Review on Potassium Research in Sudan: Past, Present and Future Prospects
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Abstract: The objective of this review is to explore the possibility of changing the old perception among agriculturist from various disciplines that Sudanese soils are rich in potassium, this article reviewed the work that had been conducted on potassium in soils of Sudan since 1927. Hereby, potassium did not receive the worth attention in Sudan agricultural system. This article reviewed the work that had been conducted on potassium in soils of Sudan since 1927. However, research work on soil potassium status and response of crops to the applied potassium is little. Early studies showed that some crops, like cotton and wheat, did not respond to the added potassium, however, sugarcane, banana, potato, and sweet potato crops responded well to the added potassium. Nevertheless, it is evident that application of potassium is a key factor in crops growth and quality. Accordingly, to improve crop production in Sudan, research for enhancing utilization of potassium element is needed. Many possible research for future directions have been suggested in the final part of this article.

Key word: Potassium, Future Prospects, Sudan soils.

INTRODUCTION
Sudan is the third largest country in Africa. Its area is about 1,886,068 km\textsuperscript{2}. The population of Sudan is 40 million people (Kavanaugh 2014). Sudan is endowed with many natural resources such as water resources which comprise rivers, groundwater and seasonal streams,
different climates and vast land suitable for agriculture. Sudan can be divided into six agro-ecological zones which are desert, Semi-desert, low rainfall savannah, high rainfall savannah, mountains and the flood zone (Wickens 1991). The soils of Sudan were classified, depending on climate zone, to five groups; soil of desert region, soil of arid region, soil of semi-arid climate, soil of monsoon climate, and soil of highland climate. The Sudan population rate is increasing rapidly, therefore, to offer enough food for this increasing population, enormous increment in crop production is required to meet the food demands of the next generations. Low soil fertility almost constitutes the main constraint of agricultural productivity, so for food security improvement soil fertility is required (Stoorvogel and Smaling 1998). Thus, the addition of fertilizers is a necessity to correct such poor soil fertility. Soils, particularly in the arid and semi-arid regions, rarely contain adequate amounts of essential plant nutrients to sustain high yields of crops. Fertilizers' use may account to 50% of crops' yield increase or even more in soils of low fertility. In Sudan, nitrogenous and phosphate fertilizers are commonly used, the rest are being neglected. Such practice is in contrast with sustainable crop production.

Potassium deficiency is a worldwide issue as reported by many researchers such as; Malo et al. (2005) in North America, Hedlund et al. (2003); Wijnhoud et al. (2003) in Asia, Harris, (1998); Wortmann and Kaizzi (1998) in Africa, Sheng et al. (2002); Zhang, (2010) in China, and Fagerberg et al. (1996) and Bengtsson et al. (2003) in Europe. Hence, K deficiency is a global problem as stated by (Dobermann et al. 1998). Accordingly, a recent literature review concluded that K nutrient, at a worldwide level, is a limiting factor for plant productivity in terrestrial ecosystems, and still was a neglected nutrient in our world (Sardans and Penuelas 2015). Therefore, the Sudanese soils, similar to many agricultural soils of the world, are generally deficient in the amount of soil K. Although, there has been a long-standing perception among agriculturist in different specialized areas that Sudanese soils are rich in K and the response of crops is limited. Such perception has led scientists to think that the K fertilization need in these soils is negligible (El khider 2003). This a long-standing perception, not only among agriculturist in Sudan but also, is a worldwide perception. For instance, Meena et al. (2014) in India, Murphy (1968) and Misgina et al. (2016) in Ethiopia,
Rijpma and Islam, (2003) in Bangladesh, Schneider et al. (1994) in Nepal and Kirkman et al. (1994) in New Zealand. All these studies showed that soils in different countries were previously rich in K but later, the studies showed that the soils need K fertilizers to increase crop production. Moreover, in recent years, evidence suggested a possible depletion of K in these soils (Fadl 2009), which may limit crop growth. This may not continue to be true as soil fertility status is a dynamic process and differs in different soils under different climates, agricultural practices and farming systems (Haile et al. 2014). Also, Fadl (2009) studied the chemical potential of exchangeable and fixed K in some Sudan soils, namely, El Goz and Gardud soils (North Kordofan state), Tozi soil (Blue Nile state), Sarafsaid soil (Elgedarif state), Shambat soil (Khartoum state), Wadelataya and Sueilmi from soils (Gezira state) and Hagu soil (Sennar state). These soils were evaluated using a modified quantity/intensity approach, and the results showed that equilibrium concentration ratio value was lower than the recommended in literature for many soils and crops. It is high time for researchers to put more concern on the situation of soil and water K in Sudan and to study different crops response to K in various soil types. As time proceeds, the old opinion of the agriculturists from various disciplines that Sudan soils are rich in K nutrient is likely to change.

Therefore, the aim of this review is to throw more light on the old perception that Sudan soils are rich in K and to reassess the response of some crops to K fertilizers.

Potassium research in Sudan agriculture

Early K fertilization studies in Sudan were conducted mainly on cotton crop. The cotton crop gained the highest attention among many crops grown in Sudan for long periods by many researchers. Cotton has been extensively grown in the Gezira since the colonial rule as a cash crop. Since that time, cotton was the main foreign exchange earner until the development of the national oil industry. Early studies in Gezira Research Station revealed that there was no response to added K fertilizers by the cotton crop. The researchers attributed the lack of response to the high content of K in Gezira soils (Walley 1927; Snow 1936). Vageler and Alten (1932) thought that this lack of response by cotton crop to the K application might be due to the high fixation of K element. Similar results were reported by Finck (1962) on Gezira soil (Clay 60%) in long-term
trials for 18 years using NPK and, in Hashaba Scheme (White Nile State). In addition, it was found that the exchangeable K was high and K in the plant was above deficiency range; hence it was concluded that the cotton crop was well supplied with K. In this context, Finck (1962) attributed the lack of response to K fertilization in Gezira soils also to the variable amounts of soluble K supplied by irrigation water from blue Nile. The research on cotton crop continued by many researchers (Burhan 1969; 1971; Burhan and Jackson 1973; Burhan and Taha 1974) who studied response of the crop for single-nutrient fertilizers in long term experiments over 18 seasons. Their results showed significant responses to N, erratic response to P and little response to K fertilizers. In Guneid scheme, K level in cotton was more than adequate, but the K in sugarcane was less than the sufficiency level even when applied (Hag Abdalla 1986). No response to K fertilizer was also reported for wheat crop at Hudeiba in the River Nile State and the White Nile State by using different rates of K up to 86 kg K₂O/ha and at two times of application (at sowing and booting) (Ibrahim and Satti 1991). Sudan soil survey reports showed marked variability of soluble and exchangeable K in various soil series studied such as Wad Hadad, Wadelataya, Gamoyah and Suilmi, where it was found that the amount of K was about 1.0 cmol/kg soil, and in Remitab and Dinder 0.9 cmol/kg soil (Idris 1998; Farah 1979), Gadambalia, Toz series were 0.2 cmol/kg, Shaheet was 0.3 cmol/kg. (Hunting, 1966), Alfisols (Hago series) 0.4 cmol/kg and in (Nasedeen series) 0.4 cmol/kg (Adam 1976; Idris 1990). The content of exchangeable K was low in the soil of central clay plain and did not exceed 2.0 cmol/kg of soil (Buursink 1971).

The main characteristics of the central clay plain soils are high clay content, alkaline pH, low organic matter (less than 1 %), poor in both N and P nutrients, and even, in some parts Dawelbeit (2010) recorded a deficiency of K. It is of interest to note that K complex fertilizers which contain NPK were found more effective in increasing yield compared with applied single fertilizers. Ali et al. (2002), found that the addition of Nitrophoska fertilizers which contain N, P and K on cotton gave high yields compared with N alone. Similarly, Ageeb and Abdalla (1988); Ali et al. (2002; 2003) and Abu-Sara et al. (2002) reported positive results of K fertilization on wheat in Gezira and New Halfa. In addition, Tomato at Rahad and Gezira responded well to K fertilizers (Abu-Sara et al. 2001). Next to cotton crop which received attention for K fertilizers is
sugarcane crop which is known as a heavy feeder crop that exhausts the soil of essential nutrients (Miller and Gilbert 2006). Several experiments were conducted to investigate the response of sugarcane in Kenana and results showed that sugarcane was of moderate response to potassium fertilizer (Abu zeid 1973; Yassin 1975; Isobe and Ali1983). However, Ali (1986) found that the sugarcane did not respond to K fertilizer addition which might be due to the higher exchangeable K in soil or even to higher level of K in the White Nile water.

Sudan sugarcane soils are generally higher in exchangeable K. Soils at New Halfa have more than 1782kg K$_2$O /ha (Ibrahim1975), and at Kenana soil K ranged between 711 and 1322kg K$_2$O /ha (Isobe and Ali1983). However, at Guneid some soils are low in exchangeable K and K fertilization was needed (Ibrahim 1977). Recently, El-Tilib et al. (2004; 2007) found that K application affected plant density, stalk diameter, yields of sugarcane plant and ratoon. They also reported significant increase in leaf N, P and K for three soils series (Dinder, Hagu, and Nasr). The soil analysis of their study revealed a depletion of extractable K after plant cane harvest.

Sudanese researchers also investigated the response of banana crop to K fertilizers. Banana crop is a fast-growing crop which produces a high quantity of vegetative biomass, and, thus, requires a high amount of nutrients (Moreira et al. 2010). Banana fruit is popular in Sudan and represents one of the most important cash crops. Farouk and Yousif (1997) found that addition of different K foliar concentrations increased the growth parameter, yield and yield components of banana crop and gave higher leaf contents of N, P, K, Ca, Mg, Mn, Fe, Zn, and Cu; also Farouk and Bakhiet (1999) showed that the addition of K fertilizer in forms of foliar or broadcast to soil increased growth parameters, yield and yield components of banana crop. According to Babiker et al. (2016), potato crop responded well to K fertilization in forms of KCl and K$_2$SO$_4$. The potato crop is well known as high K feeder, making it an indicator plant for K deficiency (Blagoeva et al. 2004). Also, addition of 160 kg K/ha significantly increased the vine weight per plant, total yield and root weight per plant of Sweet potato (Ali and Bushra 1993). Addition of K fertilizers is not only to increase crop production but also to ameliorate the negative effect of salinity. With regards to this, Khalafalla et al. (2010), found that the additions of K and calcium nitrate can ameliorate the harmful effect of salinity on the growth of tomato crop.
Most research has been concentrated on central clay plain which is regarded as the backbone of Sudan agriculture, where most of the irrigated schemes are located. The status of K in these areas is adequate and there is no need to supplement it by chemical K fertilizers. Moreover, serious research on K chemistry has not been attempted, except Finck (1962) and Fadl (2009) since K application seemed to give no significant effects on plant growth in trials conducted by different researchers in a few locations in central Sudan. So, in central clay plain, the extent of K deficiency and adequacy still needs extra evidence. Fixation of K is related to the percentage of clay and is highest in the Vertisols. However, K fixation is often higher in the presence of smectite and amorphous materials. Recently farmers in Sudan have more knowledge about compound fertilization and their positive effects on crop yields, therefore, it became an attractive trade around the country. With respect to this, to increase the efficiency of K fertilizer it is important to adopt the suitable method for application at the right rate and time.

**Why Research on Potassium nutrition is needed**

More studies on K fertilization in Sudan are necessary because of the present strategy which involved introduction of high yielding varieties, and diversification and intensification of farming systems, both of which meant to improve the welfare of farmers and securing food for the rapidly increasing population. But on the other hand, these strategies and policies ultimately will result in depletion of nutrients including K. Furthermore, local and foreign agriculture companies planned to use more agriculture land for more production for export. This can only be achieved by horizontal expansion. Such expansion is only possible currently in the third terrace soils away from River Nile. Such soils are of poor fertility which necessitates fertilization with macronutrients particularly N, P and K. However, this requires more extension work which will result in more awareness and knowledge about significant role of fertilization as an important input in increasing crop production. This can be achieved by field demonstrations, regular meetings to reflect the output the proper use of fertilizer under test.
Directions of research needs of K in Sudan agriculture

Future needs and prospects necessitate more investigations on the role of K in Sudanese agricultural system as follows:

• It is known that imported k-fertilizers are expensive to purchase compared with other chemical fertilizers. Therefore, it would be better to use local, relatively cheap materials as K sources for plants. Such materials like deposits in the Red Sea, Beyoda Desert and also extensive halite and anhydrite formations, which are local material rich in K (Elsamni 2015). Effort should be made to extract this mineral from these local deposits.

• Establishing models for better K fertilizers recommendations based on Sudanese conditions such as environmental factors, soil types, irrigation water, and crop needs. The K requirement and ability of uptake varies from plant to plant and from species to species, so, a look for crops which have the potentiality for extracting K from low available K forms would be helpful. Thus, oriented crop breeding to establish K-uptake-efficient crop genotypes should be encouraged. Fertilizer recommendations also should consider application methods which are more economical to supply K to plants; for instance, foliar sprays or deep placements can be employed. Balanced fertilization in combination with other essential nutrients also should be considered.

• Soil testing is one of the most reliable methods to predict various crops' need to K fertilizer and recommendation base on soil types and K status should not depend on available K form only but other forms like exchangeable and fixed K must be considered. This would involve looking for more fundamental methods suitable for studying k release in Sudan soils.

• Encourage research for a new alternative local source of K such as; biological K fertilizer, composting, manure, biochar, crop residue and straw, house waste, although the amount of produced available K come from these resources is little. Adopting Bio-intervention technique (composting and microbes) of K-bearing to increase crop production may also be effective.
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- Sudan is situated in the arid region; therefore, experiments are needed to test the role of K on plant resistance to stand conditions of drought and salinity.
- Studies should be executed to establish a better management methods for conservation of K to promote sustainable agriculture. This may require different kinds of management strategies to face the challenges of different soil types. The problems of K availability almost occur in soils like coarse sand, heavy clay, and calcareous soils. Therefore, it is important to adopt some measures to account for availability of K in such problematic soils. These measures include employing methods to reduce leaching in sandy soil and build up organic matter to ease compaction of clay soils. However, calcareous native effect on production can be minimized by more fertilization.

CONCLUSIONS

- This review shows that early studies on some crops, like cotton and wheat, did not respond to the added K, but recently, sugarcane, banana, potato, and sweet potato crops responded well to the added K.
- These results give a strong indication to disprove the longstanding perception that Sudanese soils are rich in K.
- Therefore, its high time to be more concerned about the situation of soil K and revise the fertilizer package for all crops throughout the country to enhance and sustain crop production.
- More researches are required to draw a map of K status in Sudan, to predict the response of different crops to K fertilizers and nutrient interactions. Nevertheless, successful fertilization programme should be planned to achieve the highest plant crop yield and considers other aspects of crop production including soil fertility status.
REFERENCES


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استعراض بحوث البوتاسيوم في السودان: الماضي والحاضر ووقعتات المستقبل

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المستخلص: الهدف من هذا الاستعراض هو استكشاف امكانية تصحيح الاعتقاد السابق وسط الزراعين بمختلف تخصصاتهم بأن الترب السودانية غنية بالبوتاسيوم. بالتالي لم يحظ البوتاسيوم بالاهتمام في نظام الزراعة في السودان. هذه المقالة تستعرض الأعمال التي تم تمت في السودان منذ عام 1927. أظهرت الدراسات المبكرة أن بعض المحاصيل، مثل القطن والمحاصيل، لم تستجيب للبوتاسيوم المضاف، ولكن أخرى قبض السكر والرحيق والبطاطس والبطاطس الحلوة استجابة جيدة للبوتاسيوم المضاف. ومع ذلك، فمن المعلوم أن تطبيق البوتاسيوم هو عامل رئيسي في نمو المحاصيل ووجودها. تبعا لذلك، لتعزيز إنتاج المحاصيل في السودان، هناك حاجة إلى إجراء المزيد من البحوث لتحسين استخدام عنصر البوتاسيوم. تم اقتراح العديد من الابحاث المحتملة للاتجاهات المستقبلية في الجزء الأخير من هذه المقالة.