EFFECT OF POTASSIUM RATES AND SOURCES ON THE GROWTH PERFORMANCE AND ON CHLORIDE ACCUMULATION OF MAIZE IN TWO DIFFERENT TEXTURED SOILS OF HARIPUR, HAZARA DIVISION

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ABSTRACT

The present study was based on the hypothesis that muriate of potash is a cheaper and rich source of potassium, but adversely affects the crops yield due to high Cl content. For this reason both column and field experiments were conducted to study the effect of potassium rates and sources on the availability of Cl, SO_4 and K to maize crop growing on Haripur and Ghazi soils during 2004. In column experiment two sources of potassium i.e. muriate of potash was applied @ 0, 50, 100 and 150 kg ha^{-1} and sulphate of potash was applied to one column @ 150 kg ha^{-1} in each column of the two sets along with a basal dose of N 120 and P_2O_5 80 kg ha^{-1}. Chloride content of both sets of columns increased with each increment of muriate of potash, but the soil Cl accumulation occurred in the lower part of each column i.e. 30-60 cm. However, some replacing effect of SO_4 on original Cl level was also observed. Moreover, the effect of muriate and sulphate of potash on soil Cl accumulation in soil profile and comparison of both potassium sources in terms of maize yield were also studied in the field at two locations. Potassium was applied @ 0, 50, 100 and 150 kg K_2O ha^{-1}as muriate and sulphate of potash along with a basal dose of N 120 and P_2O_5 80 kg ha^{-1}. Grain yield of maize crop was significantly increased with both sources of potassium fertilizers over NP alone treated plots (control). Further more results revealed that the grain nutrient ratio (GNR) and value cost ratio (VCR) of the both locations were found almost equal, indicated that Cl ions from muriate of potash had no adverse or toxic effects on grain yield of maize crop. Tissue Cl, S and K contents at silking stage were significantly increased with the addition of their respective fertilizer sources, but no harmful effect of Cl was observed on the growth of maize crop. Moreover, results indicated significantly positive and linear correlations between Cl leaching and applied MOP in both test soils at crop harvest, because present studies suggested that Cl ion was highly soluble and mobile in soils during crop growth, which leached down from the root zone with irrigation water. The overall results indicated that the effect of K in terms of sulphate and muriate of potash on the growth performance of maize crop was found statistically at par, because Cl from the muriate of potash leaches down the profile with irrigation water and does not accumulates in the root zone and therefore no toxic/adverse effects were observed on maize crop under the conditions of the experiments.

Key Words: **Muriate of potash, sulphate of potash, chloride, sulphate, texture, column and field experiments**

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INTRODUCTION

Potassium is an essential nutrient for plant growth and needed by plants in larger quantity. In Pakistan most soils contain relatively large amounts of total K as component of relatively insoluble minerals, however only a small fraction is present in available form to plants. Most of the soils have <150 mg kg^{-1} of exchangeable-K, which is considered a critical limit for soil K deficiency (Bajwa and Rehman, 1996). Presently, potassium levels in our soils are going to be depleted day by day as it is used by extensive cropping and cultivation of high yielding crop varieties, so far there is no natural source to replenish it in to the soil, however due to its low levels in soils negative effects on crop yield and quality are seen in some parts of the country. In the prevailing conditions when the release is not enough to fulfill the requirement of crops, the small available quantity has to be supplemented with commercial fertilizers. Supplementation of K-fertilizers are muriate of potash and sulphate of potash, the later one is a good source of potassium but it is very expensive and unfortunately farmers of this region are poor and can not afford it. Muriate of potash is cheaper source of potassium and also contains more K as compared to sulphate of potash but unluckily it contains chloride content, which already exists in higher amounts in our soils due to arid and semi-arid climate. Therefore, with the application of muriate of potash, chloride level in the soil will increase to touch the climax and this more chloride will damage the crops instead of getting benefit and the poor farmers may face heavy economic losses. On the other hand, in all soils chloride problem does not arise with the application of muriate of potash. Because the relative response of crops depend on soil fertility and the level of applied potassium (Hehlin and Johanson, 1973). Moreover, David *et al.*

(1986) identified the areas where muriate of potash can be used in (3) well drained barani areas in the higher rain fall zone (> 50 cm annual rainfall) and on crops which are not chloride sensitive (33) the non-saline light textured soils in irrigated areas with fairly well drained soils having adequate irrigation to meet leaching requirement. Literature indicated that the adverse effects influenced by escalating chloride residues and the degree of escalating are not similar in all type of soils. Indigenous work showed that very little or almost none chloride accumulation occurred down the available depths of profile due to applied muriate of potash with out the residual negative influence of chloride (Mian *et al.,* 1998). Moreover, these authors reported that the continuous use of muriate of potash neither had negative effect on crop yield, nor enhanced soil or plant Cl concentrations (Schumacher and Fixen 1990; Rashid *et al.,* 1992; Mian *et al.,* 1998). In fact our farm holdings are small and the farm economies do not allows considering the use of a costly potassium carrier such as sulphate of potash. In perusal of the above generalization a column's and field studies were launched to indicate the track of the residual chloride i.e. the destiny of applied muriate of potash with regard to the depth of different textured soils and in turn its influence on the yield and uptake by maize crop or the economy of farmers.

MATERIALS AND METHODS

Experimental Techniques

Two different textured soils were collected from *Haripur* and *Ghazi* areas to monitor the Cl, SO_4 and K accumulation down the profile to applied potassium under laboratory conditions. Soil samples were sieved before filling in columns in order to avoid the danger of blockage of the columns. Each soil was filled in 5 number of columns of 1m in height with a cross sectional area of 40 cm^2. The upper 5 cm depth was kept empty in order to keep free space for water retention, while the bottom of the columns was kept closed with the help of wire gauze with a filter paper on it so as to avoid soil losses. Each column has two holes at 30 and 60 cm for the collection of soil samples after leaching the applied sources of potassium and these holes were sealed with bandage tape. The treatments applied to columns were 0, 50 100 and 150 kg K_2O ha^{-1} as MOP along with 120 N and 80 P_2O_5 as urea and triple super phosphate, respectively. Only one dose i.e. 150 kg K_2O ha^{-1} of SOP was applied to 5^{th} column in both soils to study the replacing effect of SO_4 on original Cl level. The water requirement for these columns was calculated from the average water demand of maize crop, which is 300-350 mm (OFWN, 1997) and was divided in to 6 irrigations with an interval of 15 days. The same water was used in the column as used for field experiments. After one week fertilizers were applied along with 1^{st}. watering and last watering was done after 95 days (similar to field studies). At termination of the column study, seals were removed and soil samples from 30 and 60 cm were collected with the help of an auger for the determination of Cl (Richards, 1954), S (Tabatabai, 1982) and K (Knudsen *et al.,* 1982).

Experimental Descriptions

Field experiments were conducted on *Haripur* and *Ghazi* soils (same soils as used for column's experiment) to study the response of spring maize crop (cv. *Azam*) to varying levels of K such as 0, 50, 100 and 150 kg ha^{-1} as sulphate and muriate of potash along with a basal dose of N 120 and P_2O_5 80 kg ha^{-1} as urea and triple super phosphate, respectively. The experiments were laid out in randomized complete block design, replicated 4 times. The plot size was kept 5 x 5 m. Before sowing all P_2O_5 and K_2O with half N were thoroughly mixed in to soil and the remaining half N was applied at silking stage of crop. Six irrigations were applied during growth period at both locations. At harvest the crop was left in the field for one week to dry and grain yield was recorded from each treatment plot at both sites.

Plant Analysis

At silking stage of crop, 12 fully developed mid leaves at the air node were collected from each treatment plot at both sites in order to have representative leaf samples for Cl, S and K determination, using wet acid digestion procedure as suggested by Rashid (1985).

Soil Analysis

At harvest stage of crop, representative soil samples from each treatment plot were taken from the depth of 0-30 and 30-60 cm for the determination of Cl status in the experimental soils by the method of Richards (1954).

Statistical Analysis

The data collected from column, field studies were statistically analyzed using ANOVA techniques, and the means were compared using LSD-test of significance (Steel *et al.,* 1997). In addition, linear regression model was used to find out the relationship between applied K as MOP and Cl leaching in the test soils (Bhatti, 2006).

RESULTS AND DISCUSSION

Before conducting the column and field experiments a composite soil samples from the depths of 0-30 and 30-60 cm were collected for the determination of physico-chemical characteristics of the original soils(Table I). Results showed that the test soils from both locations were silty clay loam and silt loam in texture, non-saline in nature, slightly alkaline in reaction, moderately calcareous, deficient in organic matter and available potassium (Bajwa and Rehman, 1996) and adequate in sulphate-S (Ahmad *et al.*, 1992) and soluble-Cl (Krauss, 1992).

Table I ***Physico-chemical characteristics of test soils***

Properties	Unit	Values			
		Haripur soil		Ghazi soil	
		0-30 cm	30-60 cm	0-30 cm	30-60 cm
Clay	%	32.0	32.0	22.0	22.0
Silt	%	66.0	66.0	50.0	50.0
Sand	%	2.00	2.00	28.0	28.0
Texture	-	Silty clay loam		Silt loam	
Organic matter	%	0.72	0.45	0.58	0.30
Lime	%	12.0	12.8	10.3	10.8
EC_e	dS m^{-1}	0.19	0.21	0.17	0.20
pH_s (1:5)	-	7.40	7.40	7.30	7.50
Cl	mg kg^{-1}	10.6	8.87	9.23	12.0
SO_4-S	mg kg^{-1}	16.6	17.2	9.50	10.8
K	mg kg^{-1}	65.0	54.0	45.0	40.0

Nutrient Concentration in Soils

Results showed that the soluble Cl content of both soils increased with each increment of muriate of potash up to the highest level of 150 kg K_2O ha^{-1} (Fig. 1). Maximum Cl content was found in silty clay loam and silt loam soils of 27.7 and 24.9 mg L^{-1}, respectively at 60 cm depth, which is quite higher than 14.9 and 11.4 mg L^{-1}at 30 cm depth. The accumulation of Cl down the depth of profile suggested that Cl ions are highly soluble which leached down with the water. These observations are supported by a number of investigators e.g. (Mian *et al.*, 1998; Rashid *et al.*, 1992). Moreover, Cl content of the treatment receiving 150 kg K_2O ha^{-1} as sulphate of potash decreased from 8.52 to 7.55 mg kg^{-1} in silty clay loam soil. This decrease in Cl may be due to the positive adsorption of SO_4 ions over Cl ions. Similar results were reported by Bolt and Bruggenwert, (1978).

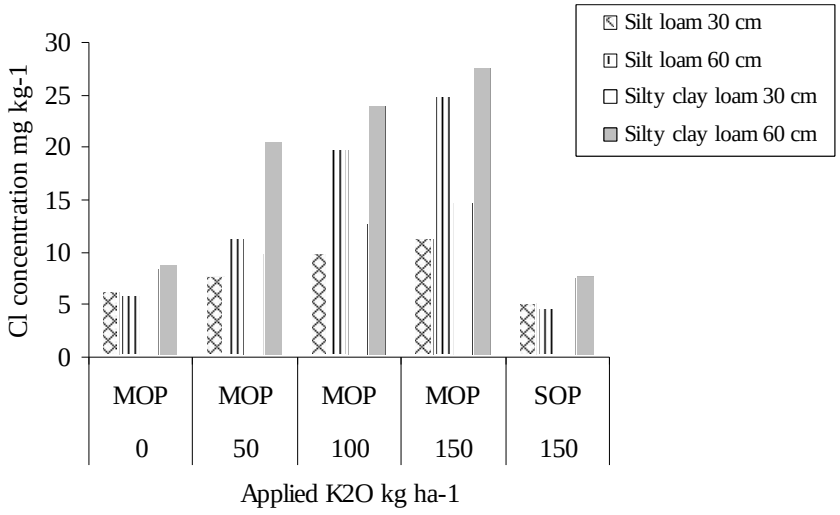


Fig. 1. Effect of applied-K on the Cl concentration in soils

Results revealed that only a single rate of sulphate of potash was applied which enhanced the SO_4-S of both soils, but markedly in the silty clay loam soil at both depths (Fig. 2). The purpose of this treatment was to find out the effect of SO_4-S on the original Cl content of test soils. Moreover, SO_4 being an anion has also shown some leaching with the irrigation water. These results on soil SO_4 build up are in line with the previous work of Barbora (1995) and Sreemanarayana *et al.*, (1998).

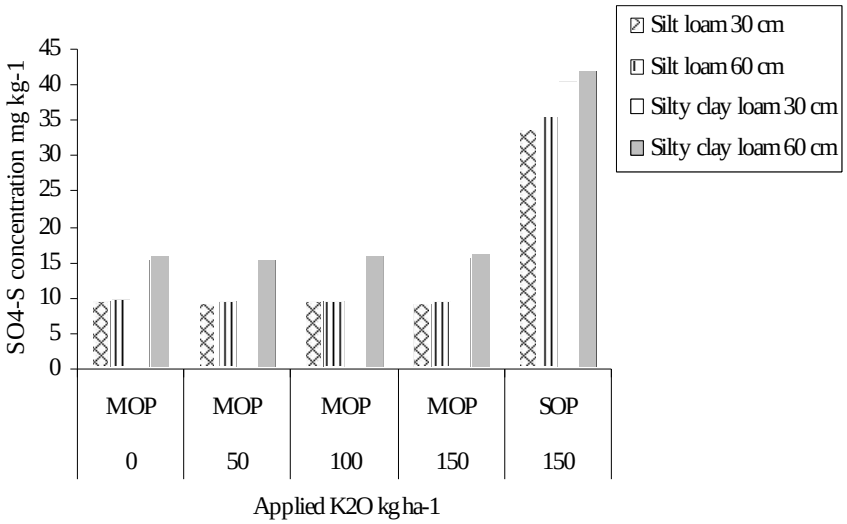


Fig. 2. Effect of applied-K on the SO_4-S concentration in soils

Results showed that the applied potassium both as sulphate and muriate of potash increased the K content over control (Fig. 3). Maximum K content of 106 and 126 mg kg^{-1} at 30 cm depth and 100 and 108 mg kg^{-1} at 60 cm depth in both soils were found in the treatment receiving 150 kg K_2O ha^{-1} in the form of muriate and sulphate of potash, respectively. The increase in soil K with increasing K addition may be due to conversion of non-exchangeable-K to exchangeable-K in soils. Similar results were reported by Tariq and Shah (2002). Results also revealed that muriate of potash supplied more K to the soil than sulphate of potash and also more K was retained and less downward movement of K has been observed in silty clay loam than silt loam soil. Similar conclusions were drawn by Ehsan (1999) on the use of muriate of potash as a good source of potassium.

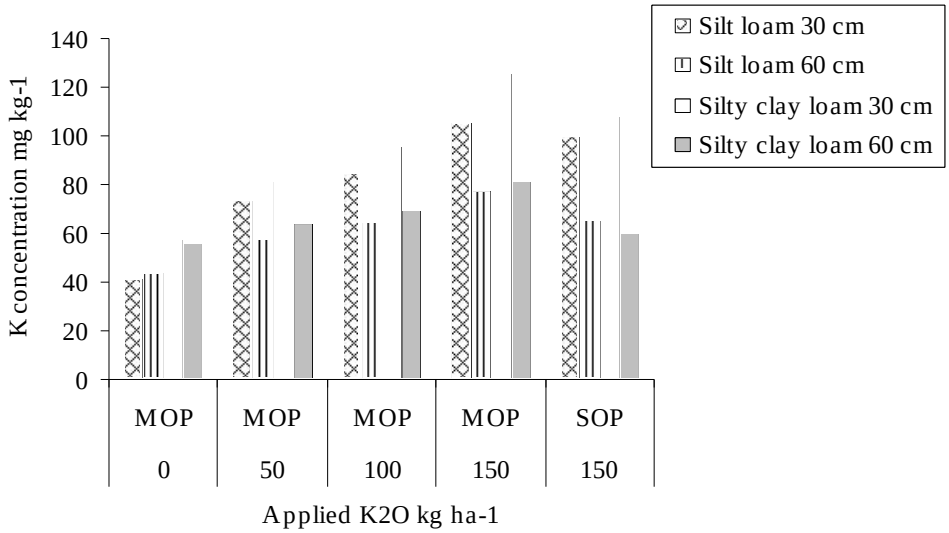


Fig. 3. Effect of applied-K on the K concentration in soils

Generally, a conclusion could be drawn from the over all results of column's experiment that the process of leaching of salts by absorbing in some height of column of water equivalent to the consumptive use of maize crop. These results showed a reducing trend in the Cl content of the surface i.e. the quantities of Cl fundamentally present in the soil plus the quantity applied in the dosage. A sort of temporary increase was recorded in the soil samples collected from the point situated at the end of 60 cm of the columns. SO_4 being an anion has also shown some leaching with the irrigation water but at the same time it decreased the original Cl level due to its positive adsorption over Cl ions. K content of the test soils was increased with each increment and source of potassium perhaps due to conversion of non-exchangeable-K to exchangeable-K and with very less amount of leaching.

Grain Yield

Results revealed that the grain yield significantly increased as the supply of potassium rates increased from both K-fertilizers sources over control (Table II). However, maximum grain yield was recorded in the treatment plot receiving 150 kg K_2O ha^{-1} from muriate and sulphate of potash in both silty clay loam and silt loam soils. This is clear indication that in both test soils available-K was below the reported critical deficiency limit (Bajwa and Rehman, 1996), which showed positive response to applied potassium from either source. Results suggest that both sources of potassium have similar effect on grain yield of maize crop under the conditions of the experiment. These results are in agreement with the findings of Ranjha (1995). The location effect in terms of soil texture was however, found non-significant because of similar nature of soils and almost similar climatic conditions during crop growth. Mian *et al.,* (1998) also compared both potassium sources in loam-textured soils and found non-significant differences in grain yield of rice-wheat rotation. Results further revealed that the grain nutrient ratio (GNR) and value cost ratio (VCR) of the both locations were found almost equal, again indicated that Cl ions from muriate of potash had no adverse or toxic effects on grain yield of maize crop. Therefore, the use of MOP fertilizer at the rate of 100 kg K_2O ha^{-1} for spring maize crop is seems to be efficient and economical as compared to SOP under the prevailing conditions. The overall results of the present experiments clearly indicated that Cl ions from muriate of potash had no toxic effect on the growth performance of maize crop, probably due to the leaching of Cl ions from the root zone down the depth of profile, which resulted almost similar grain yield, GNR and VCR

Table II ***Effect of potassium rates and sources on the grain yield of spring maize***

Applied K_2O (kg ha^{-1})	K-source	Silt loam soil			Silty clay loam soil		
		Grain yield		GNR VCR	Grain yield		GNR VCR
0	Control	3000	-	-	3099	-	-
50	MOP	3492	9.84	1.5	3502	8.06	7.1
100	MOP	3999	9.99	4.8	4057	9.59	7.3
150	MOP	4090	7.27	3.6	4138	6.93	5.3
50	SOP	3517	10.3	2.3	3628	10.6	5.1
100	SOP	4000	10.0	3.3	4062	9.63	5.0
150	SOP	4064	7.09	2.5	4162	7.09	3.1
LSD(P<0.05)		159			183		

CNR = Grain Nutrient Ratio
VCR = Value Cost Ratio

Nutrient Concentration in Leaves at Silking Stage of Maize Crop

Results clearly indicated that Cl concentration in leaf significantly increased with increasing the muriate of potash rates and being maximum at 150 kg K_2O ha^{-1} (Table III). The highest Cl content of 1.10 and 1.05% was recorded in silt loam and silty clay loam soils, respectively. Interestingly, no apparent Cl toxicity was observed on leaves at both locations, indicating maize crop is moderately tolerant to excess Cl (Bernstein, 1975) or perhaps Cl ions leached down from the root zone during growth period. Early work indicated that the reduction in crop yields are associated with 0.5 to 2% Cl for sensitive crops and with 4% or more Cl in tolerant species (Reisenauer *et al.,* 1973; Katyal and Randhawa, 1983). In the present study, Cl concentrations never become as high as the reported critical level of 4%, which could adversely affect the yield of maize crop.

Results revealed that the S concentration significantly increased with increasing the sulphate of potash rates and being maximum at 150 kg K_2O ha^{-1} over treatment plots receiving muriate of potash (Table III). Similar increase in leaf-S concentration with the addition of sulphate of potash reported by Teotia *et al.* (2000) and Khan *et al.* (2006). However, maximum S concentration of 0.47 and 0.43% was observed in silty clay loam and silt loam soils, respectively. As the sufficiency level of S in the leaf of various plants is from 0.15 to 0.50% (Ahmad *et al.,* 1992), therefore treatment plots receiving sulphate of potash have sufficient amount of S in leaves, while treatment plots receiving no S fertilization were seems to be deficient in leaf-S content of maize. Perhaps this may be due to that SO_4 ions along with Cl leached down from the root zone with irrigation water during growth period and hence reduced uptake of the both ions, or may be due to anions competition between SO_4 and Cl surrounding the roots during uptake processes.

Results showed that both muriate and sulphate of potash significantly increased the K concentration of leaves with each increment of applied potassium over control (Table III). Results also revealed that maximum K concentration of 3.28 and 3.37% were found in silt loam and in silty clay loam soil, respectively. Similar increase in leaf-K with the addition of potassium to soil reported by Tariq and Shah (2002) and Rizvi *et al.* (1981). In the present study, maize crop showed a linear response to K-fertilization at both locations, indicating that these soils were below 150 mg kg^{-1} of exchangeable-K, which is considered a critical limit for soil-K

deficiency (Bajwa and Rehman, 1996). However, application of K-fertilizers up to 150 kg ha^{-1} irrespective of source eliminates the deficiency and increase the yield of maize crop.

Table III ***Effect of potassium rates and sources on the leaf content of Cl, S and K in spring maize***

Applied K_2O (kg ha^{-1})	Source	Silt loam soil			Silty clay loam soil		
		Cl	**S**	**K**	**Cl**	**S**	**K**
		%			%		
0	Control	0.46	0.12	2.00	0.48	0.13	2.21
50	MOP	0.68	0.11	2.68	0.68	0.11	2.70
100	MOP	0.93	0.11	3.06	0.90	0.13	3.00
150	MOP	1.10	0.13	3.36	1.05	0.13	3.39
50	SOP	0.48	0.14	2.67	0.53	0.16	2.70
100	SOP	0.60	0.31	3.15	0.55	0.29	3.19
150	SOP	0.53	0.43	3.28	0.48	0.47	3.37
LSD (P<0.05)		0.15	0.05	0.25	0.17	0.05	0.20

Chloride Status in Soils at Harvesting Stage of Maize Crop

Soil Cl status was determined from both locations at harvesting stage of the maize crop, to see whether the column study run parallel to field study, in terms of Cl solubility and movement with irrigation water. Results showed Cl accumulated in soils as the applied-K in the form of MOP increases, but most of the Cl accumulation occurred at the lower depth (30-60 cm) of the profile in both test soils (Fig. 4). Graph clearly shows as the potassium rates increases Cl leaching linearly increases, hence resulted significantly positive correlation with applied MOP in both test soils, specifically in the lower depth (30-60 cm) of the soils, which showed close relationships under the conditions of the experiment (Table IV). Present studies suggested that Cl ion was highly soluble and mobile in soils during crop growth, which leached down from the root zone with irrigation water. These results are inline with the previous work of Schumacher and Fixen (1990); Rashid *et al.* (1992) and Mian *et al.* (1998) who reported that Cl status was not very high in soils after harvesting of crops, because of its high solubility characteristics and movement with irrigation water. So, it is obvious from the present studies that Cl leaches down in the field conditions as in the same way in columns; hence applied MOP gave no harm either to soils or to maize crop under the conditions of the experiment. Therefore, MOP can be used as a K-source for maize crop on non-saline light textured and fairly well drained soils having adequate irrigation to meet the leaching requirements.

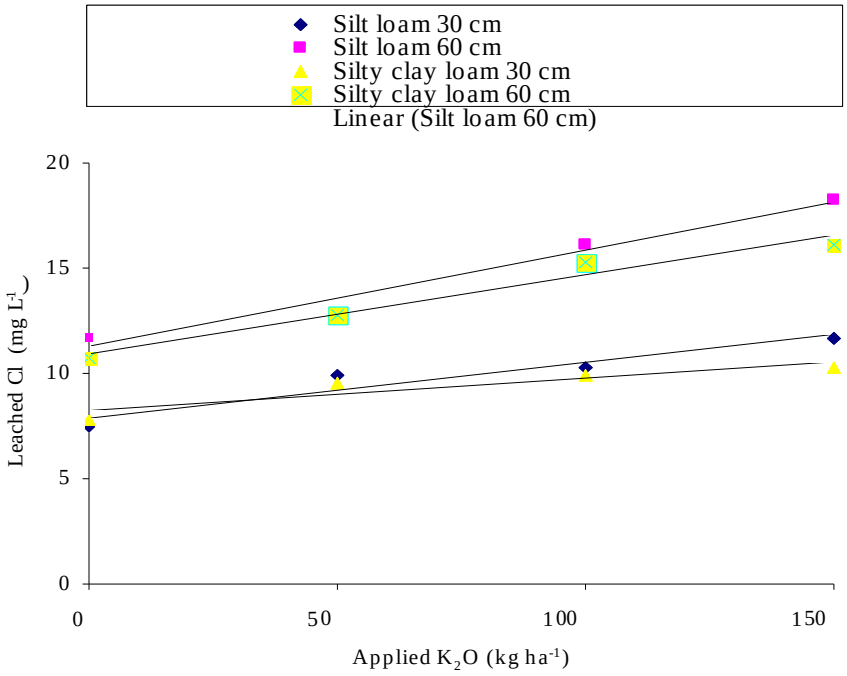


Fig. 4. Effect of applied-K as MOP on the Cl leaching of different textured soils

Table IV ***Relationships between applied-K as MOP and Cl leaching of different textured soils***

Soils	Regression equations	R^2
Silt loam (0-30 cm)	Y= 0.0262x + 7.888	0.92
Silt loam (30-60 cm)	Y= 0.0456x + 11.28	0.97
Silty clay loam (0-30 cm)	Y= 0.0157x + 8.233	0.84
Silty clay loam (30-60 cm)	Y=0.0374x + 10.92	0.96

CONCLUSION AND RECOMMENDATIONS

Soils under test gave positive response to potassium fertilization on maize crop, indicated both soils were deficient in K and needs to be fertilized with potassium carrier. The column and field studies showed that Cl leaches down the profile with irrigation water and does not accumulates in the root zone. That's why there were no toxic effects were seen on maize crop or perhaps maize is Cl tolerant, therefore both potassium sources showed almost similar response to yield. However, agronomic efficiency, grain yield and Cl status of soils after crop harvest showed that MOP fertilizer, as K-source is cheaper and rich source of potassium and can be used on non-saline light textured and fairly well drained soils having adequate irrigation, because no visual toxic or adverse effects of Cl were seen during growth period.

REFERENCES

Ahmad, N., M.T. Saleem, M. Rashid and A. Jalil. 1992. Sulphur status of Pakistan soils. NFDC Public. No. 7/92. Planning & Dev. Div. Govt. of Pakistan.

Bajawa, M.I. and F. Rehman. 1996. Soil and fertilizer potassium. In: soil science. (eds.) Bashir, E. and R. Bantle. pp. 317-341. National Book Foundation, Islamabad, Pakistan.

Barbora, A.C. 1995. Sulfur management for tea in northern India. Sulfur in Agric. 19: 9-15. Bernstein, L., 1975. Effects of salinity and sodicity on plant growth. Ann. Rev. Phytopathol. 13:295-312.

Bhatti, A.U. 2006. Statistical procedures for analysis of agriculture research experiments. Deptt. of Soil & Envir. Sci. Agric. Univ. Peshawar, Pakistan.

Bolt, G.H. and M.G.H. Bruggenwert. 1978. Adsorption of anions by soils. In: Soil Chemistry. 2nd. Ed. pp: 91-94.

David, J.G., H. Nabhan, M.T. Saleem and N. Ahmad. 1986. Potash fertilizer in Pakistan: sulphate and muriate of potash. NFDC Public. No. 7/86. National Fertilizer Dev. Centre, Islamabad, Pakistan

Ehsan, M. 1999. Research and development project on the use of MOP in Pakistan. Final Recommendations. Bullet. of Potash Dev. Instt. NARC, Islamabad, PakistanHehlin, M. and O. Johanson. 1973. Phosphorus and potassium fertilization to food potatoes. Landbr. Hogsk. Meddn. Uppsala. A. No. 192.

Katyal, J.C. and N.S. Randhawa. 1983. Micronutrients. FAO. Fertilizers and plant nutrition. Bullet. No.7. U.N..

Khan, M.J., M.H. Khan, R.A. Khattak and M.T. Jan. 2006. Response of maize to different levels of sulfur. Commun. Soil Sci. & Plant Anal. 37:41-51.

Knudsen, D., C.A. Peterson and P.F. Pratt. 1982. Exchangeable potassium. In: Methods of Soil Analysis. Chemical and microbiological properties. Part II. 2nd. Ed. Agron. 9 (eds.) Page, A.L., M.H. Miller and D.R. Keeny. Amer. Soc. Agron. Madison, WI. USA. pp. 228-230.

Krauss, A. 1992. Chloride and Crop Production in Pakistan. Status Report & Res. Proposals. Kali und Salz AG/Germany.

Mian, S.M., M. Akram, S. Ahmad, K.H. Gill, R.A. Chaudhary and G.U. Haq. 1998. Effect of MOP and SOP on plant chloride uptake and soil properties in a rice-wheat rotation. Pak. J. Soil Sci. 14(1-2): 70-74.

OFWN, 1997. Field Manual Irrigation Agronomy On Farm Water Management. Federal Water Mgt. Cell, Islamabad, Pakistan.

Ranjha, A.M. 1995. Effect of chloride applied as KCl on the growth of maize. Res. & Dev. Proj. on the use of MOP in Pakistan. Tech. Prog. Rep. 1995.

Rashid, A. 1985. Mechanism of salt tolerance in wheat crop. Ph. D Dissert., Agric. Univ. Faisalabad, Pakistan.

Rashid, M., Z. Saleem and R. Obaid. 1992. Use of MOP vs. SOP in wheat-maize cropping system. 4th National Congress of Soil Sci. Islamabad, Pakistan. pp. 151-158.

Reisenaur, H.M., L.M. Walsh and R.G. Hoeft. 1973. Testing soils for sulphur, boron, molybdenum and chloride. In: Soil Testing and Plant Analysis. Soil Sci. Soc. Amer. Inc. Madison, Wisconsin, USA. pp. 173-195.

Richards, L.A.. 1954. Diagnosis and Improvement of Saline and Alkali Soils. USDA Hand Book - 60. Washington, D.C.

Rizvi, S.A., J.K. Khattak and M. Subhan. 1981. Potassium concentration of maize as affected by KCl and K_2SO_4. Pak. J. Soil Sci. 6:3-4.

Schumacher, W.K. and P.E. Fixen. 1990. Residual effect of chloride application in corn-wheat rotation. Soil Sci. Soc. Amer. J. 53(6):1742-1747.

Sreemanarayana, B., A.S. Raju and G. Mrinalini. 1998. Effect of N and S application on different cropping sequences on status of sulfur fraction in Vertisol and Alfisols. Annals of Agric. Res. 3: 344-350.

Steel, R.G.D., J.H. Torrie and D.A. Dickey. 1997. Principles and procedures of statistics. A biometrical approach. 3rd Ed. McGraw Hill Co. Inc. New York, USA.

Tabatabai, M.A. 1982. Sulfur. In: Methods of Soil Analysis. Chemical and microbiological properties. Part II. 2nd Ed. Agron. 9 eds. Page, A.L., M.H. Miller and D.R. Keeny. Amer. Soc. Agron. Madison, WI. USA. pp. 501-534.

Tariq, M. and M. Shah. 2002. Response of wheat to applied potassium. Asian J. Plant Sci. 1(4): 470-471.

Teotia, U.S., V.S. Mehta, D. Ghosh and P.C. Srivastave. 2000. Phosphorus-sulfur interaction in mungbean (*Vigna radiata* L.): I. Yield, phosphorus and sulfur contents. Legumes Res. 23: 106-109.