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Effects of potassium on temporal growth of root and shoot of wheat and its uptake in different soils

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Abstract

In a pot culture experiment, the root length density, potassium concentration in crop, and total K uptake by wheat (*Triticum aestivum* var. HD 2285) at different growth stages (*CRIS*-Crown Root Initiation Stage, *MTS*-Maximum Tillering Stage, *FLS*-Flag Leaf Stage and *DFS*-Dough Formation Stage) were determined. Wheat crop was grown in 72 pots containing 4.5 kg of three types of soils, namely Alfisol, Vertisol, and Inceptisol. Pots were divided into two sets, that is, with 50 mg kg^{-1} K as basal and another 50 mg kg^{-1} was top dressed at 45 days after sowing and without potassium. Optimum doses of N, P and other macro-and micro-nutrients were given to the crop. At different stages of wheat growth (22, 41, 69, and 87 days after germination), the shoot was harvested and the soil in the pot was screened carefully under moist condition to collect total roots and measuring the root volume and mean root diameter. Using root volume and mean diameter of root, total root length and then root length density were calculated. Results show that the wheat dry matter yields increased gradually with crop age and it was more in Inceptisol followed by Vertisol and Alfisol. Potassium deficiency decreased total root length (*TRL*) and root length density (*RLD*) in the last stages of wheat growth particularly in Vertisol and Alfisol. Potassium concentration in wheat at different stages of crop growth was found to be less in Alfisol than in Vertisol and Inceptisol. At different stages of wheat growth, potassium uptake (mg pot^{-1}) was found to be less in Alfisol than in Vertisol and Inceptisol. The uptake values increased sharply with the age of the crop up to 69 days after germination (FLS), but the rate of potassium accumulation showed a gradual decrease thereafter, in soils, which received optimum amount of potassium.

Keywords: Growth stages; Potassium; Root length density; Total root length; Wheat crop

Introduction

Plant roots grow because new cells form in the meristematic tissues near the root tip and the newly formed tissues expand in volume, pushing the root tip forward. The amount of water and the nature of nutrient uptake from the root zone are established by the interactions of various physical, chemical, and biological processes. The root length density

(*RLD*) is an important parameter to model water and nutrient movement in the vadose zone and to study soil-root-shoot-atmosphere interactions (Qiang et al., 2004). Root length density declined gradually with depth, the period of fastest growth of root occurred after early head before anthesis and root length in each layer reached a maximum during flowering stage (Feng and Ming, 1998). Tukey (1970) was the first to use the term "leaching" to describe the removal of mineral nutrients from leaves soaked in water, a process he apparently envisioned as similar to leaching of mineral ions, such as K^+, in soil and extraction of soluble materials from decomposition leaves by rain.

Effects of K source and rate on Tifway bermudagrass shoot and root growth, quality and tissue K concentration were studied in a 3-yr field study in Central Florida. Two K sources (KCl and K_2SO_4) were applied during 90 days, at eight rates (0, 3.7, 7.4, 9.8, 14.7, 22.0, 29.4, and 36.8 g Km^{-2}) in conjunction with N applied monthly at 4.9 gm^{-2}. Potassium chloride produced a more rapid shoot growth than did K_2SO_4, but this effect may be linked to the N source. Bermudagrass shoot growth rate and tissue K concentrations were increased by potassium fertilization up to 7.4 g Km^{-2}. There were no additional increases in either of the aforementioned parameters, regardless of the K level applied. Observed turfgrass growth responses to Mehlich-1 extractable K levels suggest that 30 mg K kg^{-1} soil may be adequate for optimum growth (Sartain, 2002). In a field study, K as a KCl solution and Rb as a RbCl solution were injected into mini-plots at depths of 0, 3, 9, 15 or 21 inches on 2 Ultisols low in test K in Alabama in 1992 (Pate et al., 1994). Selected combinations of each depth were also included. K was applied at 120 lb K_2O/acre. Root length density measurements were not significantly different for surface applied or deep applied K. As Baligar (1985) reported, only a small fraction of the plant K requirement is attained by root interception. The bulk of K has to be transported to the growing roots by mass-flow and diffusion in which diffusion mechanism plays the major role. Studies were undertaken to evaluate soil and plant parameters that might have influence on K supply mechanisms in soil and on plant uptake of K. Increasing wheat plant density led to competition for K absorption and resulted in lower K uptake by plant. In high plant density treatment, about 60% of the K requirement was met by diffusion process whereas in low plant density treatment mass-flow contributed most of the K demand. Solution diffusion and mass-flow were the major mechanisms of K supply to wheat roots. The mechanism of K supply to different crop species is attributable to differences in the K requirements, water flux rates and to the differences in root parameters.

Roshani et al. (2009) reported that, the distribution of root length density with time was very closely fitted with a symmetric normal distribution curve. Thus, the *RLD* can be expressed as a function of time with the following equation: $RLD = A*\exp[-(B-t)^2/C]$.

where, *A* is a constant indicating maximum root length density attained during growth period, *B* is the number of days after emergence at which the maximum root length density is attained, *C* is a constant, and *t* is time in days after emergence. They found that the root length density increased from an initial low value to maximum at 69 days after germination and then decreased gradually. The observed root length density is the net result of growth and decay processes. While initially growth rate was more than the decay rate, after attaining maximum decay rate was more than the growth rate. For field-grown crop, this relationship was applied for all the layers of rooted soil. In that case the constant, A, depicting the maximum value was assumed to decrease exponentially with depth of layer.

The objective of the present investigation was to examine the effects of potassium on root length density of wheat at different stages of crop growth and in different soils of India.

Materials and Methods

In a pot culture experiment, the Root Length Density (*RLD*) was determined for wheat at different stages (*CRIS*-Crown Root Initiation Stage, *MTS*-Maximum Tillering Stage, *FLS*-Flag Leaf Stage and *DFS*-Dough Formation Stage). Wheat crop was grown in properly sealed 8-kg capacity stone core pots containing 4.5 kg of three types of soils, namely Alfisol, Vertisol, and Inceptisol. General descriptions of the collected Indian soils profile are presented as follows:

(i) Alluvial soil: Fine loamy, calcareous, hyperthermic Typic Haplustept.

The Mehrauli series is formed in calcareous alluvium on nearly level land at elevation of 228 m above MSL. The climate is semi-arid, sub-tropical with hot summers and cool winters. The mean monthly maximum and minimum temperatures during the year ranges from 21.3 to 40.5 ºC and 7.3 to 28.7 ºC, respectively. The mean annual rainfall is 708 mm.

(ii) Black soil: Fine, montmorillonitic, hyperthermic Typic Haplustert.

The Nabibagh-4 soils are formed in basaltic alluvium on very gently sloping to slightly undulating land at an elevation of 480 to 490 m above MSL. The climate is sub-humid sub-tropical with mean annual temperature of 25 ºC and mean annual rainfall of 1208 mm. Typically soils have dark grayish brown to very dark grayish brown, mildly alkaline, silty clay to clay soils developed over weathered basaltic alluvium. Soils are cultivated to soybean, wheat, pigeonpea and chickpea, and the natural vegetations are *Acacia* spp. (Babul) and *Ziziphus* spp. (Ber.).

(iii) Red soil: Fine, kaolinitic, isohyperthermic Typic Kandiustalfs

Soils have reddish brown to yellowish red, sandy clay loam to sandy clay A horizon and red, dark reddish brown or dark red clayey B_t horizon. They have developed on lateritic materials on granite gneiss, on gently sloping pediments at an elevation of 895 m above MSL. The climate is semi-arid tropical, with mean annual air temperature of 23.6 ºC and mean annual rainfall of 870 mm.

Basic physicochemical properties of soil used are presented in Table 1. Pots were placed randomly in greenhouse. A deionizer was used for production of large quantity of deionized water to irrigate the experimental pots, because tap water could not be used for irrigation as it contained about 6 mg L^{-1} soluble potassium. With such high K concentration, it is not possible to exhaust potassium from different soils for further experimentations. Measured quantity of deionized water was applied to the pots depending on the amount of evapo-transpiration, which was calculated by daily weighing method.

Table 1. Characteristics of the soils under study.

Soil \ Parameter	pH[1]	EC (dS m^{-1})	OC (%)	Avail. P (mg kg^{-1})	Avail. K (mg kg^{-1})	Sand (%)	Clay (%)	Texture[2]
Inceptisol	7.2	0.16	0.72	14.3	77	67.3	15.7	SL
Vertisol	7.8	0.30	0.96	9.4	166	7.2	55.5	C
Alfisol	6.9	0.14	0.61	6.8	63	48.5	37.5	SC

[1]For both pH and EC the soil: water suspension was 1: 2.5.

[2]SL, C, and SC stands on Sandy Loam, Clayey, and Sandy Clay soil texture.

Pots were divided into two sets, that is, with and without potassium. Optimum doses of N and P and other macro-and micro-nutrients were given to the crop. Potassium, was given in half the number of the pots, (50 mg kg^{-1}). This amount of applied K is optimum based on the results of the soil test and suggestions of local experts in plant nutrition. Nitrogen (50 mg kg^{-1}), phosphorous (20 mg kg^{-1}), copper (1 mg kg^{-1}), manganese (2 mg kg^{-1}), iron (5 mg kg^{-1}), and zinc (2 mg kg^{-1}) were applied as basal dose to all the pots and another 50 mg kg^{-1} N and K were top dressed at 45 days after sowing. Urea and di-ammonium phosphate were used as sources of N and P, and potassium chloride served as source of potassium.
Treatment combinations were:
Type of soils (Inceptisol, Vertisol, and Alfisol) : 3
Stages of growth and *RLD* determination: 4
Potassium treatments (with and without K) : 2
Total number of treatments : $3x^4$ x^2 = 24
Replication : 3
Total number of pots : 72

There were 72 pots, from which root length density at different stages of plant growth have been determined. At different stages of wheat growth (22, 41, 69, and 87 days after germination), the shoot was harvested and the whole soil in the pot was screened carefully under moist condition to collect total roots which were then washed and measured for root volume by measuring cylinder, mean root diameter by counting the number of root per unit length on a grid transparent paper after blotting excess water. Using root volume and mean diameter of root, total root length was calculated, and then root length density was calculated by dividing total root length by total volume of the soil (Datta, 2001). Root length density, total dry matter weight and total K uptake by plants (shoot + root) and exchangeable K in soils were analyzed following the standard procedure.

Results

Total dry matter weight

At 22, 41, 69, and 87 days after germination (DAG) shoot portion was harvested and root mass was separated from the soil of each pot. Total dry matter weight, potassium content in root and shoot, root volume, mean root diameter, total root length and root length density were determined. Total dry matter weight of wheat is presented in Table 2. The results show a steep increase of dry matter production from 22 DAG to 69 DAG. In any particular soil, there are significant differences (with 99% probability) in producing total dry matter between different stages of wheat growth (with and without potassium application). Nevertheless, except at *MTS* in which wheat planted in Inceptisol produced a significant dry matter (with 95% probability) in comparison with two other soils, there are not any significant differences between the three soils in producing dry matter.

Root growth

In the Inceptisol total root length (*TRL)* was 58.9 and 50.7 m at 22 DAG under the treatments with and without K and it was as high as 338 and 306 m, respectively at 69

DAG, but at dough formation stage *TRL* decreased slightly to 286 and 257 m at 87 DAG. The root length density (*RLD)* also followed a similar trend and it was 1.80 and 1.55 cm cm^{-3} at 22 DAG due to +K and-K treatments, respectively, while the corresponding values were 10.3 and 9.34 cm cm^{-3} at 69 DAG and finally decreased to 8.73 and 7.85 cm cm^{-3} at 87 DAG (Table 3).

Table 2. Total dry matter weight (g pot^{-1}) of wheat at different stages of crop growth.

Stages / Soil	without potassium application				with potassium application			
	CRIS[1]	*MTS*	*FLS*	*DFS*	*CRIS*	*MTS*	*FLS*	*DFS*
Inceptisol	1.85	14.6	25.1	36.9	2.24	16.2	29.1	37.5
Vertisol	1.63	10.5	20.2	38.2	2.07	12.0	25.7	34.5
Alfisol	2.18	10.5	22.6	34.0	2.65	13.4	26.4	33.6

Critical Differences (CD) at probability levels of 1% = 4.66, 5% = 3.49

[1]Crown Root Initiation Stage, Maximum Tillering Stage, Flag Leaf Stage, and Dough Formation Stage were 22, 41, 69, and87 days after germination.

Table 3. Total root length (A) and root length density (B) during crop growth of wheat.

A. Total Root Length (m) of wheat in different soils.

Stages / Soil	without potassium application				with potassium application			
	CRIS	*MTS*	*FLS*	*DFS*	*CRIS*	*MTS*	*FLS*	*DFS*
Inceptisol	50.7	131	306	257	58.9	141	338	286
Vertisol	46.4	193	249	254	60.0	241	336	303
Alfisol	38.5	99.2	150	221	43.0	127	243	240

Critical Differences (CD) at probability levels of 1% = 55.6, 5% = 41.7.

B. Root Length Density (cm cm^{-3}) of wheat in different soils.

Stages / Soil	without potassium application				with potassium application			
	CRIS	*MTS*	*FLS*	*DFS*	*CRIS*	*MTS*	*FLS*	*DFS*
Inceptisol	1.55	4.01	9.34	7.85	1.80	4.31	10.3	8.73
Vertisol	1.39	5.78	7.43	7.58	1.79	7.20	10.0	9.07
Alfisol	1.34	3.46	5.21	7.69	1.50	4.41	8.46	8.37

Critical Differences (CD) at probability levels of 1% = 1.71, 5% =1.28.

In the Vertisol *TRL* was 60 m with K and 46.4 m without K at 22 DAG, such values were 336 and 249 m at 69 DAG, and 303 and 254 m at 87 DAG. In the Vertisol also *RLD* followed a similar trend and it was 1.79 cm cm^{-3} with K application and 1.39 cm cm^{-3} without K application at 22 DAG, and the corresponding values were 10.0 and 7.43 cm cm^{-3} at 69 DAG and finally decreased to 9.07 and 7.58 cm cm^{-3} at 87 DAG.

In the Alfisol the *TRL* under treatments with and without K was 43.0 and 38.5 m at 22 DAG, while the respective values were 243 and 150 m at 69 DAG, and 240 and 221 m at 87 DAG. The values of *RLD* also followed nearly similar trend and it was 1.50 and 1.34 cm cm^{-3} at 22 DAG, 8.46 and 5.21 cm cm^{-3} at 69 DAG and 8.37 and 7.69 cm cm^{-3} at 87 DAG under all nutrient and all but K were applied at optimum dose, respectively.

Potassium concentration

In all the soils and at the first stage of crop growth, *CRIS,* the amount of potassium concentration was very high and having significant differences with 99% probability in comparison with the next stages (Table 4).

Potassium uptake

Although there was not any significant differences, but at different stages of wheat growth, potassium uptake (mg pot^{-1}) was found to be less in Alfisol than in Vertisol and Inceptisol. It followed the same trend as total dry matter production. The difference between potassium uptakes by wheat crop in different stages of crop growth was significant. The uptake values increased sharply with the age of the crop up to 69 *DAG*, but the rate of K accumulation showed a gradual decrease thereafter in soils received optimum amount of potassium (Table 5).

Table 4. Potassium concentration (%) of wheat at different stages of crop growth.

Stages / Soil	without potassium application				with potassium application			
	CRIS	*MTS*	*FLS*	*DFS*	*CRIS*	*MTS*	*FLS*	*DFS*
Inceptisol	9.39	2.53	2.71	1.66	11.67	3.37	3.63	1.80
Vertisol	8.34	3.26	3.26	1.17	8.32	4.18	3.99	1.74
Alfisol	6.09	2.91	2.79	0.91	6.26	3.67	3.61	1.44

Critical Differences (CD) at probability levels of 1% =1.69, 5% = 1.22.

Table 5. Potassium uptake (mg pot^{-1}) of wheat at different stages of crop growth.

Stages / Soil	without potassium application				with potassium application			
	CRIS	*MTS*	*FLS*	*DFS*	*CRIS*	*MTS*	*FLS*	*DFS*
Inceptisol	173	368	678	614	261	514	974	670
Vertisol	136	343	660	446	172	466	901	639
Alfisol	133	307	630	310	166	431	874	485

Critical Differences (CD) at probability levels of 1% = 77.3, 5% = 57.9.

Discussion

It is evident from the data that wheat dry matter weights were better in Inceptisol followed by Vertisol and Alfisol. Total dry matter of wheat increased gradually from 22 to 87 DAG and the trend of changes of total dry matter weight of wheat crop is shown in Table 2. Steep increases of dry matter production from 22 DAG to 69 DAG were noticed. Potassium deficiency decreases total root length (*TRL*) and root length density (*RLD*) in the last stages of wheat growth particularly in Vertisol and Alfisol. Changes in *TRL* and *RLD* with plant age showed a curvilinear relationship. As it is evident from Tables 1 and 3, because of the large increase in the biomass recorded after *CRIS,* the potassium concentration within the plant went down drastically even though potassium uptake by plant might continue. After *FLS* possibly a small quantity of potassium has been lost by the plant through roots and by leaf senescence. The loss of potassium between flowering and maturity may be the result of secretion of a substantial amount of potassium from the roots into the soil during the period of grain formation. However, experiments by Heder (1971) have shown that only one or two percent of the total K content of the plant is secreted in this way and it is suggested that this loss of K from maturing cereals is mainly due to leaf senescence (a percentage of the total biomass in the form of initial elder leaves and immature tillers) and the washing of K from maturing plant by rainfall.

Maximum potassium uptake was reached some time before maximum dry matter production and the potassium content decreased as the grain matures and then K is lost from the plant in case of all cereals. In one study (Sturm and Jungk, 1972) it was found that total K taken up by the time of flowering was as much as 200 kg K /ha whereas at maturity, the above ground portion of the crop contained only 125 kg K ha^{-1}. As it is evident from the summarized results in Table 5, in Inceptisol, even without any potassium application the amount of K uptake (mg pot^{-1}) by wheat at *DFS* decreased significantly, with 95% confidence, in comparison with *FLS* while with potassium application the decrease in K uptake is significant with 99% confidence. In both, Verisol and Alfisol, with 99% confidentiality, there are significant decreases between K uptakes by wheat crop in *DFS* with *FLS* with and without potassium application.

As Hanadi et al. (2002) reported, plant species differ in their potassium efficiency, but the mechanisms are not clearly documented and understood. Therefore, K efficiency of spring wheat, spring barley, and sugar beet was studied under controlled conditions on a K fixing sandy clay loam. The effect of four K concentrations in soil solution ranging from low (5 and 20 μM K) to high (2.65 and 10 mM K) on plant growth and K uptake was investigated at 3 harvest dates (14, 21, and 31 days after sowing). Wheat proved to have a higher agronomic K efficiency than barley and sugar beet, indicated by a greater relative yield under K-deficient conditions. Even at low K concentrations in the soil solution, sugar beet had a 7 to 10 times higher K influx than the cereals, indicating that sugar beet was more effective in removing low available soil K. Wheat and barley were characterized by slow shoot growth, low internal K requirement, i.e. high K utilization efficiency, and high root length/shoot weight ratio (RSR), resulting in a low K demand per unit root length. At low soil K concentrations, both cereals increased K influx with age, an indication of adaptation to K deficiency.

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