricultural Research Institute (ARI) Mlingano, in particular Dr. C.Z. Mkangwa for a wonderful job, hard work and marvelous performance throughout the past 2 days as well as during the preparation for the symposium. The symposium organizing committee definitely worked very hard, day and night, to ensure that their plans and dreams become a reality. I also thank the management and chef of Protea Hotel, Courtyard for preparing delicious food and timely service to all of us. The hospitality and the food that has been served with so much love have both been excellent. I want to personally thank all of the presenters for their contributions and dedication to the subject. I am gratified that the quality of the presentations was very high. I think this is a tribute to the high quality screening process carried outby Dr. Mkangwa and his entire scientific community from ARI Mlingano and Dr. Mshindo Msolla of AFAP for this. I also commend the efforts of the organizing committee in putting together a good program and the attention individuals have given to the papers.

Ladies and gentlemen

On behalf of the organizing committee and myself, let me thank you very much once again. After these few remarks, it is now my pleasure to declare that the 1st National Potash Symposium is officially closed, and I wish you safe journey back home.

Thank you to all of you.

Annex 4. List of participants

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