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PARTIAL SUBSTITUTION OF POTASSIUM BY SODIUM IN WHEAT

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ABSTRACT

A greenhouse experiment was conducted with a K-deficient red and laterite soil (Alfisols) of eastern India to assess the possibility and the extent of substitution of K by Na in wheat (*Triticum aestivum* L.). Treatments comprised of five levels of K substitution by Na on the basis of their equivalent weight: 0 (control), 2, 5, 10, and 20 percent. Available potassium in soil decreased progressively with advancement of plant growth and the highest decline was observed in 5 percent K substitution for Na, while the least decline was observed with 20 percent K substitution. Among the treatments where K was substituted by Na, the highest amount of available potassium was recorded in 2 percent substitution at all the stages of sampling. Dry matter production in 2 percent substitution of K by Na was at par with control. At all stages of sampling the calcium and magnesium concentration in plant with 2 percent substitution of K by Na was also at par with control. The experimental results thus suggested that 2 percent K substitution by Na could be permissible without sacrificing the yield of wheat in this soil.

INTRODUCTION

India and some other countries import huge quantity of potassic fertilizer each year as they do not have any potential K-bearing mineral reserve from which they can manufacture economically viable potassic fertilizer. Potassium plays many essential roles in plants, such as enzyme activation, osmotic regulation, photosynthesis, protein synthesis, starch formation, sugar translocation and for increasing crop resistance against biotic and abiotic stresses (Behera *et al*, 2015; Maurya *et al*, 2014). On the other hand, the role of Na in plants and its status as an essential element for all the higher plants is still debated. The low concentration of Na may be required for normal growth and development of some species under the family Chenopodeaceae. Sodium has been found to carry out some functions similar to K by substituting K to a considerable amount, especially when K is present in suboptimal concentrations (Jennings, 1976; Storey and Jones, 1979). The extent of such substitution, however, depends much on the uptake potential for Na^+, which varies with the plant species. Sodium improves the water balance of plants when the water supply is limited. Subba Rao *et al*. (2003) reported that Na can fully replace K in certain non-specific metabolic functions. Zhang *et al*. (2006) observed that growth and yield of cotton could be improved by adding appropriate amount of K and Na.

In this back-drop, the present greenhouse experiment was conducted with a K-deficient red and lateritic soil under the soil order Alfisols to study the possibility and extent of substitution of K by Na without sacrificing the growth of wheat so that India and other countries as well can save a considerable amount of foreign currency by reducing the import of K-fertilizers.

MATERIALS AND METHODS

Materials details

The surface soil (0-15 cm) sample used in the present investigation was collected from a cultivated field at the experimental farm of Viswa Bharati situated at 23°66′N latitude and 87°66′E longitude. The soil belongs to the soil order Alfisols. The processed soil sample (< 2 mm) was analyzed for pH, electrical conductivity (EC), organic carbon, cation exchange capacity, exchangeable calcium, magnesium and sodium following standard procedures (Jackson, 1973) and the values were 5.65, 0.07 dS m^{-1}, 3.8 g kg^{-1}, 11.25, 7.55, 1.90 and 0.60 cmol (p+) kg^{-1}, respectively. The particle size distribution measured by hydrometer method was 64.6 percent sand, 14 percent silt and 21.6 percent clay (Day, 1965).The initial nutrient status of soil with respect to primary nutrients was low: available nitrogen-125 mg kg^{-1}(Subbaih and Asija, 1956), available potassium- 47.73 mg kg^{-1}(Hanway and Heidel, 1952), 1N HNO_3 extractable K - 320 mg kg^{-1} (< 600 mg kg^{-1}) (Wood and Deturk, 1940), and available phosphorus - 9.58 mg kg^{-1}(Olsen *et al*., 1954).

Experimental details

The greenhouse experiment was conducted with 5 kg air-dried, processed (< 2 mm) soil sample placed in each plastic flower pot. The recommended fertilizer dose for wheat in this soil was: 100: 60: 60 (N: P_2O_5: K_2O), in which K was partially substituted at various levels with Na. Five treatments were: (i) no substitution (control), (ii) 2 percent substitution, (iii) 5 percent substitution, (iv) 10 percent substitution, and (v) 20 percent substitution of K by Na on the basis of their equivalent weights (Table 1). Nitrogen, phosphate and potash were supplied through laboratory grade ammonium sulphate, potassium dihydrogen phosphate and potassium chloride.

Calculated amounts of Na for various treatments were applied as sodium chloride. Ten seeds of a widely cultivating wheat variety of India (variety: UP-262) were sown in the 1st week of December, 2013 and of which five healthy seedlings were maintained in each pot. Treatments were replicated thrice and separate sets of treatment were maintained for destructive sampling at each sampling stage i.e., 30, 60, 90 and 120 days after sowing (DAS) of seeds. The experiment was laid out in completely randomized design. Irrigation was provided uniformly to each pot with de-mineralized water.

The soil samples collected at each sampling stage after air-drying and processing were analyzed for available K, 1N boiling HNO_3-K, exchangeable Ca, Mg and Na. Plant samples after harvesting at each sampling stage were air-dried followed by oven drying at 70°C The dry matter yield of plant samples was recorded, and each sample was ground separately and passed through a 20 mesh sieve. The concentration of K, Ca, Mg and Na in dry plant samples were determined in tri-acid digest (HNO_3: H_2SO_4: $HClO_4$:: 9 : 3 : 1).

Statistical analysis

The various soil and plant parameters at each sampling stage were statistically analyzed for analysis of variance. The treatment means were compared by least significant difference (LSD) test at 5% level of probability.

RESULTS AND DISCUSSION

The available K content in soil decreased progressively with plant growth in all the treatments (Table 2). The highest decline (41.40 mg kg^{-1}) was noticed in treatment (T_3) where 5 percent of K was substituted by Na, while the least (36.63 mg kg^{-1}) was recorded in treatment (T_5) where 20 percent substitution of K was done. Among the treatments receiving Na, the highest amounts of available soil K at 30, 60, 90 and 120th DAS (47.17, 45.58, 38.58 and 36.67 mg kg^{-1}) were recorded in treatment T_2 in which 2 percent potassium dose was substituted by Na, whereas at harvest, the least amount of available K (34.83 mg kg^{-1}) was recorded in T_3 treatment (5 percent K substituted by Na). The significant variation in available K contents in different treatments was not only the reflection of variable amount of K additions through differential degree of substitution of K by Na, but also because of variable K uptake pattern in the presence of Na.

1 N HNO_3 extractable K gives the measure of non-exchangeable K, since the latter form of K is computed as the difference between the former and available (1N NH_4OAc extractable) K. Irrespective of treatments, 1N HNO_3-extractable K decreased with the crop growth, signifying the fact that K was released from non-exchangeable sites to meet the demand of the crop for K (Table 2). Since the experimental soil was poor in available-K (< 52 mg kg^{-1}), the K nutrition in this soil was largely depended on the K-release from non-exchangeable sources. The results were in agreement with the findings of Bhangu and Sidhu (1990). At any growth stage, the 1N HNO_3-extractable K content in soil followed the order of- $T_5 > T_4 > T_3 > T_2 > T_1$. The highest amount of 1N HNO_3- K recorded in T_5 treatment with 20 percent substitution of K by Na was possibly attributed either to lesser demand for K since the role of K in plant metabolism was partially performed by Na^+ ion as evidenced by lesser decline in available K or harmful effect of Na^+ ion on plant growth as evidenced by lesser dry matter production (Table 4). The result was in conformity with Elshourbagy and Ahmed (1975) and Storey and Jones (1979) who reported the role of Na in osmotic relation, as well as with Besford (1978) and Marschner (1971) who mentioned the role of Na in mineral nutrition of plants particularly in K-deficient soil.

At any stage of sampling, available Na content in soils under various treatments responded positively to the degree of substitution of K by this element (Table 3). At the end of experimentation, there was a net decline in the available Na content from its initial value of (13.73 mg kg^{-1}) up to the treatment T_3 where 5 percent substitution of K by Na was done. The result thus indicated that up to this level of

Table 1: Treatment details

Treatment (% K substitution)	Amount of K substituted by Na (mg kg^{-1} soil)	Amount of Na added (mg kg^{-1} soil)	Available K* at 0th day
T_1 (0)	0	0	77.73
T_2 (2%)	0.6	0.35	77.13
T_3 (5%)	1.5	0.88	76.23
T_4 (10%)	3.0	1.76	74.73
T_5 (20%)	6.0	3.53	71.73

* Soil native available K plus fertilizer K

Table 2: Effect of levels of K-substitution by Na on available and1N HNO_3-K content in soil (mg kg^{-1})

Treatment	Available K				1N HNO_3-K			
	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS
T_1	43.25	40.80	39.17	37.58	308.00	280.66	260.00	252.00
T_2	47.17	45.58	38.58	36.67	309.33	296.00	283.33	270.66
T_3	46.92	41.58	37.83	34.83	312.33	303.33	287.33	276.66
T_4	46.42	39.67	36.00	35.83	315.66	304.23	291.33	279.33
T_5	43.83	42.17	38.58	35.10	318.16	302.56	294.66	284.17
S.E(m) ±	0.015	0.008	0.008	0.012	4.303	6.565	4.953	8.608
LSD (0.05)	0.033	0.018	0.017	0.026	9.587	14.627	11.035	19.179

Table 3: Effect of levels of K-substitution by Na on available Na, exchangeable Ca and Mg content in soil

Treatment	Available Na (mg kg^{-1})				Exchangeable Ca [cmol(p$^+$)kg^{-1}]				Exchangeable Mg [cmol(p$^+$)kg^{-1}]			
	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS
T_1	13.50	12.50	11.50	10.50	6.65	6.10	5.96	5.81	1.66	1.53	1.49	1.45
T_2	15.00	14.00	12.50	11.50	6.73	6.29	6.01	5.86	1.68	1.57	1.50	1.47
T_3	17.50	15.00	13.00	11.50	6.82	6.41	6.10	5.97	1.70	1.60	1.52	1.49
T_4	20.00	18.50	15.00	14.00	7.07	6.50	6.22	6.15	1.77	1.62	1.55	1.54
T_5	22.00	21.00	19.00	17.50	7.46	6.82	6.41	6.31	1.87	1.71	1.60	1.58
S.E(m) ±	1.56	0.78	0.76	0.71	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.01
LSD (0.05)	3.46	1.75	1.70	1.60	0.07	0.05	0.05	0.04	0.04	0.03	0.02	0.02

Table 4: Effect of levels of K substitution by Na on dry matter yield (g pot^{-1}) of wheat

Treatment	30 DAS	60 DAS	90 DAS	120 DAS
T_1	1.22	1.84	2.52	3.06
T_2	1.19	1.82	2.49	3.04
T_3	1.01	1.51	2.17	2.85
T_4	0.92	1.49	2.06	2.60
T_5	0.86	1.48	2.01	2.40
S.E(m) ±	0.01	0.01	0.01	0.02
LSD (0.05)	0.03	0.03	0.03	0.04

Table 5: Effect of levels of K-substitution by Na on K, Na, Ca and Mg content (%) in wheat plant

Treatment	K content				Na content				Ca content				Mg content			
	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS
T_1	2.33	2.50	2.80	3.06	0.175	0.180	0.185	0.192	0.690	0.940	1.210	1.660	0.390	0.640	0.807	1.120
T_2	2.26	2.43	2.56	2.93	0.250	0.268	0.287	0.290	0.580	0.920	1.150	1.620	0.380	0.610	0.780	1.090
T_3	2.18	2.36	2.49	2.76	0.266	0.290	0.305	0.312	0.560	0.890	1.120	1.590	0.373	0.600	0.760	1.060
T_4	2.06	2.26	2.40	2.65	0.285	0.300	0.308	0.325	0.520	0.740	1.080	1.520	0.343	0.500	0.720	1.020
T_5	2.03	2.20	2.36	2.56	0.305	0.310	0.320	0.345	0.510	0.730	1.000	1.400	0.343	0.490	0.680	0.930
S.E(m) ±	0.02	0.02	0.03	0.02	0.003	0.004	0.004	0.004	0.029	0.024	0.028	0.018	0.029	0.023	0.019	0.016
LSD (0.05)	0.06	0.05	0.038	0.04	0.006	0.009	0.009	0.009	0.064	0.053	0.062	0.040	0.065	0.051	0.042	0.036

Table 6: Effect of levels of K-substitution by Na on K, Na, Ca and Mg uptake by wheat plant (mg pot^{-1})

Treatment	K uptake				Na uptake				Ca uptake				Mg uptake			
	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS
T_1	28.43	46.00	70.56	95.63	2.130	3.310	4.663	5.877	8.410	17.300	30.500	50.800	4.770	11.770	20.400	34.260
T_2	26.89	44.35	63.90	87.07	2.975	4.891	7.164	8.816	6.902	16.790	28.704	49.248	4.522	11.133	19.469	33.136
T_3	22.00	35.63	51.21	65.55	2.680	4.373	6.620	8.890	5.660	13.400	24.300	45.327	3.730	9.057	16.500	30.210
T_4	18.95	33.67	49.44	63.18	2.617	4.483	6.340	8.447	4.780	11.020	22.250	39.520	3.220	7.460	14.823	26.520
T_5	17.45	34.48	50.05	60.72	2.620	4.583	6.427	8.227	4.390	10.800	20.100	33.600	2.920	7.260	13.670	22.320
S.E(m) ±	0.49	0.79	0.04	0.07	0.053	0.085	0.100	0.124	0.023	0.030	0.037	0.020	0.019	0.017	0.018	0.027
LSD (0.05)	1.09	1.76	0.10	0.16	0.118	0.189	0.223	0.276	0.051	0.067	0.082	0.045	0.042	0.038	0.040	0.060

substitution the uptake of Na exceeded the supply of Na from fertilizer source. Mengel and Kirkby (2001) reported the beneficial effects of Na^+ on plant growing on inadequate K^+ supply.

At any stage of sampling the degree of substitution of K by Na had a significant bearing on exchangeable calcium content in the soil. Exchangeable calcium content significantly increased with an increase in the degree of substitution. This result was attributed to the decrease in dry matter production and thereby decrease in calcium uptake with increase in the level of substitution of K by Na. The result was corroborated well with the findings of Rengel (1992) and Cramer (2002) who concluded that the concentration of Ca was affected by the concentration of Na, since Na and Ca might compete for influx through non-selective cation channels. Exchangeable Mg content in the soil behaved similarly as the exchangeable Ca content. Higher was the level of substitution of K by Na, lesser was the amount of Mg absorption by the plant and therefore higher was the exchangeable Mg content in the soil.

At any growth stage, the highest dry matter yield (1.22, 1.84, 2.52 and 3.06 g pot^{-1}) was recorded in treatment T_1 where there was no substitution of K by Na (Table 4). Barring few exceptions, with an increase in the level of K substitution by Na, the dry matter production decreased significantly, possibly either due to deficient supply of K or the toxic effect of Na ion on the wheat plant. At harvest, the dry matter production in treatment T_2 (3.04 g pot^{-1}) was at par with the treatment T_1 (3.06 g pot^{-1}), suggesting 2 percent substitution of K by Na could be done without sacrificing the dry matter yield of wheat. The result was in conformity with the findings of numerous workers who opined that despite the non-essentiality of Na, its application to the growth medium stimulated the growth of many plants including wheat (Larson and Pierre, 1953; Subba Rao *et al*., 2003). However, the substitution of K by Na to the tune of 20% (equivalent weight basis) caused 21.5% reduction in dry matter yield compared with the control (T_1).

Table 7: Effect of levels of K-substitution by Na on nutrient ratios in 120 DAS old wheat plant

Treatment	Na^+/K^+	Na^+/Ca^{2+}	Na^+/Mg^{2+}
T_1	0.063	0.120	0.163
T_2	0.107	0.180	0.263
T_3	0.123	0.200	0.290
T_4	0.133	0.210	0.320
T_5	0.146	0.250	0.370
S.E (m) ±	0.003	0.014	0.023
LSD (0.05)	0.007	0.031	0.051

Potassium content in plant increased with the growth but decreased with the degree of substitution of K by Na (Table 5). The decrease in K concentration in wheat plant with increase in the level of substitution at any stage of sampling might be either due to less availability of K or toxic effect of Na ion to wheat plant. On the contrary, the concentration of Na in plant increased both with the plant growth and level of substitution of K by Na. The decrease in the concentration of K with the degree of substitution was almost quantitatively equivalent to the increase in Na concentration up to 2 percent substitution of K. This finding was corroborated with the observation of Subba Rao *et al*. (2003) who opined that Na could replace K for vacuolar functions for which 95 percent of total absorbed K was required. However, the degree of substitution of K by Na had a negative impact on Ca and Mg content in plant. At any stage of sampling Ca and Mg contents at 2 percent substitution were at par with the treatment T_1 where no substitution was done which indicated that 2 percent substitution of K by Na could not significantly affect Ca and Mg intake of plant and the dry matter yield.

Potassium uptake by wheat plant increased progressively with crop growth, but decreased significantly with progressive increase in the level of substitution of K by Na at any stage of sampling (Table 6). This was attributed to the cumulative effect of decrease in dry matter production and K concentration in plant with an increase in the level of substitution. Zhang *et al*. (2006) also reported that lower level of K substitution (1/3rd) by Na enhanced early development of cotton seedlings, while higher replacement (2/3rd or 100% with Na) restricted seedling growth and nutrient uptake. In comparison with K uptake, the uptake of Na by the wheat plant was at a lesser amount. However, the highest Na uptake at any stage of sampling was always (except in 120 DAS old plant) recorded with T_2 treatment where 2 percent K was substituted by Na. This was attributable to the cumulative effect of highest dry matter production coupled with higher Na concentration in plants in this treatment. Beyond this level of substitution, though Na concentration in plants increased with increasing substitution levels, possible toxic effect of Na on plant reduced the Na uptake.

Sodium nutrition had a negative effect on both Ca and Mg uptake by the wheat plant (Table 6). Reduced Ca concentration in the plant might be attributable to inhibitory effect of Na on Ca uptake through non-selective cation channels in the plasma lemma of root epidermal cells (White, 1998) or NaCl interference with active Ca release from the root endodermal cells into the xylem vessels (Halperin *et al*., 1997).

The Na to K ratio in the wheat plant varied between 0.063 and 0.146, whereas Na to Ca ratio between 0.120 and 0.250 and Na to Mg ratio between 0.163 and 0.373 (Table 7). The data revealed that ratios between Na to other cations became almost double with 20 percent (T_5) substitution of K by Na in comparison with the control (T_1). Maathuis and Amtmann (1999) suggested that non selective cation channels in plasma membrane had high Na/K selectivity and provided a pathway for the entry of Na into plant cells. Furthermore, Ebert *et al*. (2002) and Shabala *et al*. (2006) confirmed the competition between Na and Ca for non-selective cation channels. However, Wakeel (2008) proposed that non-selective cation channels might not be responsible for higher Na/Ca ratio with increase in the degree of substitution, rather reduced translocation from root to shoot might be responsible for the decreased Ca uptake.

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