Int.J.Curr.Microbiol.App.Sci (2018) *7*(8): 1052-1061

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 7 Number 08 (2018)**
Journal homepage: http://www.ijcmas.com

EXCELLENT PUBLISHERS

Original Research Article https://doi.org/10.20546/ijcmas.2018.708.119

Effect of Integrated K Management on Productivity and Nutrient Use Efficiency of Maize-Wheat Cropping System

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Keywords

Farmyard manure, K dynamics, Muriate of Potash, Nutrient use efficiency, Productivity

Article Info

Accepted:
08 July 2018
Available Online:
10 August 2018

A B S T R A C T

A field experiment was conducted during the rainy (June - October) and winter (November – March) seasons for two years during 2010-2012 at research farm of ICAR - Indian Agricultural Research Institute, New Delhi, India. The experiment was laid out in a randomized block design consisting of seven treatments and three replication. Results revealed the integrated application of 90 kg K ha^{-1} supplemented through muriate of potash (MOP) @ 60 kg K and farmyard manure (FYM) @ 30 kg K resulted in highest grain yield of 4.93 t ha^{-1} and biological yield of 11.71 t ha^{-1} in maize. Similarly, highest grain yield of 5.44 t ha^{-1} and biological yield of 14.03 t ha^{-1} were observed in treatment applied with integrated dose of K @ 90 kg K ha^{-1} supplemented through MOP and FYM in wheat crop. The highest uptake of K was observed under treatment applied through 30 kg K through MOP + 30 kg K through FYM in both cropping cycles. Nutrient use efficiency of N, P and K increased by K application. In soil, decline was observed in different fractions of K irrespective of different applied K treatments. All the treatments where K was added showed a negative balance of K availability in soil. Application of 60 kg K ha^{-1} through MOP in both the season showed minimum negative K balance (-281.3 kg ha^{-1}). Integrated K application @ 90 Kg K ha^{-1} resulted in highest exchangeable and nonexchangeable K in the soil for both seasons. To achieve a sustained yield level, nutrient use efficiency and soil fertility integrated K application @ 60 kg K ha^{-1} for the rainy season in maize and a dose of 60 kg K ha^{-1} through MOP alone in the winter season for wheat crop may be recommended.

Introduction

Potassium (K) is one of the major essential nutrients for growth and yield of crops. A large amount of K is absorbed from rhizospheric soil through roots and it plays crucial role in antagonistic and synergistic interaction with other essential nutrients of required for crops (Zhang *et al.,* 2010). Timsina *et al.,* (2010) observed that even with the recommended levels of nutrient application, there is continuous gap between nutrients removal to nutrient applied in soil under different cropping systems. Continuous intensive cropping, low K application and heavy mining of K results into declining in available K in soils under long-term fertilizer experiments (Sharma *et al.,* 2014). In another finding, Kumar (2016) reported that when exchangeable K decreases in the soil pearl millet and wheat crop started extracting K from non-exchangeable K reserves in the soils. Globally, North America is one of the largest producer with a share of 49% of K fertilizers production followed by East Europe and Central Asia with a share of 39 % by the end of 2018 (FAO, 2015). The K fertilizer demand is expected to reach 34.5 MT in 2018 which can be meet out by the total production of 51.4 million tonnes around the world. But, it might be uneconomical approach for farmers due to higher K fertilizer input index with low food output price index that will raise food insecurity problems in different parts of the world. Hence, there is pertinent need to find out some alternative source of K. Farmyard Manure (FYM) may be a better option to overcome such problems which is cheaper, easily available, improves soil health and capable to solubilize native K in soil. FYM accelerates mineral weathering and aids in solubilization of plant nutrients from otherwise insoluble minerals. It also provides slowly available carbon and energy source to support a large diverse, metabolically active microbial community which helps solubilization and availability of nutrients to crop plants (Paul, 2014). Keeping in view the above facts, the present study was conducted to investigate the effect of integrated K management on productivity and nutrient use efficiency under maize - wheat cropping system in an inceptisol.

Materials and Methods

Experimental site

Field experiments were conducted during 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 msl.

Treatments details

The experiment was carried out in randomized block design with three replication and seven K management treatments were applied to both maize (M) in rainy season and wheat (W) in winter season at fixed site. K management treatments consisted of: T_1 (control, no K applied to both maize & wheat), T_2 (30 kg K ha^{-1} through MOP + 30 kg K ha^{-1} through FYM to maize and 60 kg ha^{-1} K through MOP to wheat), T_3 (60 kg K ha^{-1} through MOP + 30 kg K ha^{-1} through FYM to maize and no application of K to wheat), T_4 (30 kg K ha^{-1} through MOP+30 kg K ha^{-1} through FYM to maize and no application of K to wheat), T_5 (60 kg K ha^{-1} through MOP to maize and 30 kg ha^{-1} K through MOP+30 kg K ha^{-1} through FYM to wheat), T_6 (60 kg K ha^{-1} through MOP to maize and 60 kg ha^{-1} K through MOP to wheat) and T_7 (no application of K to maize and 60 kg K ha^{-1} through MOP+ 30 kg K ha^{-1} through FYM to wheat). Recommended doses of 150 kg N/ha and 26 kg P ha^{-1} were applied to maize through urea and diammonium phosphate (DAP), respectively. The full dose of P, K and 50 kg N/ha were given as basal dose and remaining 100 kg N ha^{-1} was given in two splits of 50 kg N/ha each at 30 and 60 days after sowing (DAS). Muriate of potash (MOP) and farmyard manure (FYM) were used as sources of K and applied as per treatments. Wheat was given 120 kg N ha^{-1} through urea and 26 kg P ha^{-1} through DAP. During 2010 and 2011, the amount of N, P and K in FYM applied was 5 and 6 g N/kg, 4 and 4 g P kg^{-1} and 5 and 4 g K kg^{-1} respectively. The amount of N, P and K applied through urea, DAP and FYM were adjusted in all the treatments to maintain the required nutrient combinations. All the nutrients were given by broadcast and thoroughly mixed in the soil before sowing. The variety chosen were "PEHM 2" for maize and "HD 2967" for wheat. The spacing adopted was 60 cm x 20 for maize cm and 22.5 cm row spacing for wheat. The seed rate used for maize was 20 kg ha^{-1} and wheat 100 kg ha^{-1}.

Yield observation recording

At maturity, plants of maize and wheat were harvested manually from centre of each plot in an area of 4.8 m^2 and 4.5 m^2. After separation of stems and grains dry weights were determined. The aboveground biomass per hectare was calculated based on the dried plant samples. The yield per hectare was calculated based on the dried plant samples.

Soil-plant sampling and K estimation

Soil samples were collected and processed as per standard procedures. The K was determined in plants by flame photometer (Prasad *et al.*, 2006). Water soluble K and non-exchangeable K was extracted using procedure described by Page *et al.*, (1982). Exchangeable K was extracted by procedure given by Hanway and Heidel (1952).

K balance estimation

Annual apparent K balances were estimated for all the treatments by using different inputs and outputs measured during the present experiments. Average crop yields were considered for apparent balance estimation.

K balance= ∑ (fertilizer K, manure K, rain K, irrigation K) - ∑ (K uptake, Losses of K)

Among inputs, K contents in mineral fertilizer, organic manure and irrigation water were measured in the present study.

The K contribution of 5 kg ha^{-1} yr^{-1} with rainfall water was estimated from the water collected in raingauge analyzed by the protocol given by Standford and English (1949). Leaching loss of K was taken to be 150 g kg^{-1} K input (Smaling and Fresco, 1993).

Nutrient use efficiency

Partial factor productivity (PFP) was obtained to indicate the nutrient use efficiency of the applied N, P, and K and calculated as grain yield (kg) per unit (kg) of N, P and K applied. In addition, the K use efficiency was also assessed by:

(i) agronomic efficiency (AEK), calculated as the increase in grain yield from applied nutrients relative to the control treatment in the same production practice (kg grain kg^{-1} K applied via fertilizer); (ii) apparent recovery efficiency (REK), defined as the amount of added K that was recovered in the aboveground plant biomass at the end of the cropping season (Dobermann, 2005) and calculated as

PFP = (Grain Yield/Nutrient applied)……. (1)

AEK = (Grain Yield in fertilized plot– Grain yield in control plot)/Amount of fertilizer applied....…… (2)

REK = (K uptake in fertilized plot - K uptake in control plot)/ K applied………. (3)

Statistical Analysis

The standard error of mean (SEm±), least significant difference (LSD) at 0.05 probability were worked out for each parameter of the study by using Analysis of Variance (ANOVA) technique for randomized block design in both maize and wheat crop as per standard procedure (Gomez and Gomez, 1984).

Results and Discussion

Yield of maize and wheat

A significant positive response of grain, stover and biological yield was observed in all the treatments applied with K and found significantly superior over treatments without K application (Table 1). Application of 60 kg K ha^{-1} through MOP + 30 kg K ha^{-1} through FYM to maize and no K to wheat (T_3) recorded highest grain (4.93 Mg ha^{-1}), stover (6.78 Mg ha^{-1}) and biological yield (11.71 Mg ha^{-1}) of maize which was closely followed by application of 30 kg K ha^{-1} through MOP + 30 kg K ha^{-1} through FYM to maize and 60 kg ha^{-1} K through MOP to wheat (T_2) and application of 30 kg K ha^{-1} through MOP+30 kg K ha^{-1} through FYM to maize and no K to wheat (T_4). Whereas, application of 60 kg K ha^{-1} through MOP+30 kg K ha^{-1} through FYM to wheat and no K to preceding maize (T_7) recorded highest grain (5.44 Mg ha^{-1}) and biological yield (14.03 Mg ha^{-1}) of wheat which was significantly higher than other K application treatments. No significant difference was observed in straw yields of wheat. The improvement in yield was due to applied K which is vital to many plant processes including photosynthesis, translocation of photosynthates, protein synthesis, activation of plant enzymes etc (IPNI, 1998). Kumar *et al.,* (2014) reported that integrated use of K (FYM and MOP) recorded significantly higher yield compared to 100% NP and 100% NPK fertilizers due to availability of different macro and micro nutrients in available form through biological decomposition. Similarly, Zhang *et al.,* (2011) found that inorganic NPK fertilization significantly increased grain yields of wheat (21%) and maize (16-72%) compared to inorganic N and P fertilization indicating the importance of application of K. Similar, results were reported in wheat crop by Polara *et al.,* (2009) and Wani *et al.,* (2014).

K uptake and balance

Application of K significantly affected K uptake in grain, stover/straw and their total uptake during both the cropping cycle (Table 2). The highest uptake of K was observed with application of 30 kg K ha^{-1} through MOP+30 kg K ha^{-1} through FYM to maize and 60 kg ha^{-1} K through MOP to wheat (T_2) closely followed by application of 60 kg K ha^{-1} through MOP+30 kg K ha^{-1} through FYM to maize and no K to wheat (T_3) during both the cropping cycles. The least uptake of K was observed in treatment T_1, where no K was applied during both the cropping cycles. This higher uptake in treatment applied was recorded due to higher concentration of K in the grain and stover/straw and increased yields due under K fertilized treatments, which resulted into higher amount of K uptake from the soil. Zafar *et al.,* (2016) reported that increase in K concentration and uptake in wheat grains and straw increased significantly with application of K. Uptake of K in under treatment with no K application may be attributed to interactive effect of N and K. The greater K uptake was recorded when K was supplemented through FYM along to K added through MOP in comparison with K application through MOP alone (Zhang *et al.,* 2011).

After completion of two cropping cycles of maize –wheat cropping system, all the integrated K application treatments showed negative balance (Table 3). The highest negative K balance (-382.3 kg ha^{-1}) was observed with the application of 60 kg K ha^{-1} through MOP+30 kg K ha^{-1} through FYM to maize and no K to wheat (T_3) followed by T_4. The least K negative balance was observed in treatment T_6 (-281.3 kg ha^{-1}). The extra K uptake under the NP fertilized treatment was probably either from the deeper subsoil or from the release of non-exchangeable K, which was one of the important K source for plants under the treatment applied with no K (Markgraf *et al.,* 2012; Zhao *et al.,* 2014).

The highest negative balance was observed in treatments applied with FYM along with MOP which was due to increased yield and higher uptake by the crop from applied K as well as from soil (Paramasivan *et al.,* 2012; Mazumdar *et al.,* 2014). The negative apparent K balance under treatment applied with K through MOP were probably related to higher K fixation in the clay interlayer when additional amount of K was present, this resulted into decreased availability of K for uptake by the crops (Qiu *et al.,* 2014).

K dynamics

During both the rainy and winter season all the K forms showed a decreasing trend with different magnitude irrespective of treatments applied (Table 4). In rainy season, highest water soluble K (17.03 mg kg^{-1}), exchangeable K (94.18 mg kg^{-1}) and non exchangeable K (787.45 mg kg^{-1}) was recorded in treatment T_3 which was significantly superior over treatment T_1.

In winter season, highest water soluble K was observed in treatment T_2 whereas highest exchangeable K (90.87 mg kg^{-1}) and non exchangeable K (737.92 mg kg^{-1}) was observed in treatment T_3. The decrease in different forms of K was attributed to heavy withdrawal of K by crop plants from the soil compared to the K applied to soil. Setia *et al.,* (2009) reported that under maize - wheat rotation, when only N and P were applied, available K [ammonium acetate (NH_4OAC)–extractable K] decreased significantly over time. Lack of K application resulted into decrease in water soluble and exchangeable K. Similar findings were also reported by Sattari (2014).

Nutrients use efficiency

A significant positive response was observed in PFP of N and P for both maize and wheat crop with K application (Table 5). In maize, highest PFP of N (32.9) and P (189.6) was observed with application of 60 kg K ha^{-1} through MOP+30 kg K ha^{-1} through FYM to maize and no K to wheat (T_3), which was found significantly superior over T_1 treatment. Highest PFP (73.2), agronomic efficiency (36.8) and crop recovery efficiency (1.23) of K was also observed in T_3 treatment. In wheat, highest PFP of N (45.3) and P (207.1) was also observed in T_3 treatment, which was found significantly higher than T_1 treatment. The highest PFP (85.1), agronomic efficiency (21.0) and crop recovery efficiency (0.82) of K was observed in T_5 treatment. Increasing the input of K nutrient is a practical way to balance the N/P/K ratio to improve the nutrient use efficiency (Yang *et al.,* 2014).

The PFP of N increased with increasing K input under the same production practice, which indicates positive interactions between N and K. Similarly the PFP of P was increased in the treatments applied with higher amount of K which leads to higher uptake of K due to synergistic effect of K with P ion. K is an important element which plays major role in translocation of different ions in plant part from soil which leads to improvement in various nutrient use efficiencies (Niu *et al.,* 2011).

Table.1 Effect of integrated K fertilization on yield (Mg ha^{-1}) of maize and wheat in maize - wheat cropping system (mean of two years)

Treatment		Maize				Wheat		
		Grain	Stover	Biological		Grain	Straw	Biological
T_1		2.46	4.87	7.33		3.84	7.44	11.28
T_2		4.29	6.33	10.62		5.00	8.33	13.33
T_3		4.93	6.78	11.71		4.27	7.93	12.20
T_4		4.27	6.23	10.50		4.14	7.91	12.05
T_5		3.64	5.83	9.47		5.11	8.46	13.57
T_6		3.61	5.82	9.43		4.84	8.09	12.93
T_7		2.71	5.15	7.86		5.44	8.59	14.03
LSD ($P \leq 0.05$)		0.56	0.61	0.87		0.44	NS	1.22

Table.2 K uptake (kg ha^{-1}) as influenced by K application in maize – wheat cropping system

Treatment		Cropping Cycle I (2010-11)				Cropping Cycle II (2011-12)		
		Grain	Stover/Straw	Total		Grain	Stover/Straw	Total
T_1		12.88	73.79	86.67		13.97	81.02	94.98
T_2		22.82	109.96	132.78		28.57	122.24	150.81
T_3		22.69	109.44	132.12		26.89	119.25	146.14
T_4		19.15	97.48	116.63		22.48	107.95	130.43
T_5		21.09	99.70	120.79		27.22	120.19	147.41
T_6		19.85	97.45	117.30		25.25	113.04	138.29
T_7		19.90	96.10	116.00		23.51	115.34	138.85
LSD ($P \leq 0.05$)		2.19	13.97	15.37		3.32	14.23	14.61

Table.3 Apparent K balance (kg ha^{-1}) as influenced by K application in maize – wheat cropping system (over two years)

Treatment		Input				Output			Balance
		Manure/fertili	Irrigatio	Rain		Grain	Stover/	Leaching	
T_1		0	20	5.0		53.6	309.6	4.2	-345.7
T_2		240	20	5.0		102.8	464.3	40.7	-336.3
T_3		180	20	5.0		99.2	457.4	30.7	-382.3
T_4		120	20	5.0		83.2	410.8	21.6	-371.6
T_5		240	20	5.0		96.7	439.8	41.0	-304.2
T_6		240	20	5.0		90.2	421.0	40.6	-281.3
T_7		180	20	5.0		86.8	422.9	32.4	-326.3

Table.4 Effect of K fertilization on K dynamics (mg kg^{-1}) in soil under maize- wheat cropping system (means of two years)

Treatment	Rainy Season			Winter Season		
	Water soluble K	Exchangeable K	Non-Exchangeable K	Water soluble K	Exchangeable K	Non-Exchangeable K
T_1	13.72^{d}	74.53^{d}	704.00^{b}	11.82^{e}	65.45^{e}	650.18^{b}
T_2	16.75^{ab}	90.20^{a}	773.27^{a}	15.83^{a}	85.80^{ab}	730.95^{a}
T_3	17.03^{a}	94.18^{a}	787.45^{a}	15.23^{ab}	90.87^{a}	737.92^{a}
T_4	16.53^{ab}	89.00^{ab}	770.92^{ab}	14.82^{bc}	83.35^{bc}	719.28^{a}
T_5	15.90^{bc}	84.15^{bc}	762.05^{ab}	15.17^{b}	80.80^{bc}	719.20^{a}
T_6	15.58^{c}	82.83^{c}	761.33^{ab}	14.25^{c}	78.33^{cd}	710.45^{ab}
T_7	14.32^{d}	78.88^{cd}	724.13^{ab}	13.52^{d}	75.18^{d}	687.22^{ab}

Table.5 Effect of K fertilization on nutrient use efficiency in maize- wheat cropping system (means of two years)

Treatment		Maize						Wheat				
		PFPN	PFPP	PFPK	AE K	CRE K		PFPN	PFPP	PFPK	AE K	CRE K
T_1		16.4	94.8	-	-	-		32.0	146.2	-	-	-
T_2		28.6	164.9	71.4	30.4	0.98		41.6	190.0	83.3	19.2	0.72
T_3		32.9	189.6	73.2	36.8	1.23		35.6	162.4	-	-	-
T_4		28.5	164.2	71.1	30.1	0.92		34.5	157.6	-	-	-
T_5		24.3	140.1	60.7	19.7	0.62		42.6	194.3	85.1	21.0	0.82
T_6		24.1	139.0	60.2	19.2	0.62		40.4	184.9	80.7	13.8	0.62
T_7		18.0	104.1	-	-	-		45.3	207.1	60.4	13.7	0.72
LSD ($P \leq 0.05$)		2.83	16.2	13.1	8.4	0.30		3.58	17.49	4.8	5.6	0.14

It is concluded that the study showed integrated application of K brought significant improvement in yield of both maize and wheat crops in a cropping cycle compared to sole source of K application. Inclusion of FYM as a source of K also results in increased use efficiency of K. It also enhanced the use efficiency of N and P. To achieve a sustained yield levels, nutrient use efficiency and soil fertility in a maize – wheat cropping cycle, it can be recommended that application of 60 kg K ha^{-1} by integration of 30 kg K through MOP and 30 Kg K through FYM to maize and 60 kg K ha^{-1} through MOP to wheat crop.

Acknowledgements

We are thankful to Indian Council of Agricultural Research and Indian Agricultural Research Institute for all supports including financial support to conduct this study.

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How to cite this article:

Sanjeev Kumar, Shiva Dhar, Yadav, R.S., Chandrakala, M., Kochewad, S.A., Meena, L.R., Meena, L.K., Magan Singh and Arpan Bhowmik. 2018. Effect of Integrated K Management on Productivity and Nutrient Use Efficiency of Maize-Wheat Cropping System. *Int.J.Curr.Microbiol.App.Sci.* 7(08): 1052-1061. doi: https://doi.org/10.20546/ijcmas.2018.708.119