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A Review on Evaluation of Soil Potassium Status and Crop Response to Potassium Fertilization

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Abstract
Potassium (K) is an essential nutrient for plant growth. Because large amounts are absorbed from the root zone in the production of most agronomic crops, it is classified as a macronutrient. Different soils types can supply K for crop production, but when the supply from the soil is not adequate, K must be supplied in a fertilizer program. This review paper provides information important to the basic understanding of K soil status and nutrition of plants, its reaction in soils, its function in plants, and its role in efficient crop production.
Keywords: soil potassium status, potassium fertilization, crop response

1. Introduction

POTASSIUM (K) is an essential nutrient for crop production and fulfils a number of important roles in plant growth. However, the importance of these roles is not fully understood by grow and their advisers when considering K application to their crops. Plants require K for photosynthesis, ATP production, translocation of sugars, starch production in grains, nitrogen fixation in legumes, and protein synthesis. In corn and other crops, K strengthens stalks and stems, thus helping with disease and lodging.

In most of the intensive cropping systems in India, potassium (K) balance is negative since the additions of K seldom match the K removals resulting in larger dependence on soil K supply. Under such onditions there is greater pressure on non-exchangeable K for meeting the K requirement of crops. Long-term intensive cropping, in the absence of K inputs, adversely affected the K supply to crop plants and consequently crop yields (Swarup, 1998; Swarup and Ganeshmurthy, 1998). Higher crop K requirement comes with higher crop yields. Potassium is importance in plant growth and development has been known for over 150 years. Most crops take up as much or more K than N, about 70 to 75% of the K absorbed is retained by leaves, straw, and Stover. The remainder is found in harvested portions such as grains, fruits, nuts, etc. Whenever the soil cannot adequately supply the K required to produce high yields, farmers must supplement soil reserves with fertilizer K (Cavalot *et al.,* 1990). It is necessary to continually emphasize the role and importance of K in crop production as balanced fertilizer use has a direct bearing on the country's capability to produce its ever-increasing requirement of food, fiber, and other farm-based commodities. Improvements in both quantity and quality will add to export earnings. It is thus clear that for the long term and sustainable use of agricultural lands, the removal of K needs to be balanced by adequate K inputs if a decline in soil fertility is to be avoided. The most important potassium fertilizers are Muriate of potash, Sulfate of potash, Sulfate of potash magnesia, Kainit, Potassium nitrate, Potassium metaphosphate (15). Two major groups may be distinguished, the chlorides and the sulfates. The latter are more expensive than the chlorides. For this reason, the chlorides are preferred, provided that the crop is not chlorophobic. Most field crops are not sensitive to chloride and should therefore be fertilized with potassium chloride (muriate of potash).

In Ethiopia, so far there was a general understanding that Ethiopian soils are rich in K and there was no need for its application based on the research conclusion of Murphy (1968) some 47 years ago. However, with time it is likely that in some soils deficiency of K could occur due to continuous mining, leaching loss, and soil erosion so on. In some highlands of southern Ethiopia such as Chencha and Hagereselam areas of southern Ethiopia, soil acidity is a serious problem to crop production and in most cases soil acidity is associated with K deficiency. This is particularly so when cropping continues with N + P application without K addition. The K release rates from soils under long-term cropping, fertilization and manuring helps to predict the fate of added K in soil as well as nature of K supply from soil to plant K nutrition. This paper critically reviews the work done on soil K status and crop response to k fertilization and provide information on K fertilizer application for sustainable agricultural land production.

2. Material and Methods

Methodology

Potash fertilizer recommendations for various agronomic crops currently given due consideration for agricultural industry. Because a serious attitude towards K application is still lacking among farmers and extension workers. There is an urgent need to educate both about the importance of K in agriculture for nutrient balance and efficiency, top crop yields and quality, and farmer profitability. Currently, potassium and crop related experiment has been exclusively carried out by for example Public Agricultural Research Institutes. Accordingly these research institutes were the primary sources of both published and unpublished data. Additional information gathered for this review paper was collected using secondary data from different sources including tertiary institutions libraries, government libraries e.g. Agricultural Transformation Agency of Ethiopia Library etc. Other secondary data sources were collected from several relevant journals, text books and conference proceedings. Appointment with retired or serving soil scientists and research technicians were also sought to give their personal insights etc.

3. Result and Discussion

3.1 Potassium Status in Soils

The average potassium concentration of the earth's crust is 23 g/kg (Helmke P.A, 2000)in which most important potassium-bearing minerals in soils are alkali feldspars (30 to 20 g K/kg), muscovite (K mica, 60 to 90 g K/kg), biotite (Mg mica, 36 to 80 g K/kg), and illite (32 to 56 g K/kg). These are the main natural potassium sources from which K^- is released by weathering and plants feed. The weathering of the mineral begins at the surface and is associated with the release of K^-. This process is promoted by very low K^- concentrations in the soil solution in contact with the mineral surface, and these low concentrations are produced by K^- uptake by plants and microorganisms and by K^- leaching (Sparks D.L, 2003). It is generally believed that H_ released by roots also contributes much to the release of K_ from K-bearing minerals. This process, however, is hardly feasible since in mineral soils the concentration of free protons is extremely low and is not reflected by the pH because of the very efficient H_ buffer systems in mineral soils (Mills, H.A. et al., 1996). It is the decrease of the K_ concentration in the adjacent solution that mainly drives the K_ release (Peñalosa, J.M. et.al., 1995). Only high H_ concentrations (pH_3) induce a remarkable release of K_, associated with the decomposition of the mineral (D.W. Johnson,W.T. et al., 1993).

Potassium exists in the soil as dissolved K+ ions (solution K), exchangeable K, non exchangeable, and mineral K (Figure 1).

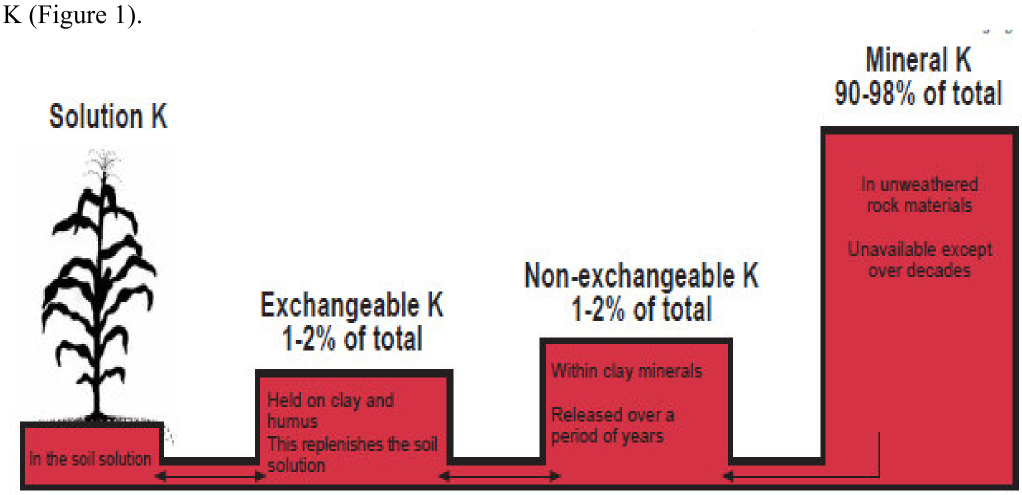

Figure 1. Forms of K found in the soil (Hoeft et al., 2000).

Solution K+ exists in equilibrium with the exchangeable, non exchangeable and mineral phases of potassium (Figure 2). Unlike N and P, K is not incorporated into the plant structure; therefore, K is not bound in organic forms, but is quickly released back into the soil from crop residues and roots. Exchangeable K is weakly sorbed to the surfaces of soil particles and can rapidly replenish solution K. Non exchangeable or "fixed" K is held within clay layers by strong bonds that make the nutrient inaccessible to plants.

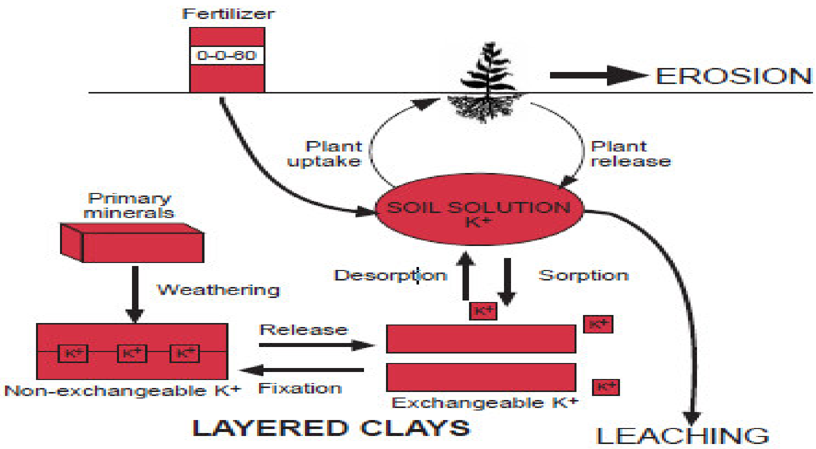

Figure 2. The potassium cycle.

Mineral K is contained largely in unweathered primary minerals such as feldspars and micas. The processes governing the availability of K are mineral weathering, clay fixation and release, sorption and desorption, leaching, erosion, and plant uptake.

3.2 Role of K in crop production

3.2.1 Factors that affect potassium uptake by crops

Higher crop K requirement comes with higher crop yields. Potassium importance in plant growth and development has been known for over 150 years (Rehanul Hasan. 2002). Several decades ago it was assumed that the 'activity ratio' between the K^- activity and the Ca^{2-} plus Mg^{2-} activities in the soil solution would describe the K^- availability in soils according to the equation (Beckett. P.H.T., 1964).

$$AR = K^+/\sqrt{(Ca^{2+}\ Mg^{2+})}$$

In diluted solutions such as the soil solution, the K^- activity is approximately the K_ concentration. It was found that this activity ratio does not reflect the K^- availability for plants (Wild, A. et al., 1969). Of utmost importance for the K_ availability is the K_ concentration in the soil solution. The formula of the AR gives only the ratio and not the K_ activity or the K_ concentration. The K_ flux in soils depends on the diffusibility in the medium, which means it is strongly dependent on soil moisture and on the K_ concentration in the soil solution, as shown in the following formula (Barber S.A.., 1962):

$$J = D_1\ (dc_1/dx) + D_2(dc_2/dx) + c_3v;$$

where J is the K_ flux toward root surface, $D1$ the diffusion coefficient in the soil solution, $c1$ the K_ concentration in the soil solution, $D2$ the diffusion coefficient at interlayer surfaces, $c2$ the K_ concentration at the interlayer surface, x the distance, dc/dx the concentration gradient, $c3$ the K_ Concentration in the mass flow water, and v the volume of the mass flow water. Growing roots represent a strong sink for K_ because of K_ uptake. Generally the K_ uptake rate is higher than the K_ diffusion, and thus a K_ depletion profile is produced with lowest K_ concentration at the root surface (Jungk. A.O., 2002), there are different factors that affect availability of potassium for crops; the most dominants are oxygen level, soil moisture concentration, soil tilling and soil temperature. The high CEC clays cause fixation and release to be significant processes in K cycling in which some clays bind K in much the same way as micas and are capable of 'fixing' the nutrient within their layered structures. Clay fixation immobilizes K in a

Non-exchangeable form making it temporarily unavailable for crop uptake. With high K concentrations and dry conditions, the clay layers shrink together and make K unavailable to plant roots (Nathan. K, et al, 2002). Potassium fixation and release by clay is closely related to soil pH and CEC, CEC generally have large reserves of fixed K that can be slowly released for plant uptake.

3.2.2 Potassium deficiency symptoms

The beginning of K_ deficiency in plants is growth retardation, which is a rather nonspecific symptom and is thus not easily recognized as K_ deficiency. The growth rate of internodes is affected, and some dicotyledonous species may form rosettes (Bergmann. W., 1993). Potassium deficiency in crop plants under different agro ecosystems is not as common as N and P deficiencies. Furthermore, K+ deficiency is not as easily identified as N and P deficiencies, which are accompanied by major changes in leaf color and tillering. Slaton et al. (1995) and Williams and Smith (2001) reported that prior to the early 1990s, K+ deficiency of rice was rare in the rice-producing areas of the United States. However, K deficiency is now recognized as an annual problem on many soils as rice and rotation crop yields have increased, soils have been mined of K+, and production practices have changed. Potassium, like N and P, is highly mobile in plant tissues. Hence, K+ deficiency symptoms first appear in the older leaves and its deficiency symptoms show up as scorching along leaf margins of older leaves (Fig 3.)

Figure 3. A, shows K deficiency symptoms in corn in which normal corn is in Leaf in the left, while most severe symptoms is next to the normal leaf and B, shows Potassium deficiency symptoms in soybeans.

Figure 4. K efficiency in Banana and Tomato

Potassium-deficient plants grow slowly (Williams and Smith, 2001). They have poorly developed root systems. Stalks are weak, and lodging is common. Seed and fruit are small and shriveled, and plants possess low resistance to disease. Plants under stress from short K^+ supplies are very susceptible to unfavorable weather. Although it cannot be detected as it is happening, stand loss in forage grasses and legumes is a direct result of K^+ deficiency. In grass/legume pastures, the grass crowds out the legume when the K^+ runs short, because the grass has a greater capacity to absorb K and the legume is starved out.

3.2.3 Management Practices for Potassium

Suggested management practices for K vary with crop and soil type. The identification of K deficiency in the soil and applying the recommended supplement for it was still paradoxical for both soil scientist and farmers. Therefore, for the ease of management option it is better to focus on the status of K in the soil. The possible causes for the occurrence of K deficiencies in some highland areas of southern Ethiopia and possibly in other similar areas of Ethiopia could be soil erosion caused by torrential rainfall along, which K is removed, deforestation, continuous mining of K through crop export, leaching of cations including K and other possible reasons (Wassie *et al*., 2009). There is a higher probability of successful establishment of perennial crops such as alfalfa and grasses if the soil test for K is in the medium range or higher. For these crops, the best strategy would be to apply potash fertilizers before seeding followed by annual top dress applications because the annual applications should be based on the results of routine soil tests for K.

Potassium deficiencies are now more wide spread even on heavy textured soils such as alluvial illitic soils in India. Several studies have shown substantial contribution of non-exchangeable K towards K nutrition of crops grown on illite dominant alluvial soils (Srinivasa Rao *et al.,* 2001; Swarup and Chhillar, 1986). This is particularly so when cropping continues with N + P application without K addition. Available K is measured in parts per million (ppm). According to (Nathan Korb, et al, 2001) only the top six inches of soil is generally tested for K because the surface soil is the most significant source of K for most plants and because it can be managed directly with fertilizers, tillage, and cropping systems. The relationship between soil test K and relative yield response in Montana and Wyoming has been a subject of significant research, sciettis of the area try to calculate amount of time potassium existed within a soil with and without application of K fertilizer. According to the question adopted from Based on a soil test level of 300 ppm K in the top 6" of soil, how long will the present 'pool' of exchangeable and solution K support an alfalfa crop which removes 150 lb K2O/ac per year?

The K release rates from soils under long-term cropping fertilization and manuring helps to predict the fate of added K in soil as well as nature of K supply from soil to plant K nutrition. Although K does not pose the potential environmental concerns that nitrogen (N) and phosphorous (P) do, an understanding of K cycling and availability is important for the management of profitability of long-term cropping systems because K exists in finite amounts in the soil and can limit plant use of other nutrients. K supplies may need careful management of soil which results on successful management of nutrient, erosion by wind and water removes soil from the top of the profile where plant available K is usually highest, due to plant recycling of the nutrient, Therefore, minimizing erosion losses will help maximize the amount of K available for crops.

3.2.4 Views and perceptions of K nutrition

Lack of farmer awareness about the importance of K indicates need for more education, training, verification trial from researcher. For example, farmers may not realize the effect of applied K on the size, shape, color, and quality of produce at maturity, so its need may be overlooked (Rehanul Hasan. 2002). In contrast, the benefits from N and P are more readily apparent from initial stages of crop growth. Another reason for inadequate use of K fertilizers may be the lack of crop response to applied K, even on low K testing soils. However, significant responses to applied K may be noted in high K soils. To overcome such anomalies, intensive research is needed at national and state levels to consider total K, exchangeable and non-exchangeable K, and K-fixing capacity of the soils under different soil-crop-climatic conditions.

Currently K get due concern in the case of Ethiopia also in which for a long time soils of Ethiopia considered as high K, but there were some indication in which K was affecting the production capacity, quality and size of many crops dominantly grown.

3.3 Effects of K on crop yields and quality

Higher crop K requirement comes with higher crop yields. Potassium importance in plant growth and development has been known for over 150 years (Rehanul Hasan, 2002). Most crops take up as much or more K than N. About 70 to 75% of the K absorbed is retained by leaves, straw, and Stover. Grain harvest index (GHI = grain yield/grain plus straw yield) and potassium harvest index (KHI = potassium uptake in grain/potassium uptake in grain plus straw) are important indices in the determination of crop yields and potassium distribution in plants, respectively. These two indices are influenced by potassium fertilization in dry bean crop, Potassium interaction with other nutrients is an important aspect in improving crop yields. Potassium plays several roles in plant metabolism, and to perform these roles positively, it should interact positively with other essential nutrients. Positive interactions of K with N and P have been reported (Clark, R. B. 1990.). Also it is reported that the increased K allowed for rapid assimilation of absorbed $NH4^{+}$ ions in the plant, maintaining a low, nontoxic level of NH3. Increased yield of crops with the addition of N and P requires higher level of K in the soil (Clark, R. B. 1990.).

4. POTASSIUM FERTILIZERS

According to traditional nutrient management strategies, fertilizer is not recommended for a nutrient that tests high in the soil because it will likely not result in a yield response. In Ethiopian soil, where nearly all agricultural soils test high for K, substantial research has shown that potash can increase yield significantly because diffusion of K is inhibited by cool soil temperatures, low water contents, and the presence of highly charged clays.

The most common test for available K_ is the exchangeable K_ obtained by extraction with 1M NH4Cl or NH4 acetate. This fraction contains mainly soil solution K_ plus K_ of the hydrated K_ fraction and only a small part of the interlayer K_. Concentrations of _100 mg K/kg are frequently in the deficiency range; concentrations between 100 and 250 mg K/kg soil are in the range of sufficiently to well-supplied soils. Since one cannot distinguish between interlayer K_ and K_ from the hydrated fraction, this test gives no information about the contribution of interlayer K_. The interpretation of the exchangeable soil test data therefore requires some information about further soil parameters, such as clay concentration and type of clay minerals. But even if these are known, it is not clear to what degree the interlayer K_ is exhausted and to what degree mica of the silt fraction contributes substantially to the crop supply (Hague, 1990).

The most important potassium fertilizers are shown in Table 1. (Mengel K., Kirkby E.A.). Two major groups may be distinguished, the chlorides and the sulfates. The latter are more expensive than the chlorides. For this reason, the chlorides are preferred, provided that the crop is not chlorophobic.

Table1. Important Potassium Fertilizers

Fertilizer	Formula	Plant Nutrient Concentration (%)					
		K	K_2O^a	Mg	N	S	P
Muriate of potash	KCl	50	60	-	-	-	-
Sulfate of potash	K_2SO_4	43	52	-	-	18	-
Sulfate of potash magnesia	K_2SO_4 MgSO4	18	22	11	-	21	-
Kainit	$MgSO_4$ +KCl +NaCl	10	12	3.6	-	4.8	-
Potassium nitrate	KNO_3	37	44	-	13	-	-
Potassium metaphosphate	KPO_3	33	40	-	-	-	27

[a]Expressed as K_2O, as in fertilizer grades.
***Source*: From K. Mengel and E.A. Kirkby, *Principles of Plant Nutrition*. 5th ed. Dordrecht: Kluwer Academic Publishers, 2001.**

Except two important fertilizer, the importance of other k fertilizer were beyond the scope of this paper.

Most field crops are not sensitive to chloride and should therefore be fertilized with potassium chloride (muriate of potash). Oil palm (*Elaeis guineensis* Jacq.) and coconut (*Cocos nucifera* L.) have a specific chloride requirement, with Cl^- functioning as a kind of plant nutrient because of its osmotic effect (von Uexküll. H.R, 1972).

The quantities of fertilizer potassium required depend on the status of available K_ in the soil and on the crop species, including its yield level. Provided that the status of available K_ in the soil is sufficient, the potassium fertilizer rate should be at least as high as the quantity of potassium present in the crop parts removed from the field.

5. Conclusion and Recommendation

Effective K management in soils requires not only a thorough understanding of K valiablty in the soil, but also an awareness of how climate, aeration, and water can affect the ability of a plant to access the large reserves of soil K. Potassium exists in large, albeit finite, amounts in the soil, but the available forms can be depleted over long-term agricultural utilization in which these idea evidenced by many agricultural research. Amounts of K removed from the soil during harvest, in most parts of agriculture based farming is not on the way can replace K pool of the soil. Therefore, Proper management and knowledge of K cycling in the soil can help to maintain the present K reserve in agricultural soils and ensure its efficient utilization. Besides to this government policy should also focus on the concern of K fertilization especially for developing country like Ethiopia to improve agricultural yield and quality since many highland soils of Ethiopia facing the Paradoxical K status and crop response to K fertilization.

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