Original Research Article

Effect of Potassium Sulfate Fertilizer on the Mineral Profile of Sorghum Forage and Their Uses as Ruminant Feed

Abstract: This study aimed to determine the effect of Potassium sulfate fertilization on the mineral profile of sorghum forage. A field trial was conducted at University of Khartoum Experimental farm at Shambat. The treatment consisted of six levels of Potassium sulfate fertilizer 0, 10, 20, 30, 40, and 50 kg/Acre. The data were subjected to analysis of variance (ANOVA) with a complete randomized design using SPSS software program. The evaluation was done by determining the percentage of Ash, NO_3, macro minerals (N, P, K, Ca, Na and Mg), and micro minerals (Cu, Mn, and Zn). The results showed that the application of potassium sulfate fertilizer increased significantly (P<0.01) the nitrogen content of the sorghum forage from 1.4 % in the control to 2.14 % in the 50 kg/Acre potassium sulfate fertilizer, while the effect on NO_3 was found to be insignificant. The potassium content of forage sorghum increased significantly ($P \leq 0.01$) with the increase in potassium sulfate fertilization level and the highest value (0.77) was recorded in 50 kg/Acre level of fertilization. The Mg content decreased with an increase in fertilization level and the control recorded the highest value (0.44 %). The effect of potassium sulfate fertilization on Cu, Mn, and Zn was found to be significant ($P \leq 0.01$). The potassium concentration of sorghum forage is significantly ($P \leq 0.05$) and positively correlated with nitrogen (γ=**0.67**) and negatively correlated with phosphorous and magnesium (γ= **- 0.65**) and (γ= **- 0.59**), while non-significant correlation was observed between potassium and Ash, NO_3, Ca, Na, Cu, and Mn. It could be concluded that the quality of forage sorghum increased by potassium sulfate fertilization because the nitrogen and potassium content in the plant increased and the concentration of NO_3 decreased.

Keywords: Potassium Sulfate, Mineral Profiles, Nitrite

Introduction:

Sorghum (*Sorghum bicolor* (L.) Moench) is an indigenous crop to Africa, and though commercial needs and uses may change over time, sorghum will remain a basic stable food for many rural communities. Sorghum belongs to the grass family, Graminea. Sorghum is the 5th most important grain crop after wheat, maize, rice and barley [1]. Sorghum could contribute more to food supplies than at present, especially to those regions and peoples in greatest need. Forage sorghums are similar to grain types but are taller and have higher forage quality. Sorghum in general can be classified into two types: forage types (mainly for forage or animal feed) and grain types mainly for human consumption [2].

Potassium (K^+) is an essential element for plant growth and development and is the most abundant cation in plants, making up 3–5% of a plant's total dry weight [3]. Potassium fertilizer is commonly added to improve the yield and quality of plants growing in soils that are lacking an adequate supply of this essential nutrient. This macronutrient is essential for many plant processes such as enzyme activation, protein synthesis, photosynthesis, and osmoregulation during cell expansion [4].

Potassium ions contribute significantly to the osmotic potential of the vacuoles even under drought conditions [3]. Thus, adequate K fertilization of crop plants may facilitate osmotic adjustment, which maintains turgor pressure at lower leaf water potentials and can improve the ability of plants to tolerate drought stress ([3] and [6].

Most K fertilizers come from ancient salt deposits located throughout the world. The word "potash" is a general term that most frequently refers to potassium chloride (KCl), but it also applies to all other K-containing fertilizers, such as potassium sulfate (K_2SO_4, commonly referred to as sulfate of potash or SOP). In a nutrient solution study, higher rates of K allowed for the efficient use of more nitrogen (N), which resulted in better early vegetative growth and higher grain and straw yields as K and N rates increased [7]. Potassium affects nitrate (NO_3) absorption and reduction. Rapid NO_3 uptake depends on adequate K in the soil solution [7].

Potassium is an essential mineral element for plant growth and development and plays a key role at various points in N metabolism. It was reported that rapid nitrate uptake depends upon adequate K in the soil solution. [8] reported that balanced application of N, P and K might cause up to 122% increase in sorghum yield. In order to minimize the risk of nitrate poisoning in ruminants and protect the soil and underground water from potential nitrate pollution without compromising with the yield, a balanced fertilization with application of K and maintaining a proper harvesting time may be beneficial [9].The objective of the present study is to investigate the effect of potassium level on macro minerals, micro minerals and nitrate absorption by sorghum forage and its effect on the chemical composition of the forage.

Material and Methods:

The study was carried out in the Experimental Farm of Shambat Research Station (latitude 15°37', longitude 32°32', altitude 380m). The treatments included fertilization of Potassium sulfate. The field was divided into six plots with three replications. The first plot was assigned as control. Then potassium sulfate was added by the rate of 10, 20, 30, 40, and 50 kg/ Acre. The harvesting was done after 75 days. The samples were lefts for 25 days for air drying at room temperature, and then grinded and kept for subsequent analysis.

Macro Mineral Determination (Ca, Mg, Na, N, P, K, NO_3):

These elements were analyzed as according to the Methods of soil analysis, Part 2: Chemical and mineralogical properties. [10]. Plant analysis handbook. Micro-Macro Publishing [11]. Physical and chemical methods of soil and water analysis [12].

Micro Mineral Determination (Cu, Mn, Zn):

Samples preparation: 1 g of dried ground plant tissue was weighed and placed in a porcelain crucible. The samples were placed in a cool muffle furnace and ached at 500 °C overnight. The samples were cooled and the ash dissolved 5-mL of 20% HCl, the solutions were warmed to dissolve the residue, and Filtered through an acid washed filter paper into a 50-mL volumetric flask. The filter paper was washed and the solution diluted to volume with deionized water. [13], and analyzed the samples by Buck 210VGP atomic absorption spectrophotometer.

Statistical Analysis

The data was subjected to analysis of variance (ANOVA) for the completely randomized design [14]. The least significant difference (LSD) procedure was used for mean separation.

Results and Discussion

Ash, N and NO_3 Concentration of Forage Sorghum

The effect of potassium sulfate fertilizer on crude Ash, N, and NO_3 of forage sorghum is shown in table (1). Highly significant difference ($P<0.01$) was found for Ash and nitrogen (N), while there was no effect was found for NO_3. The Ash content decreased from (13.7) in the control to (5.28) in the 40 level of potassium sulfate fertilizer. The obtained results are different from the results reported by [15] who stated that forage K content was positively correlated with forage ash contents. [16] reported that the total mineral content of feedstuffs is called ash. Forages normally contain 3% to 12% ash on a dry matter basis. Organic matter is determined by subtracting ash from 100. Minerals can be divided into two groups. Macro are those required by animals in relatively large amounts and include calcium, phosphorus, potassium, magnesium, Sulfur, and salt (sodium chloride) while micro or trace minerals are required in small amounts and include iron, iodine, cobalt, copper, manganese, zinc, and selenium.

The data in table (1) showed the application of potassium sulfate fertilization increased significantly the nitrogen content of the sorghum forage from 1.4 % in the control to 2.14 in the 50 application level. The results obtained were in the line with the results obtained by [17], [7], and [18] who reported an increase in nitrogen concentration of forage as a result of the application of different levels of potassium sulfate.

There was no significant difference($p>0.005$) of applications of Potassium sulfate on NO_3 of forage sorghum (Table 1). [19] reported that the application of potassium significantly contributed to the amount of NO_3 in edible parts of rockets, but significant differences only related to the rate of K. The increasing amount of K caused a reduction in the amount of N-NO_3, but no significant differences were found in the series with the medium and the highest rates of K. Increased potassium fertilization has an effect on a reduction in nitrate accumulation in plants. Moreover, comparable results were obtained by [20] who stated that nitrate contents in vegetables were raised with increasing N supply but decreased with potassium application, especially at high N application levels. In this respect, [21], [22], and [23] mentioned that the increase in potassium fertilizer levels resulted in reducing nitrate accumulation in some vegetable crops. In addition to that [19] and [24] reported that the increase in K fertilization reduces nitrate accumulation in plants. The application of double rate of K and phosphorus contributed to a reduction in nitrate content of rocket plants even at high rates of N [25]. The Increasing amount of K caused a reduction in N-nitrate in rocket leaves [26].

The problem of nitrate accumulation due to its uptake from the soil as a result of intensive application of nitrogen fertilizers carried out by the farmers becomes a major task [25]. Nitrite (NO_2) could be accumulated in animal blood after ingestion of NO_3 would cause a methaeno globinemia. Potassium application enhances the activities of leaf carbonic anhydrase (CA) and nitrate reductase (NR), thereby inducing efficient photosynthesis and the formation of primary organic N-containing molecules necessary for amino acids required for protein synthesis [27] and [28] demonstrated that sorghums can accumulate nitrates (NO_3) during any weather condition that interferes with normal plant growth; however, drought is the most common cause, this NO_3 is converted to nitrite (NO_2) in the rumen, which diffuses out into the bloodstream and binds to hemoglobin. This prevents the transport of oxygen (O_2) causing the animal to die from oxygen deprivation. Most NO_3 accumulate in the stem or lower portion of the plant. If NO_3 in the feed exceeds 0.35% it should either be discarded or diluted with safe feed (preferably grain). Unlike HCN, NO_3 will not leach out by the sun, however ensiling the forage can lower the NO_3 by approximately 50%.

Table (1): Ash, Nitrogen (N) and NO_3 Content of Sorghum Forage as Effected by Different Levels of Potassium Sulfate Fertilizer Application.

Parameters	Treatment						
	control	**10**	**20**	**30**	**40**	**50**	**L.S**
Ash	**13.7^{a}**	**6.53^{c}**	**6.18^{d}**	**6.53^{c}**	**5.28^{e}**	**8.93^{b}**	*****
NO_3	**0.01^{a}**	**0.02^{a}**	**0.03^{a}**	**0.02^{a}**	**0.01^{a}**	**0.01^{a}**	**N.S**
N	**1.4^{c}**	**1.61^{b}**	**1.37^{c}**	**1.68^{b}**	**1.23^{d}**	**2.14^{a}**	*****

A, b, c means with different superscripts in the same raw are statistically different at (P<0.01)

Effect of Potassium Sulfate Fertilization on Macro Mineral Composition

Data in the table (2) showed the effect of the addition of potassium sulfate on macro elements in sorghum forage. The addition of potassium sulfate to the soil had a significant ($P \leq 0.01$) effect on Mg, Na, K and while the Ca was not affected ($p > 0.005$). The application of Potassium sulfate in the soil has a significant effect of potassium level in the forage ($p \leq 0.01$). As the level of application increased the K percent increases too. The highest average of K was found in 50 kg/sedan potassium sulfate level, while the lowest average of K was found in control samples. These results are in the conformity of the results obtained by [17] and [29] who indicated that in maize (Zea mays) plants, there is a significant positive correlation between K concentration in external solution, K concentration of leaf tissue and DM increase. Moreover, these results were confirmed by the results of an earlier study [26] and they stated that the content of potassium and chlorine in the plant material studied increased with an increasing amount of potassium in the nutritional environment of the plants [30]. It was also found that the content of K in white clover increased with application of potash [31]. [16] suggested that some ruminants with high producing, under stress such as heat stress, may require K level above 10 g/kg, Potassium levels of 0.6% to 0.8% of ration dry matter are considered adequate for cattle. [32] reported that excess potassium antagonizes the uptake of sodium that has become naturally deficient in forages causing a complication of the cation imbalance, and When herbivores consume these high potassium-low sodium forages, acute electrolyte and mineral imbalances may occur if they do not have readily available supplemental sodium chloride to counteract the high potassium in forages. When animals are exposed to high potassium forages, they display signs of salt deprivation and aggressively devour sodium chloride to counteract the excessive potassium in forages. This may occur with any forage, but is especially common if herbivores consume rapidly growing lush grass and legumes [16]. Grass tetany which is commonly seen in cattle and other herbivores including horses, sheep and goats exposed to high levels of potassium may suffer from a multitude of disease syndromes. These include reproductive losses with abortions occurring during all stages of pregnancy, premature births, and weak offspring at birth [33].

The mean value of Mg content decreases with the increase in potassium sulfate application. This result was in the line with the result obtained by [34] who stated that excessive amounts of potassium reduce uptake of magnesium to a greater extent and calcium to a lesser extent. Applications of potassium fertilizers reduce the plant's ability to absorb magnesium. The result also was consistent with that obtained by [7] who found that High plant K can have an antagonistic effect on Mg concentrations, particularly when Mg is low in soils. Low magnesium (Mg) or calcium (Ca) in forages can affect animals by producing low blood serum Mg or Ca causing grass tetany. The incidence of grass tetany tends to be lower if forage Mg exceeds 0.2 percent and Ca exceeds 0.4 percent. In a greenhouse study [35] studied the interrelationships of K and Mg with alfalfa (Medicago sativa L.) they observed that added K decreased Mg dramatically, whereas added Mg Depressed K^+ concentration slightly. They concluded that there was a "one-way" competition between K^+ and Mg_2^+. [36] reported research with rice where cation antagonism was brought about by a lack of adequate K rather than a surplus of K. Low K^+ levels favored the uptake of Mg_2^+ and Ca_2^+ and resulted in lower plant yields than higher K levels. [37] suggested that K-Mg antagonism is related to ionic balance and not to specific competitive effects for carriers. Also a work with cotton (Gossypium hirsutum L.) in northern Nigeria on five Savannah soils, increased K application rates, reduced leaf Mg_2^+ levels [38]. Similar types of effects are reported in several other crops, [39] working on a soil low in K and Mg, reported that K fertilizer decreased Mg concentrations in all crops studied except in potato (Solanum tuberosum L.) tubers and sugar beet (Beta vulgaris L.) roots. However, this result does not match the results obtained by [26] who found no significant influence of the increasing rate of potassium on the magnesium concentration in the plant material studied. The concentration of Mg in this study is enough to meet the theoretical requirement of Mg for beef cattle and for lactating cows (1.2 - 2.1 g/ kg DM) [40] and higher than the recommended requirements for growing lambs and lactating ewes and goats [41].

For sodium content the results revealed a significant difference ($p \leq 0.001$) of application of potassium sulfate. The highest average of Na was found in control samples (0.31), while the lowest average of Na was found in 20 kg/ Acre (0.03) and 40 kg/ Acre potassium level (0.30). These results match the results obtained by [17]. The antagonistic relationship between K and Na uptake has been observed by others [42] and [43] who explained that the ions K^+ and Na^+ compete for the same non-selective cation channels for uptake, it is possible that a surplus of K^+ ions lowered the uptake potential for Na^+ ions and resulted in less Na content in plant tissues. Moreover, [34] reported that the only element that affects sodium levels in the soil is potassium. [44] reported that the application of N along with K decreased significantly Na^+ uptake in leaves of sugarcane and increase plant salt tolerance to produce high biomass. The Na requirement for ruminants is often debated in the literature concerning the dietary concentration demand of the animals. An adequate range from 1 - 4 g/kg has been recommended by various researchers [45]. The Sodium concentrations in this study for forage sorghum were below the levels recommended for optimal animal productivity and production. To meet the need of highly productive animals, forage should contain more than 0.15% sodium.

The P as affected by different applications of potassium sulfate showed significant ($p \leq 0.001$) difference. The highest average of P was found in 30 kg/ Acre level (0.67 ± 0.00), while the lowest average of P was found in 50 kg/ Acre potassium sulfate level (0.49 ± 0.01). as the percent of potassium fertilizer increases the percent of phosphorous increases too. [7] reported that the synergistic effect of K and P on yield was perhaps of more widespread importance than individual effects, P and K together produced an extra 15 percent positive yield interaction for soybeans and 50 percent for Coastal Bermuda grass. [46] showed the need for an appropriate balance between P and K on soybean yields. [47] demonstrated a similar positive P-K interaction on the yield of 'Coastal' Bermuda grass. [48] worked on a solution culture with cowpeas (Vigna unguiculata (L.) They found a potential P-K interaction in the uptake phase, and they suggested that since K^+ deficiency markedly decreased P uptake, even though P was adequate in the solution.

The results in table (2) found no significant difference of application of potassium sulfate fertilizer on Ca element. This result is similar to the results obtained by [34] who stated that excessive amounts of potassium in soil reduces the uptake of magnesium to a greater extent and calcium to a lesser extent. Reiterating, calcium, magnesium, and potassium compete with each other and the addition of any one of them will reduce the uptake rate of the other two. [49] found that top tissue levels of Ca and Mg in grain sorghum decreased as the ratio of K^+ / Mg_2^+ increased in the nutrient solution. Similar results obtained by [50] who reported that the increased in K application rates on Coastal Bermuda grass decreased the amount of Ca_2^+ and Mg_2^+ in the forage tissue. Mean Ca concentrations from all sampling sites during different sampling were above the critical value of 0.30% DM [51] for different classes of ruminants. Forage Ca concentrations of 2 - 6 g/kg, with higher requirements for lactation have been variously recommended for cattle and sheep.

Table (2): Effect of Different Application of Potassium Sulfate Fertilizer on Some Macro minerals.

Parameters	Treatment						
	Control	10	20	30	40	50	L.S
Ca	1.4[a]	1.6[a]	1.4[a]	1[a]	1.4[a]	1.4[a]	N.S
Mg	0.40[a]	0.25[b]	0.20[b]	0.10[c]	0.10[c]	0.20[b]	***
Na	0.31[a]	0.11[b]	0.03[d]	0.06[c]	0.30[d]	0.06[c]	***
K	0.19[e]	0.35[d]	0.48[b]	0.42[c]	0.48[b]	0.77[a]	***
P	0.59[c]	0.66[b]	0.54[d]	0.67[a]	0.54[d]	0.49[e]	***

Means with different superscripts in the same raw are statistically different at (P<0.01)

Effect of Potassium Sulfate Fertilization on the Micro Mineral Composition

The data in the table (3) showed the effect of the addition of potassium sulfate on microelements in sorghum forage. A significant difference was found between the elements under study (P<0.01). The mean value of Copper was found to increase significantly with the increase in the application of Potassium sulfate. The highest average of Cu was found in 20 kg/ Acre level of potassium sulfate (0.07), while the lowest average of Cu was found in 50 kg/ Acre potassium sulfate (0.03). And this matches the results of [52] reported that K applications increased Cu_2^+ concentration in the blue joint forage. And agree with [53] who reported that K^+ additions increased Cu_2^+ levels in bent grass (Agrostis palustris Huds.). Also [15] reported that forage Cu content was positively correlated with the contents of Mg, K, Mn and Zn in forages. [54] reported that the dietary requirement of ruminants for Cu ranges from 8 to 14 mg/kg. Copper deficiencies in forages can cause poor reproduction, broken bones, weak calves, and light colored hair. Discoloration normally occurs first around the eyes and tips of the ears. Sometimes, changes in hair color are not noted and the effect of a copper deficiency simply occurs as reproductive problems [55].

The Mn showed a significant (p≤0.001) difference among different treatments. It was found increase with the increase of Potassium sulfate fertilization. [34] recorded that Potassium has direct synergistic relationships with two micronutrients namely: iron and manganese. Moreover, [7] recorded that the Manganese (Mn) content of the corn plants increases when available K levels are increased. However, this result disagreed with the results obtained by [53] reported that K additions to bent grass turf reduced Mn, N, Ca, and Mg content of the foliage. The magnitude of these changes was not considered critical under the conditions of the experiment. High levels of manganese in forage can retard the growth of livestock. Forage Mn levels were above 40 mg/kg, is in the critical level and found to be sufficiently higher to meet the requirements of ruminants [16].

The effect of addition different levels of Potassium sulfate on zinc content was found to be in significant (table 2). Previous reports indicated that in corn a reduction in P induced zinc (Zn) deficiency of corn when available K levels are increased, (Mn) content of the corn plants also increases, indicating there is some relationship of K, P, Mn, and Zn in this complex effect resulting in less severe Zn deficiency [7]. However, [56], In one of their experiments, for example, where K at 150 kg/ha produced a large increase in grain yield (1.47 t/ha) and zinc a response of 0.47 t/ha, there was an indication of positive K x Zn interaction at 0.23 t/ha. It has been suggested that 30 mg/kg to be a critical level of dietary Zn, although it has been recommended that concentrations of 12 - 20 mg/kg are adequate for growing ruminants [57]. Whereas cattle and sheep in particular require 35 mg Zn / kg diet [55]. The deficiency of Zinc will result in parakeratosis, stiffness of joints, smaller testicles, and lowered libido of goats. A minimal level of 10 ppm of zinc in the diet prevents deficiencies. Excessive dietary calcium (alfalfa) may increase the likelihood of zinc deficiency in goats [58]

Table (3): Effect of Different Application of Potassium Sulfate Fertilizer on Some Micro Minerals of Forage Sorghum.

Parameters	Treatment						
	Control	10	20	30	40	50	L.S
Cu	0.03^{e}	0.04^{c}	0.07^{a}	0.04^{b}	0.04^{cd}	0.03^{de}	***
Mn	0.13^{c}	0.13^{b}	0.16^{a}	0.12^{d}	0.11^{e}	0.11^{e}	***
Zn	0.32^{d}	0.24^{f}	0.28^{e}	0.33^{b}	0.43^{a}	0.33^{c}	***

Means with different superscripts in the same raw are statistically different at (P<0.001)

Correlation coefficients between mineral contents in the sorghum forage as affected by Potassium sulfate fertilizes.

The correlation analysis (Pearson partial correlation coefficients) between mineral contents in sorghum forage as affected by different levels of potassium sulfate is shown in table (4). The potassium concentration of sorghum forage is significant ($P \leq 0.05$) and positively correlated with nitrogen (γ=**0.67**) and negatively correlated with phosphorous and magnesium (γ= - **0.65**) and (γ= - **0.59**), while weak and non-significant correlation were observed between potassium and Ash, NO_3, Ca, Na, Cu, and Mn. The positive correlation between Potassium and nitrogen reported in this study was supported by [17], [7], and [18] who reported that the increased potassium content resulted in nitrogen increment also.

The negative correlation between potassium and magnesium noticed in this study came in the line of [34] who stated that the Applications of potassium fertilizers reduce the plant's ability to absorb magnesium, moreover, [35] studied the interrelationships of K and Mg with alfalfa (Medicago sativa L.) they observed that added K decreased Mg dramatically.

The concentration of NO_3 revealed a strong positive correlation with Mn (γ= 0.79) with highly significant differences (P<0.01), and had a significant negative correlation with Na (γ= - **0.62**) and Zn (γ= - **0.66**). It was also noticed that from this result Mg has a positive correlation with Ash (γ= **0.79**) and a negative correlation with Na (γ= - **0.67**

Table (4) Correlation Coefficients Between Mineral Contents in the Sorghum Forage as Affected by Potassium Sulfate Fertilizes.

Element	Mg	Na	K	P	Cu	Mn	Zn	Ash	No_3	N
Ca	ns	ns	ns	Ns	ns	ns	ns	ns	Ns	ns
Mg		0.67*	-0.59*	Ns	ns	ns	ns	0.79**	Ns	ns
Na			ns	Ns	ns	ns	ns	ns	-0.62*	ns
K				-0.65*	ns	ns	ns	ns	Ns	0.67*
P					ns	ns	ns	ns	Ns	ns
Cu						0.60*	ns	ns	Ns	ns
Mn							-0.73**	ns	0.79**	ns
Zn								ns	-0.66*	ns
Ash									Ns	ns
No3										ns

Conclusions:

Based on the current research results, it could be concluded that the addition of potassium sulfate as fertilizer to sorghum forage increases the levels of N, P, K, Cu, Mn, and Zn, while decreases the levels of Mg, P, Mn, Zn, but does not affect Ca and NO_3.

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