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Responses of *Cassia senna* (L.) to Added Nitrogen, Phosphorus and Potassium in the Semi-arid Zone of Central Sudan

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Abstract: The responses of *Cassia senna* (L.) to added nitrogen, phosphorus and potassium in the semi-arid zone of central Sudan was investigated. The study was carried out by soil mechanical and chemical analysis and soil-culture experiments. The results of soil analysis showed that the sandy loam soil of the investigated site was a slightly alkaline (pH = 7.74±0.65) (characterized with high levels of Ca, adequate quantities of Mg, K and Na and low levels of NH_4-N and P. Mn levels, however, were very low and associated with soil alkalinity. The growth response of *C. senna* (L.) to a range of separate additions of phosphorus treatments was higher compared with that of corresponding nitrogen treatments and this most likely because *C. senna* (L.) is a leguminous plant capable of fixing nitrogen in the root nodules. The analysis of variance of the results of the factorial additions of N, P and K to *C. senna* (L.) growing in a soil collected from the investigated site showed that the growth of the investigated species is limited by phosphorus. The significant positive interactions between P-N, P-K and NPK suggest that N and K would come second in limiting the growth of *C. senna* (L.) after P.

Key words: *Cassia senna* (L.), nitrogen, phosphorus, potassium, soil-culture experiments, semi-arid zone of central Sudan

INTRODUCTION

Cassia senna (L.) is widely distributed in central Sudan (Hayati, 2005). It is present in western and eastern Sudan, on the Nubian gravel desert and along the river Nile course from Khartoum to Dongola in Northern Sudan and it occurs on all types of soils with best yield on clay soils (El-Amin, 1990; Vetaas, 1993).

The positive correlation between soil mineral nutrient content and performance of plant species has widely been investigated. Added nitrogen was found to increase the production of annual species in semi-arid habitats when compared to their unfertilized control treatments (Obied and Mahmoud, 1971). In addition to that, the growth of some common weeds in Sudan were found to be significantly stimulated by the addition of nitrogen, phosphorus and potassium (Yahia, 1992).

Hayati and Yahia (2002) examined the relationships between soil mineral nutrient elements and uptake of these elements by *Cassia senna* (L.) in three sites in central Sudan and found that the patterns of nutrient uptake by this species were not in simple relationships either with the content of available nutrients in the soil, or with its performance in natural habitats. This finding raised the question of which elements were limiting the growth of *Cassia senna* (L.) in its natural habitats. To answer this question soil mechanical and chemical analysis and soil-culture experiments were undertaken. It is hoped that the study will contribute to a better understanding of the ecology of this species in the semi-arid zone of central Sudan.

MATERIALS AND METHODS

The site chosen for this study was the enclosed reserved area at the northern location of the Faculty of Education, University of Khartoum, Sudan (Lat. 15°30' N; Long. 32°33' E). It lies on the Nubian sandstone, about 380 m above sea level. The mean annual temperature is about 37°C with a maximum of about 46.8°C in May and a minimum of 12.7°C in December. The site is more or less flat with very gentle undulations. In addition to *C. senna* (L.) the site is also dominated by perennials and annuals and occupied by an upper layer of scattered trees and shrubs mainly *Acacia nilotica* (Benth.), *A. mellifera* (Val.) and *Ziziphus spina-christi* (L.).

The investigation was carried out by soil mechanical and chemical analysis and soil-culture experiments. Twenty five random soil samples were collected from the investigated site. The samples were taken from the plough depth (15-20 cm), because the plough layer is thought to be the most useful part of the soil and will best represent its ability to supply nutrients. The samples were placed in plastic bags and stored in the laboratory at temperature of about 25°C. Cations, ammonium nitrogen and phosphorus (expressed in mg 100 g^{-1} soil), were extracted from a measured volume of soil (5 g from each sample). Cations were extracted with ammonium acetate at pH = 7; ammonium nitrogen was extracted with 6% sodium chloride and extractable phosphorus with 2.5% acetic acid.

Analytical procedures, in general, followed those of Hayati and Proctor (1991), Hendry and Grime (1993) and Harris (2002). K and Na were estimated by flame emissions and other metallic cations by atomic absorption spectrophotometer. Ammonium-nitrogen was estimated colorimetrically using the Nessler reaction method. Phosphorus was analyzed colorimetrically by the molybdenum blue method using the spectrophotometer. The soil mechanical analysis was determined by hydrometer method. The pH of the collected soil samples was determined on a 1:2 suspension of a soil sample in deionized water, using a glass electrode.

Two soil culture experiments were performed. In the first experiment a range of N or P concentrations were added separately to *C. senna* (L.) seedlings. NH_4NO_3 was used as a source of N. Six levels of N were used, together with control, making total of seven treatments as: 0, 5, 10, 20, 30, 40 and 50 mg N. These weights are equivalent to 0.0000, 0.0143, 0.0286, 0.0572, 0.0857, 0.1144 and 0.1429 g of NH_4NO_3. On the other hand, NaH_2PO_4 was used as a source of P. Likewise, six levels of P were used, together with control, making total of seven treatments as: 0, 5, 10, 20, 30, 40 and 50 mg P. These weights are equivalent to 0.0000, 0.0194, 0.0388, 0.0774, 0.1161, 0.1548 and 0.1935 g of NaH_2PO_4. The levels of P and N were prepared by dissolving each equivalent amount of NH_4NO_3 or NaH_2PO_4 in 60 mL of deionized water.

The second experiment was a factorial one in which the effects of P, N and K on the growth of *C. senna* (L.) were investigated. The treatment concentrations were made of 20 mg P equivalent to 0.0774 g of NaH_2PO_4 and 30 mg N equivalent to 0.0857 g of NH_4NO_3 and 50 mg K equivalent to 0.0955 g of KCl. The solutions for the treatments were prepared by dissolving each weight in 60 mL of deionized water.

The soil for the experiments was collected from the investigated site. The soil was well mixed together and the plastic pots were filled equally with 2 kg of soil. Seeds of *Cassia senna* (L.) were sown in plastic pots. Only three seedlings were allowed to grow per pot. To each pot three treatments were given as a dilute solution: one after one week of germination and the other two at two weeks intervals. Distilled water was used for watering. Before treatments were added, the pots were completely randomized. In these experiments, each treatment was replicated three times. The plants were harvested after 45 days of growth. Dry weights of the whole plants (the root and shoot systems) were measured. The data of the growth experiments were analyzed by simple descriptive statistical procedures and analysis of variance.

RESULTS

The results of soil mechanical analysis showed that the investigated site is characterized by high amount of sand (47%) moderate amount of silt (35%) and low amount of clay (18%).

The results showed that the site was slightly alkaline (pH = 7.74±0.65) and characterized with high levels of Ca, adequate quantities of Mg, K and Na, low levels of NH_4-N and P and very low levels of Mn (Table 1).

It is clearly evident that the mean dry weight of *C. senna* (L.) at all nitrogen treatments showed relatively higher mean dry weight than the control (Table 2). The highest mean dry weight of *C. senna* was produced at the level of 30 mg N. Since the dry matter of *C. senna* (L.) continued to increase with increasing levels of N up to 30 mg, where the maximum growth was obtained, it seems that the critical concentration of this nutrient falls between 30 and less than 40 mg. A relative decrease in mean dry weight of *C. senna* (L.) was apparent as the nitrogen concentration increased above the critical concentration up to 50 mg N.

Table 1: Summary of the soil chemical analysis data. pH and extractable ions expressed in mg 100 g^{-1} soil of the investigated site

Characteristics	Values
pH	7.74±0.650
Ca	436.90±72.20
Mg	64.32±21.80
K	45.48±17.58
Na	38.76±14.80
NH_4-N	3.22±1.900
P	3.80±1.170
Mn	0.21±0.090

Values are means±SD calculated from 25 soil samples

Table 2: Mean dry weight of *C. senna* (L.) growing in separate pots each filled with 2 kg of soil after addition of different levels of nitrogen or phosphorus. Each reading of the mean total dry weight represents an average of three replicates

Levels of N or P (mg 2 kg^{-1} soil)	Mean dry weight after nitrogen addition (g)	Mean dry weight after phosphorus addition (g)
0	0.88	0.88
5	1.03	1.78
10	1.10	1.94
20	1.63	3.45
30	2.52	2.96
40	1.73	2.79
50	1.36	1.28

Table 3: Summary of analysis of variance for the factorial addition of N, P and K to *C. senna* (L.) growing in soil collected from the investigated site

Treatments	df	SS	MS	F-value	p-value
N	1	0.675	0.675	02.330	NS
P	1	4.675	4.675	16.121	<0.01
K	1	0.310	0.310	01.070	NS
NP	1	4.466	4.466	15.400	<0.01
NK	1	0.665	0.665	02.290	NS
PK	1	3.150	3.150	10.860	<0.01
NPK	1	5.631	5.631	19.420	<0.01
Error	16	4.646	0.290		
Total	23	24.218			

NS: Non Significant

Like nitrogen the mean dry weight of *C. senna* (L.) at all phosphorus treatments showed relatively higher mean dry weight than the control. The highest mean dry weight of *C. senna* was produced at the level of 20 mg P. The critical concentration of P for this species falls between 20 mg and less than 30 mg P. A relative decrease in mean dry weight of *C. senna* (L.) was apparent as the phosphorus concentration increased above the critical concentration up to 50 mg P.

Of the single treatments only P treatment produced significant growth suggesting that P is a limiting nutrient for this species. Comparisons within the Table 3 showed significant interactions between NP, PK and NPK.

DISCUSSION

The high levels of soil Ca and very low levels of Mn were associated with alkalinity of the investigated site. It was reported that Mn precipitates as dark-colored nodules in the lower horizons of semi-arid soils due to the high pH at those horizons (Thompson and Troeh, 1978). The relatively low levels of P were not surprising because the concentration of phosphorus in the soil solution will be largely governed by the soil pH and calcium content (Hayati and Proctor, 1991). In most alkaline soils with high calcium content phosphorus availability decreases as the value of pH goes beyond 7, because calcium ions binds P as calcium-phosphate creating an insoluble compound that is not available to plants (Barber, 1995; Brady and Well, 1999). Therefore, it is necessary to add large quantities of phosphate fertilizers to alkaline soils.

The relatively low levels of NH_4-N may be associated with the nature of the investigated site in the semi-arid zone of central Sudan characterized with low organic matter content and a type of soil composed of high amount of sand (47%) moderate amount of silt (35%) and low amount of clay (18%). This type of soil was classified as sandy loam (Yahia, 1992). Actually retention of NH_4-N in the soil depends largely on the soil colloidal materials (clay particles and organic matter content) because the cationic nature of NH_4^+ permits its adsorption by the exchangeable capacities of the soil colloidal materials. The sandy loam soil of the investigated site characterized with low organic matter content most likely permits downwards leaching of NH_4-N from the upper soil horizons. So the availability of NH_4-N in the upper soil horizons of the examined site was mainly governed by the ammonification process accomplished by heterotrophic bacteria and fungi (Etherington, 1982; Taiz and Zeiger, 1998).

Nitrogen and phosphorus are essential elements for plant growth. Nitrogen is an important element in building most of the organic compounds in plants i.e., amino acids, nucleic acids, many enzymes and energy transfer molecules such as chlorophyll. Whereas, phosphorus is found in plants as a constituent of nucleic acids, phospholipids, nucleotides and most important in the energy molecules ADP and ATP. Actually nitrogen and phosphorus were considered as the most limiting nutrients for plant growth in most natural soils (Epstein, 2004). In this investigation *C. senna* (L.) respond positively to added nitrogen and phosphorus treatments. Although the growth of *C. senna* (L.) in response to all nitrogen and phosphorus treatments were higher than that of the control, the response of this species to added phosphorus was relatively higher compared with that of nitrogen (Table 2). This is most likely because *C. senna* (L.) is a leguminous plant capable of fixing nitrogen in the root nodules (Ismail and Babikir, 1986).

The reduction of mean dry weight of the investigated species at high levels of nitrogen and phosphorus may be related to the effect of relatively high additions of NH_4NO_3 and NaH_2PO_4 on increasing soil acidity. The acidification process of these two compounds affects the availability of some of the essential elements in the soil solution particularly K, Mg and Ca (Tisdale *et al*., 1985; Epstein, 2004). The overall result would be reduction in growth of the investigated species. On the other hand, the soil culture experiment showed that the investigated species continued to show apparent decrease in dry matter at levels of N and P higher than 30 and 20 mg, respectively. This may indicate that NaH_2PO_4 has a greater effect on increasing soil acidity than NH_4NO_3.

Analysis of variance for the factorial addition of N, P and K to *C. senna* (L.) showed phosphorus is a limiting nutrient for this species. The non-significant responses to the single additions of N and K were not surprising. This is because *C. senna* (L.) as mentioned above is a leguminous plant capable of fixing nitrogen. On the other hand, the non-significant response to K can be attributed to the relatively high amount of this nutrient already found in the soil used for experimentation (Table 1). The significant interactions between NP and PK indicated that N and K would come second in limiting the growth of *C. senna* (L.) after P. In other words, if P were not in short supply in the investigated site, then the expected limiting nutrients in this case would be N and K. This can also very clearly be seen from the NPK treatment which showed the highest F-value.

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