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Enhanced root traits and productivity of maize (*Zea mays*) and wheat (*Triticum aestivum*) in maize - wheat cropping system through integrated potassium management

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ABSTRACT

A field experiment was conducted during the *kharif* and *rabi* seasons of 2010-11 and 2011-12 at Indian Agricultural Research Institute, New Delhi to find out the performance of maize (*Zea mays* L.) – wheat (*Triticum aestvum* L.) cropping system with potassium (K) fertilization through muriate of potash and farmyard manure. Ten treatments were evaluated in randomized block design with three replications. All the treatment with potassium irrespective of sources showed significant increase in grain yield. Application of 60 kg K through muriate of potash + 30 kg K through farmyard manure produced highest grain yield of maize (4.44 and 5.42 tonnes/ha) and wheat (5.39 and 5.49 tonnes/ha), which was significantly superior over grain yield of maize (2.21 and 2.72 tonnes/ha) and wheat (3.80 and 3.89 tonnes/ha) as obtained from control during both the years. Application of K showed better root growth over no K application. In maize, application of 90 kg K/ha, supplemented 60 kg K/ha through MOP and 30 kg K/ha through farmyard manure (FYM) recorded highest root length density (4.51 and 4.33 cm/cm^3), surface area density (1.31 and 1.11 cm^2/ cm^3) root volume density (30.5 and 28.6 cm^3/cm^3) and dry weight (9.0 and 10.1 g/plant). Similarly, in wheat the same treatment also recorded highest root length density (2.7 and 3.03 cm/cm^3), surface area density (0.60 and 0.64 cm^2/ cm^3), root volume density (12.52 and 16.9 cm^3/cm^3) and dry weight (2.43 and 2.84 g /plant) during both the years.

Key words: Farmyard manure, Root length density, Root surface area density, Root volume density, Root dry weight, Yield

Potassium (K) is one of the essential nutrients for plant growth and development. In most of the crops large amounts are absorbed from the root zone. It is very crucial as it does interact with other essential nutrients both antagonistically and synergistically. K improves root growth (Polara *et al.* 2010), maintains turgor, reduces water loss and wilting, drought resistance (Nejad *et al.* 2010), prevents energy losses, enhances translocation of nutrient and assimilates, produces grain rich in starch, increases protein content of plants, builds cellulose and reduces lodging, retard crop diseases. Potassium deficient conditions may result into reduction in both the number and the size of leaves, reduced assimilates production and transport from the leaves to the sink and reduced yield and quality production (Pettigrew 2008).

Being a major organ for nutrient uptake, the root plays an important role in soil-plant system (Lynch *et al.* 2007). Its growth is directly related with the growth and biomass yield of shoots. Generally, plants have a characteristic of enhancing their efficiency of nutrient acquisition to overcome the stress from nutrient deficiency or root competition. Flexibility in biomass allocation, root morphology and root distribution pattern has been found to be an important adaptive mechanism to exquisite nutrients (Lynch *et al.* 2007, Xie *et al.* 2006, Yang *et al.* 2005, Rengel and Marschner 2005).

Høgh-Jensen and Pedersen (2003) reported that low and moderate K levels affected the root morphology in pea, red clover, lucerne, barley, rye, perennial ryegrass and oilseed rape. Crops modify their root hair length in response to low K, and thereby maintain the uptake from sparingly soluble K sources. Similarly, Jia *et al.* (2008) reported that deficiency of potassium results into small root morphology and growth. Eldardiry *et al.* (2010) reported that increase in K-application rate increased the yield of grains and straw as well as seed index and grain/straw ratio in wheat crop.

In view of the above facts the present study was undertaken to study the effect of K management on root growth and yield of maize (*Zea mays* L.) - wheat - (*Triticum aestivum* L.) cropping system to enhance crop productivity.

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MATERIALS AND METHODS

The field experiments were conducted during the rainy (*kharif*) and winter (*rabi*) seasons of 2010-11 and 2011-12 at Research Farm of Indian Agricultural Research Institute, New Delhi situated in north western India (28.35 N, 77.12' E) and at 228.6 m above mean sea level. Ten sets of treatment combinations for both maize in *kharif* and wheat in *rabi* season were evaluated at fixed site in randomized block design with three replications. The soil of was sandy loam with pH 8.0, organic carbon 0.4%, medium in available N 173.2 kg/ha by alkaline permanganate method, P 13.8 kg /ha and K 261 kg/ha was estimated by Flame photometer. Recommended dose of 150 kg N/ha and 26 kg P/ha were applied to maize through urea and DAP, respectively. The full dose of P, K and 50 kg N/ha were applied as basal and remaining 100 kg N/ha was given as 50 kg N/ha each in two splits at 30 days after sowing (DAS) and 60 DAS. Muriate of potash (MOP) and farmyard manure (FYM) were used as sources of potassium and applied as per treatments. The amount of urea, DAP and FYM was adjusted based on their nitrogen, phosphorus and potassium content. In wheat, the recommended dose of P, K and 60 kg N/ha was given as basal and remaining 60 kg N/ha as 30 kg N/ha each at 30 DAS and at 60 DAS. Similarly, potassium was applied as per treatments: No K to maize and wheat – K$_0$ (M) – K$_0$ (W), 60 kg K/ha through MOP in maize and no K in wheat – MOP $_{60}$ (M) – K$_0$(W), 30 kg K through MOP and 30 kg K through FYM in maize and 60 kg K through MOP in wheat – MOP$_{30}$ + FYM$_{30}$(M) – MOP$_{60}$ (W), 60 kg K through MOP and 30 kg K through FYM in maize and no K in wheat – MOP$_{60}$ + FYM$_{30}$ (M) – K$_0$ (W), 30 kg K through MOP and 30 kg K through FYM in maize and no K in wheat – MOP$_{30}$ + FYM$_{30}$ (M) – K$_0$ (W), no K in maize and 60 kg K through MOP in wheat – K$_0$ (M) –MOP$_{60}$ (W), no K in maize and 30 kg K through MOP and 30 kg K through FYM in wheat – K$_0$ (M)– MOP$_{30}$ + FYM$_{30}$ (W), 60 kg K through MOP in maize and 30 kg K through MOP and 30 kg K through FYM in wheat – MOP$_{60}$ (M) – MOP$_{30}$ + FYM$_{30}$ (W), 60 kg K through MOP in maize and 60 kg K through MOP in wheat – MOP$_{60}$ (M)– MOP$_{60}$ (W), no K in maize and 60 kg K through MOP and 30 kg K through FYM in wheat – K$_0$ (M) –MOP$_{60}$ + FYM$_{30}$ (W). All the nutrients were given by broadcast and thoroughly mixed in the soil before sowing. The maize variety PEHM 2 and wheat variety HD 2967 were used for the experiment. The spacing for maize was adopted 60 cm × 20 cm and for wheat 22.5 cm row distance using 20 kg/ha seed for maize and 100 kg/ha for wheat. Root studies were carried out at 0-15 and 15-30 cm soil depths during both the years at silking stage and panicle initiation stage for maize and wheat respectively. The soil adhered to roots were washed gently following the method of Costa *et al.* (2000). Root length, surface area and volume were measured using a Hewlett Packard scanner controlled by WIN RHIZO Programme V. 2002C software (Regent Instruments Inc. Ltd, Quebec, Canada). After measurement, roots and above ground plant parts were kept dried and dry weight was measured to calculate root: shoot ratio. The converting into density root length, surface area and root volume were divided by volume of soil sample taken through 15cm long augur with 10 cm diameter. The experimental data were statistically analyzed using 'ANOVA' technique for randomized block design (Gomez and Gomez 1984). The least significant difference (LSD) at 0.05 probabilities was worked out for comparing mean values of treatments for all parameters.

RESULTS AND DISCUSSION

Root studies

Different root parameters, viz. root length density, surface area density, root volume density and root dry weight were recorded (Table 1 and 2) at silking stage in maize and at boot leaf stage in wheat at 0-15 cm and 15-30 cm depth.

During *kharif* season 2010, treatments applied with potassium showed significant superiority over treatments

Table 1 Effect of potassium fertilization on root parameters (0-15 cm depth) of maize during 2010 and 2011

Treatment	Root length density (cm/cm^3)		Surface area density (cm^2/cm^3)		Root volume density (× 10^{-3}) (cm^3/cm^3)		Root dry weight (g/cm^3 volume of soil)	
	2010	2011	2010	2011	2010	2011	2010	2011
K$_0$ (M) – K$_0$ (W)	2.93	1.59	0.87	0.53	16.9	9.7	2.5	2.9
MOP $_{60}$ (M) – K$_0$(W)	3.46	3.65	0.98	0.85	18.9	17.8	5.4	5.8
MOP$_{30}$+FYM$_{30}$(M) –MOP$_{60}$ (W)	3.90	4.03	1.11	1.00	22.8	25.6	6.9	8.0
MOP$_{60}$+ FYM$_{30}$ (M) – K$_0$(W)	4.51	4.33	1.31	1.11	30.5	28.6	9.0	10.1
MOP$_{30}$+ FYM$_{30}$ (M) – K$_0$(W)	3.96	4.02	1.10	0.99	22.4	23.4	7.0	7.8
K$_0$(M) –MOP$_{60}$ (W)	3.06	1.67	0.87	0.58	16.8	10.7	2.4	3.5
K$_0$(M) – MOP$_{30}$+ FYM$_{30}$(W)	3.04	1.80	0.87	0.58	16.5	11.7	2.4	3.6
MOP$_{60}$(M)–MOP$_{30}$ +FYM$_{30}$(W)	3.46	3.80	0.98	0.90	19.2	19.3	5.4	6.6
MOP$_{60}$ (M) – MOP$_{60}$ (W)	3.45	3.65	0.98	0.86	18.9	18.1	5.3	5.9
K$_0$ (M) –MOP$_{60}$ +FYM$_{30}$ (W)	3.08	1.83	0.87	0.60	16.9	12.5	2.4	3.8
LSD(P=0.05)	0.37	0.29	0.10	0.07	1.9	2.8	0.7	0.9

Table 2 Effect of potassium fertilization on root parameters (0-15 cm depth) of wheat during 2010-11 and 2011-12

Treatment	Root length density (cm/cm^3)		Surface area density (cm^2/ cm^3)		Root volume density (× 10^{-3}) (cm^3/ cm^3)		Root dry weight (g/cm^3 volume of soil)	
	2010	2011	2010	2011	2010	2011	2010	2011
K_0 (M) – K_0 (W)	1.38	1.43	0.41	0.43	6.38	6.5	0.94	1.03
MOP $_{60}$ (M) – K_0(W)	1.49	1.61	0.42	0.45	6.84	7.3	1.06	1.16
MOP_{30}+FYM_{30}(M)–MOP_{60} (W)	2.51	2.91	0.54	0.59	9.24	13.5	1.97	2.56
MOP_{60}+ FYM_{30} (M) – K_0(W)	1.57	1.70	0.45	0.47	7.44	8.3	1.11	1.25
MOP_{30}+ FYM_{30} (M) – K_0(W)	1.51	1.66	0.44	0.46	7.17	7.9	1.02	1.18
K_0(M) –MOP_{60} (W)	2.40	2.54	0.50	0.53	8.87	10.7	1.67	1.80
K_0(M) – MOP_{30}+ FYM_{30}(W)	2.58	2.59	0.55	0.54	10.67	11.2	2.12	1.92
MOP_{60}(M)–MOP_{30}+FYM_{30}(W)	2.64	2.96	0.57	0.61	10.46	13.8	2.15	2.60
MOP_{60} (M) – MOP_{60} (W)	2.49	2.66	0.51	0.57	9.13	11.4	1.76	2.28
K_0 (M) –MOP_{60} +FYM_{30} (W)	2.70	3.03	0.60	0.64	12.52	16.9	2.43	2.84
LSD(P=0.05)	0.20	0.31	0.04	0.06	1.04	1.75	0.26	0.21

Table 3 Effect of integrated potassium fertilization on grain and straw yield (tonnes/ha) of maize and wheat in maize-wheat cropping system

Treatment	Maize				Wheat			
	Grain		Stover		Grain		Straw	
	2010	2011	2010	2011	2010-11	2011-12	2010-11	2011-12
K_0 (M) – K_0 (W)	2.21	2.72	4.48	5.26	3.80	3.89	7.30	7.59
MOP $_{60}$ (M) – K_0(W)	3.06	4.07	5.07	6.33	4.10	4.18	7.75	8.06
MOP_{30}+FYM_{30}(M) –MOP_{60} (W)	3.68	4.89	5.90	6.75	4.94	5.05	8.13	8.53
MOP_{60}+ FYM_{30} (M) – K_0(W)	4.44	5.42	6.53	7.03	4.22	4.31	7.78	8.09
MOP_{30}+ FYM_{30} (M) – K_0(W)	3.72	4.82	5.83	6.62	4.10	4.19	7.76	8.07
K_0(M) –MOP_{60} (W)	2.21	2.96	4.54	5.64	4.78	4.95	7.86	8.17
K_0(M) – MOP_{30}+ FYM_{30}(W)	2.21	3.02	4.39	5.72	5.15	5.25	8.18	8.66
MOP_{60} (M) – MOP_{30} + FYM_{30} (W)	2.99	4.30	5.14	6.53	5.05	5.16	8.14	8.77
MOP_{60} (M) – MOP_{60} (W)	3.02	4.21	5.21	6.43	4.81	5.01	7.93	8.24
K_0 (M) –MOP_{60} +FYM_{30} (W)	2.21	3.20	4.47	5.83	5.39	5.49	8.20	8.98
LSD(P=0.05)	0.46	0.51	0.44	0.71	0.5	0.6	NS	NS

without K application (control). In maize treatment MOP_{60}+FYM_{30}(M)–K_0(W) showed highest root length, surface area, average diameter, root volume, root dry weight, root:shoot ratio compared to other treatments. The treatment MOP_{60}+FYM_{30}(M)–K_0(W) was closely followed by treatment MOP_{30}+FYM_{30}(M)–K_{60}(W) and MOP_{30}+ FYM_{30}(M)–K_0(W). Treatment MOP_{60}(M)–K_0(W), MOP_{60}(M)–MOP_{30}+FYM_{30}(W) and MOP_{60}(M)–MOP_{60}(W) also showed significant superiority over treatments applied with no potassium in maize. Similar trend was observed in *kharif* 2011.

In case of wheat during *rabi* 2010-11 treatments with potassium recorded significant superiority over treatment with no potassium application. Treatment applied with K_0(M)–MOP_{60}+FYM_{30}(W) recorded highest root length, surface area, average diameter, root volume, root dry weight, root:shoot ratio. The treatment MOP_{60}(M)–MOP_{30}+ FYM_{30}(W) and K_0(M)–MOP_{30}+FYM_{30}(W) and MOP_{30}+FYM_{30}(M)–MOP_{60}(W) closely followed the treatment K_0(M)–MOP_{60}+FYM_{30}(W). Treatment MOP_{60}(M)–MOP_{60}(W) and K_0(M)–MOP_{60} (W) also significantly superior over no potassium application. Similar trend was observed during *rabi* 2011-12.

Potassium is a multifunctional and high mobility element with direct and indirect influence on almost all biochemical and biophysiological processes. It catalyzes numerous enzyme reactions. It helps the formation, transport and deposit of the products of photosynthesis. The deficiency of K resulted into decreased stomatal conductance which resulted into decreased photosynthesis rate per unit leaf area (Wolf *et al*. 2006). The transport of photosynthetic assimilates away from source tissue *via*, the phloem is also reduced in extreme K deficiency conditions. The restriction on the transport of photosynthates can lead to an accumulation of sugars in the leaf tissue of K^+ deficient plants (Bednarz and Oosterhuis 1999, Pettigrew 1999). This result into inhibition of root growth due to deficiency of photosynthates supplies (Zhao *et al.* 2001, Pettigrew 1999). These results are in conformity with the findings of Polara *et al.* (2010) and Roshni and Narayanasamy (2010).

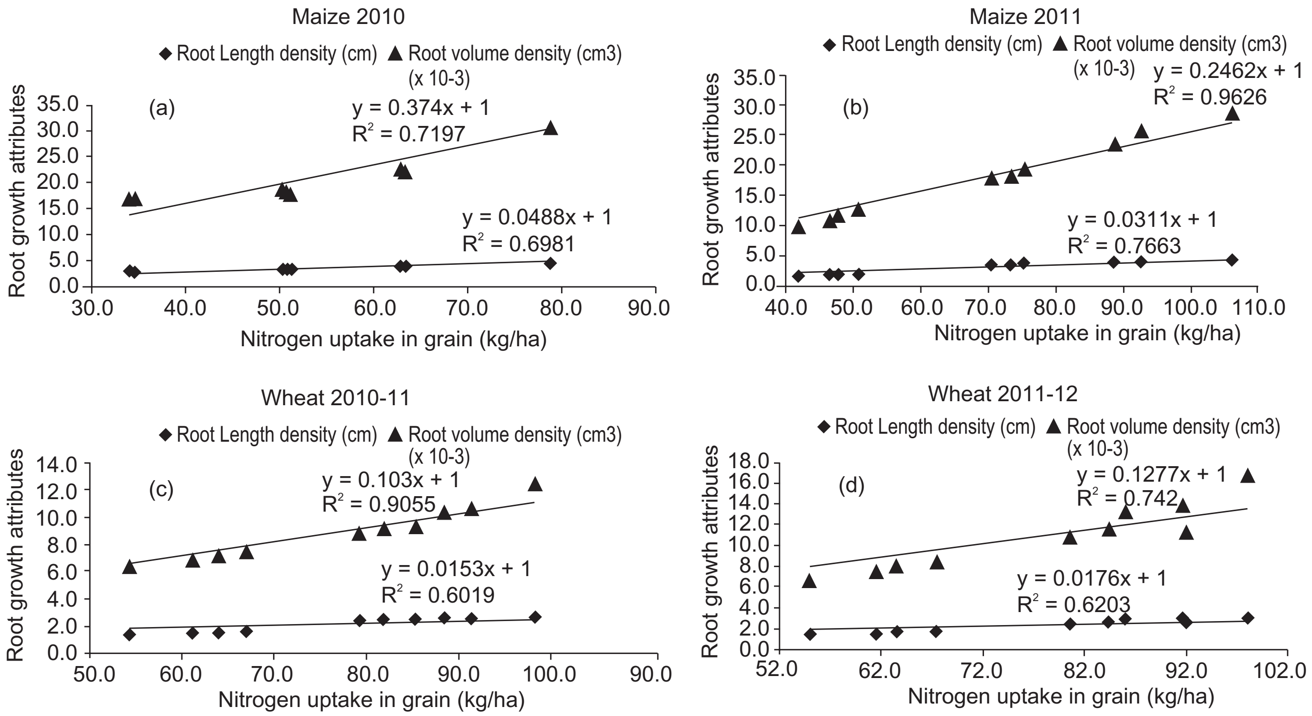

Fig 1 (a-d): a) Relationship between root growth attributes and with respect to nitrogen uptake in grain in maize 2010, b) Relationship between root growth attributes and with respect to nitrogen uptake in grain in maize 2011, c) Relationship between root growth attributes and with respect to nitrogen uptake in grain in wheat 2010-11 and d) Relationship between root growth attributes and with respect to nitrogen uptake in grain in wheat 2011-12.

Yield of maize and wheat

All the treatments applied with K showed significant superiority over no K treatments for grain yield in maize and wheat during both years 2010-11 and 2011-12 (Table 1). In case of stover yield maize followed the same trend as of grain yield whereas wheat straw yield was found non-significant. The treatment MOP_{60}+FYM_{30}(M)–K_0(W) recorded highest grain yield (4.44 tonnes/ha and 5.42 tonnes/ha) over remaining treatments during *kharif* 2010 and 2011 respectively. The treatment MOP_{60}+FYM_{30}(M)–K_0(W) was followed by treatment MOP_{30}+FYM_{30}(M)–MOP_{60}(W) and MOP_{30}+FYM_{30}(M)–K_0(W) which were found at par with each other and significantly superior over treatment 60 kg K applied through MOP alone and treatment with no potassium.

In wheat application of 90 kg K in the treatment K_0(M)–MOP_{60}+FYM_{30}(W) produced highest grain and straw yield. Application of 60 kg K supplemented with 30 kg K through MOP+30 kg K through FYM was at par with 90 kg K and treatments applied with 60 kg K through MOP and FYM and application of 60 kg K through MOP alone. Application of MOP_{30}+FYM_{30}(M)–MOP_{60}(W) was also found at par with treatment having 90 kg K supplemented 60 kg K through MOP+30 kg through FYM during both the year of experimentation. Same trend was observed in grain yield during 2011-12.

Application of K is vital to many plant processes including photosynthesis, translocation of photosynthates, protein synthesis, activation of plant enzymes etc. The significant improvement due to addition of 60 kg K through MOP and 30 kg K through FYM followed by application of 30 kg K through FYM and 30 kg K through MOP compared to 60 kg K through MOP alone. Farmyard manure supplies N, P and K in available forms to the plants through biological decomposition along with micronutrients which resulted into higher yields. Sharma and Subehia (2003) reported that integrated use of FYM with balanced chemical fertilizers gave higher yield compared to 100% NP and 100% NPK fertilizers. Mumtaz (2009) and Tabatabaii *et al.* (2011) reported that increased application of K increase grain yield which was attributed due to greater number of grains/cob and 1 000 grain weight in maize. Rehman *et al.* (2008) reported that different levels of NPK and FYM alone or in combination had significant effect on spikes/m^2, grains/spike, biological yield and thousand grain weight. Farmyard manure at 45 tonnes/ha produced the maximum spikes /m^2 (191.2), grains /spike (54.4), thousand grain weight (34.6 g) and biological yield (10 tonnes/ha) in wheat crop.

Pearson's correlation matrix between nitrogen uptake and root growth parameters

In maize during 2010 and 2011 significant and positive correlations (Fig 1 a and b) were observed *(P=0.01)* between nitrogen uptake with root length density (r^2=0.719 and 0.963) and root volume density (r^2=0.698 and 0.766) at 0-15 cm soil depth. Similarly, in wheat positive correlations (Fig 1 c and d) were observed *(P=0.01)* between nitrogen uptake with root length density (r^2=0.905and 0.742) and root volume density (r^2=0.602 and 0.620) at 0-15 cm soil depth. Correlation studies have shown significant relationship between nitrogen uptake and root growth parameters. This correlation implies that application of potassium results into better growth of root, better root growth helps in better uptake of applied nitrogen which results into higher yield.

CONCLUSIONS

Application of 60 kg K/ha or 90 kg K/ha through MOP and FYM enhanced development of root system by increasing root length, surface area, roots diameter, root volume, etc., which resulted into better root length density, surface area density, root volume density and root dry weight in both maize and wheat crop in maize-wheat cropping system. Positive correlations were observed between root growth and nitrogen uptake. Better root growth helps plant to have better nitrogen uptake cause better shoot growth and resulted into higher yields.

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