Agropedology 2014, 24 (01), 70-81

Plant Induced Depletion of Soil Potassium in some soils of the Indo-Gangetic Plains and the Brahmaputra Valley

SAMIRON DUTTA AND A.V. SHANWAL

Department of Soil Science, CCS Haryana Agricultural University, Hisar-125 004, India

Abstract: An exhaustive cropping pot culture experiment using six soil samples from the alluvial soils of Indo-Gangetic Plains and the Brahmaputra Valley was conducted to study the effect of plant induced depletion of soil potassium in the soils. Four batches of pearl millet (variety: HHB-94) and two batches of wheat (var: HD-2009) were grown up to 40 days in 0.50 kg capacity polyethylene lined pot without K fertilization. During the experimental period, 54 – 78% NH_4OAc- K, 31-55% non-exchangeable K and 6-13% mineral K has been depleted from the soils. Remarkable depletion of non-exchangeable K (800 mg kg^{-1}), mineral K (3732 mg kg^{-1}) from the clay fraction was observed. It was observed that more than 60% of the total depleted K was contributed by the finer fraction of these soils. The X-ray diffractograms of clay fractions recorded after 240 days of intensive cropping showed some differences with initial diffractograms, though they are not significant. The most important changes that frequently noticed in the final diffractograms of the clay fractions were broadening of the 14 Å peak in Mg clay and shifting of 14 Å peak to 18 Å or higher in Mg- glycolated clays. Development of small peaks in the higher region of Mg clay was observed in the final diffractograms of the clay fractions of Brahmaputra valley.

Additional key words: *Potassium depletion, clay mineralogy, mineral transformation, interstratifications*

Introduction

The micas are the most important natural source of potassium in soil. During the course of weathering, the tightly held interlayer K of micas are replaced by hydrated exchangeable cations and transformed to vermiculite. Plant may also contribute to the transformation process of micas. Plant induced transformation of micaceous phyllosilicates as related to the removal of interlayer K was demonstrated by few researchers (Hinsinger and Jaillard 1993 and Hinsinger *et al*. 1993). However, most of these works were confined to release of K from pure trioctahedral micas. The transformation of biotite, concentrated mainly in the coarse clay and silt fractions to vermiculite and smectite owing to continuous release of interlayer K was also reported in the alluvial soils of India (Pal *et al*. 1987). The alluvial soils of Indo-Gangatic plain is believed to be sufficient in potassium supply because of presence of large amount of K bearing micas and hence K fertilization often being regularly overlooked. Under intensive cropping in the absence of potassium fertilization, non exchangeable and lattice potassium plays a dominant role in K nutrition to plant. It has been estimated that contribution of non exchangeable K in crop uptake reached as maximum as 83% of total K requirement of crop in some alluvial soils of India (Kundu *et.al.* 1990). Hence there is possibility of

Present Address: [1]Department of Soil Science, Assam Agricultural University, Jorhat, 785 013, India [2] Deceased

transformation of layer silicate minerals due to continuous removal of interlayer K. However, studies in this aspect is still meager though it is of critical importance as the new transformed product will only determine the future course of potassium availability. The present investigation is therefore an attempt to study the depletion of potassium and its possible impact on clay mineral structure.

Materials and Methods

The present investigation was carried out using six soil samples collected from the alluvial belt of India. Out of the total six samples, three soil samples (Palwal, Sonepat and Karnal) were taken from the semi arid Yamuna alluvial plain, Haryana and the remaining three (Jorhat, Kokila and Chatia) were collected from the humid Brahmaputra valley, Assam. Samples were collected in such a way that they represent three textural groups, namely sandy loam (Sonepat and Kokila), sandy clay loam (Karnal and Chatia) and clay loam (Palwal and Jorhat). Soils were sampled from the sub-surface horizon in order to minimize the interfering factors like effect of organic matter, addition of manures and fertilizers *etc*.

Soils were processed (<2 mm) and analyzed for pH (1:2.5 soil water suspension), organic carbon and NH_4OAc extractable K following standard procedures (Jackson 1973). Non-exchangeable K was measured according to the procedure described by Knudsen *et al*. (1982) and total K with HF-$HClO_4$ digestion method (Lim and Jackson 1982). Mineral K was calculated as the differences between the total and HNO_3 extractable K. Potassium in all the filtered extracts was measured by flame photometer. The different particle size groups *i.e*. sand (2-0.05 mm), silt (0.05-0.002 mm) and clay (< 0.002 mm) were quantitatively separated by gravity sedimentation technique (Jackson 1986). Both non-exchangeable and mineral K of the clay fraction was measured following the same procedures employed for "whole soil". X-ray diffraction pattern of clay fraction was obtained from basally oriented specimens for five different treatments (Mg saturated air dried, Mg glycerol solvated, K air dried, K-300^{o}C and K-550^{o}C) using a Phillip diffractometer with Ni filtered Cu-Kα radiation. Semi-quantitative estimation of clay minerals was done as per the procedure of Gjems (1967).

A pot experiment was conducted to study the transformation processes of micas in the clay fraction due to plant induced removal of interlayer K. Two exhaustive crop, pearl millet (var. HHB-94) and wheat (var. HD-2009) were grown in small size polyethylene lined pot of 0.5 kg capacity containing 250 g ground soil and 150 g inert material (acid washed, sterilized 3-5 mm size stone particles). First, pearl millet was grown in the pots. Seeds were sown and 10 healthy plants were maintained up to 40 days and then removed completely from the pots very carefully without any loss of soil. Plant samples were kept for K determination. In this way another three batches of pearl millet and two batches of wheat crop were grown for 40 days in the same pots. The quantity of seeds was same for the other five batches of crop also. Plant samples were kept for K determination as above. During the experiment period, plants were supplied with deionised water and nutrient solution without K. The dry matter yield for each batch of crop was recorded. Potassium concentration in the dried and ground plant samples was determined (Jackson 1973). At the end of the experiment, 50-100 g soils were taken out from the pots and different particle sizes were separated following the procedures as described earlier. Soils and particle size classes were analyzed for various forms of K both at the initial stage and after completion of pot experiment. Similarly, X-ray diffractograms of clay fraction were also obtained in both the stages *i.e.* before and after cropping.

Results and Discussion

Soil properties

Selected physical and chemical properties of the soils, along with their classification, are presented in Table 1. Soils of Palwal (semi-arid) and Jorhat (humid) contained comparable quantity of sand (37.8 and 43.8%), silt (36.0 and 27.4%) and clay (26.2 and 29.1%). Similar relationship was also maintained between Sonepat and

Kokila and Karnal and Chatia soils. However, in respect of other properties such as pH, electrical conductivity (EC), cation exchange capacity (CEC), there were differences between the two regions. Soils of semi-arid region were alkaline and saline in nature and possessed high CEC but low organic carbon (OC) content, while humid region soils were acidic, with high OC but low CEC. Mica was the only important K bearing mineral identified in the finer fraction of the studied soils. Semi-arid soils contained 65-86% micas in their clay fraction while in humid soils it ranged between 20-35%, indicating intense weathering condition of the soils.

Table 1. Physical and chemical properties of soil

Location and classification	Horizon	Particle size distribution (%)			pH	EC (dSm^{-1})	CEC [cmol $(p^+)kg^{-1}$]	OC (%)	Dominant clay minerals (%)
		Sand	Silt	Clay					
Palwal (Typic Haplustept)	B1 [a](25-57)	37.8	36.0	26.2	8.8	2.70	11.5	0.39	[b]M [c](86), K (5), O(4)
Sonepat (Typic Ustifluvent)	AB (15-62)	80.1	8.7	11.2	10.1	0.30	6.5	0.15	M(65),K (27),V(7)
Karnal (Typic Natrustalf)	BA (15-48)	51.8	24.5	23.7	9.6	2.53	12.6	0.32	M(71),K (12), S(10)
Jorhat (Oxaquic Dystrochrept)	Bw1 (20-58)	43.5	27.4	29.1	4.7	0.04	8.2	0.59	K(70), M(20),V (4)
Kokila (Typic Fluvaquent)	2C1 (5-12)	82.5	9.2	8.3	6.8	0.00	6.7	1.25	K(50),M (35),V(6)
Chatia (Fluventic Dystrochrept)	BA (10-32)	57.6	20.5	21.9	4.5	0.03	7.3	1.01	K(65), M(25)

[a]depth of horizon(cm) ; [b] M:mica, K:kaolinite, O:others, V:vermiculite, S:smectite; [c] Per cent content of the mineral

Potassium status of soil and clay fraction

Palwal soil was recorded for highest amount of all the three fractions of soil potassium followed by Karnal soils because of higher amount of clay and micas in the finer fraction (Table 2). On the other hand Jorhat soils, despite its highest clay content exhibited the lowest amount of all soil potassium forms. Similar observations were recorded for potassium content of clay fraction of all soils except Kokila. This soil was composed of fresh alluvium containing appreciable amount of unweathered/ partially weathered micas and weathered alkali feldspar (Dutta and Shanwal 2006).

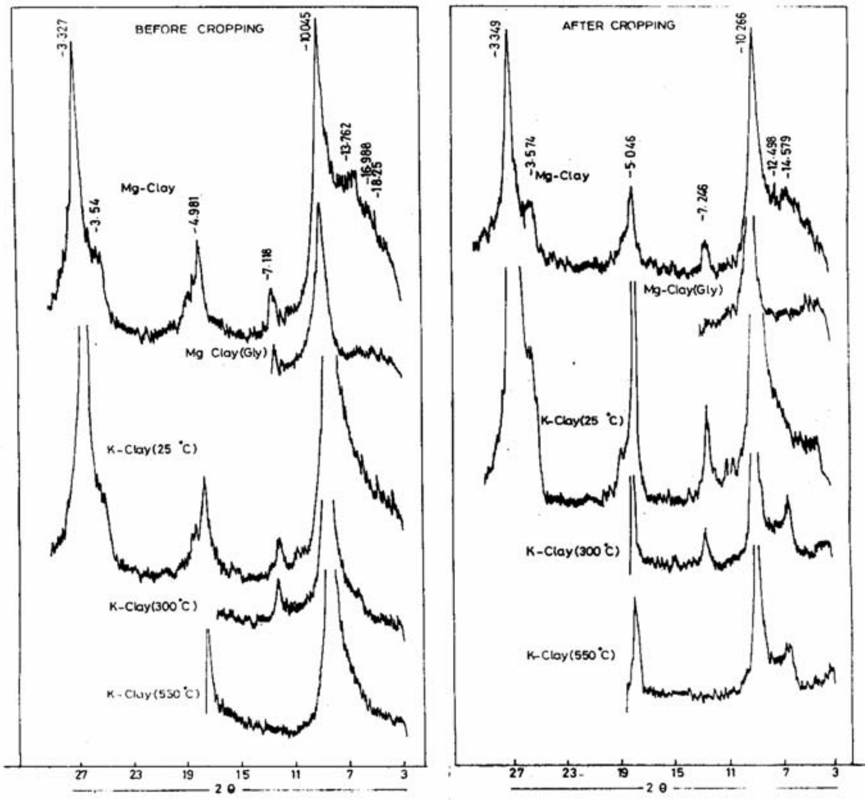
Table 2. Potassium status of soils and clay fraction

Location	Potassium status of soil (mg kg^{-1})			Potassium content of clay fraction	
	NH_4OAc-K	Non-Exch- K	Mineral-K	Non-Exch- K	Mineral-K
Palwal	156	984	22360	1720	34380
Sonepat	52	576	13872	1650	33850
Karnal	108	920	18372	1850	28850
Jorhat	44	280	10276	500	18200
Kokila	72	724	17304	1875	25625
Chatia	92	432	11376	850	23450

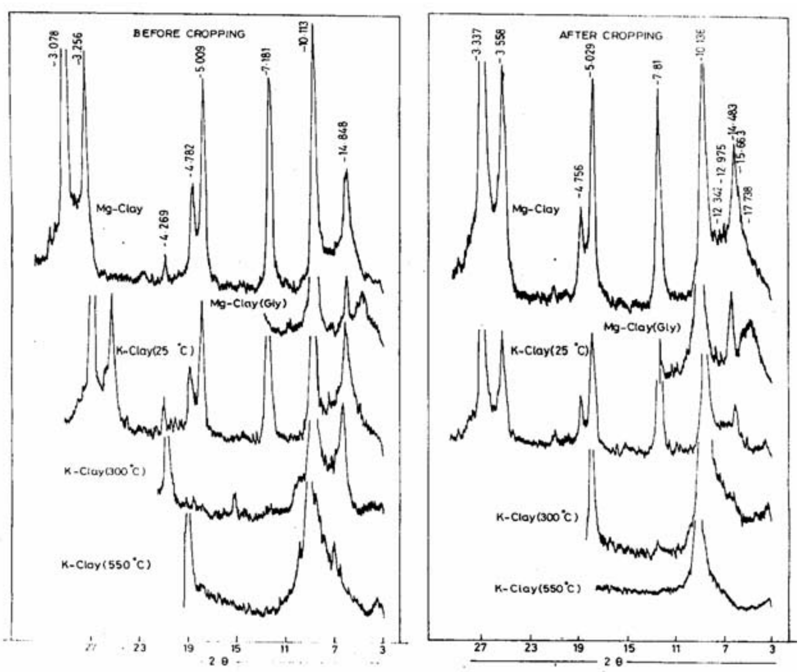
Changes in clay mineral structures

The clay fraction of all the samples was subjected to X-ray diffraction after completion of intensive cropping for 240 days in the pot experiment. The X-ray diffractograms obtained both at the initial stage (before cropping) and after cropping are presented in Fig. 1a-f. The strong and sharp diffraction maxima at 10Å with its submultiples at 5 Å and 3.3 Å in K as well as Mg-saturated clays which remain unaffected on glycolation and heating up to 550^{o}C in the X-ray diffractograms of semi-arid region soils indicated the dominance of micas in the finer fraction (Fig.1.a-c). The characteristic first order diffraction in 7.13 Å with its second order diffraction at 3.56 Å of Mg clay, both of which collapsed after heating of K saturated clay to 550^{o}C confirmed the presence of high amount of kaolinite in humid region soils (Fig.1d-f). The diffraction pattern of clay fraction recorded after cropping showed some differences with the initial diffractograms. The most important changes noticed in the diffractograms taken after cropping were broadening of the 14 Å peak in Mg clay, shifting of 14 Å peak to 18 Å or higher in Mg-glycolated clays and development of small peaks in the higher region of Mg clay. The observations are in conformity with the findings of Hinsinger and Jaillard (1993) and Sen and Ghosh (2011). The broadening of 14 Å peak was detected in most of the samples except Palwal and Jorhat. Shifting of 14 Å peak to 18 Å was more pronounced in the clay fraction of semiarid soils including Kokila of humid region. The development of small peak was however mainly restricted to the clay fraction of humid region soils.

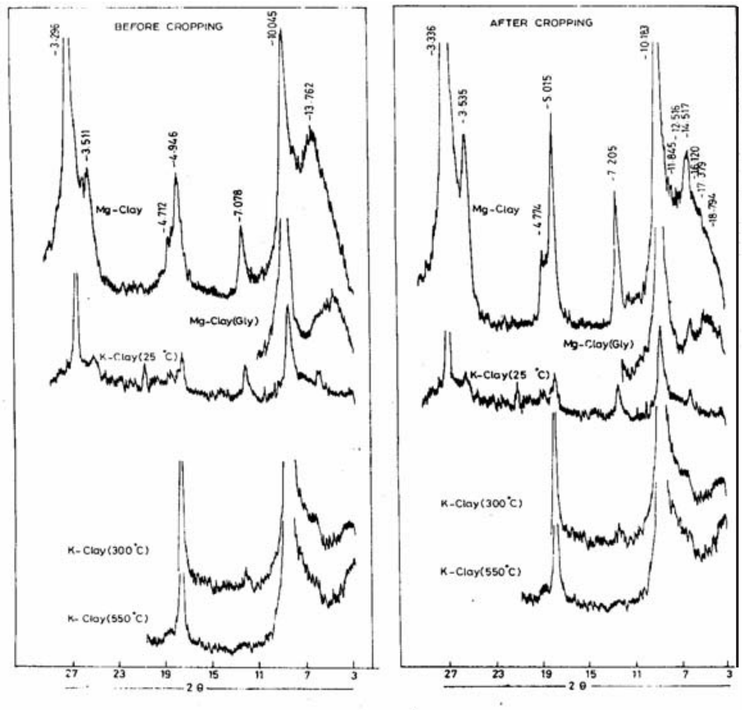
(a)


BEFORE CROPPING
AFTER CROPPING
Mg-Clay
Mg Clay(Gly)
K-Clay(25 °C)
K-Clay(300 °C)
K-Clay(550 °C)
2 θ

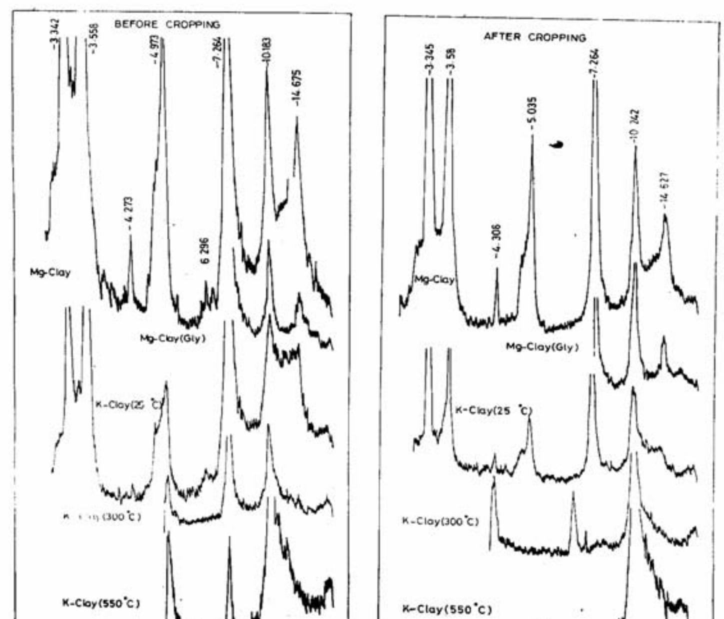
(b)


BEFORE CROPPING
AFTER CROPPING
Mg-Clay
Mg-Clay(Gly)
K-Clay(25 °C)
K-Clay(300 °C)
K-Clay(550 °C)
2 θ

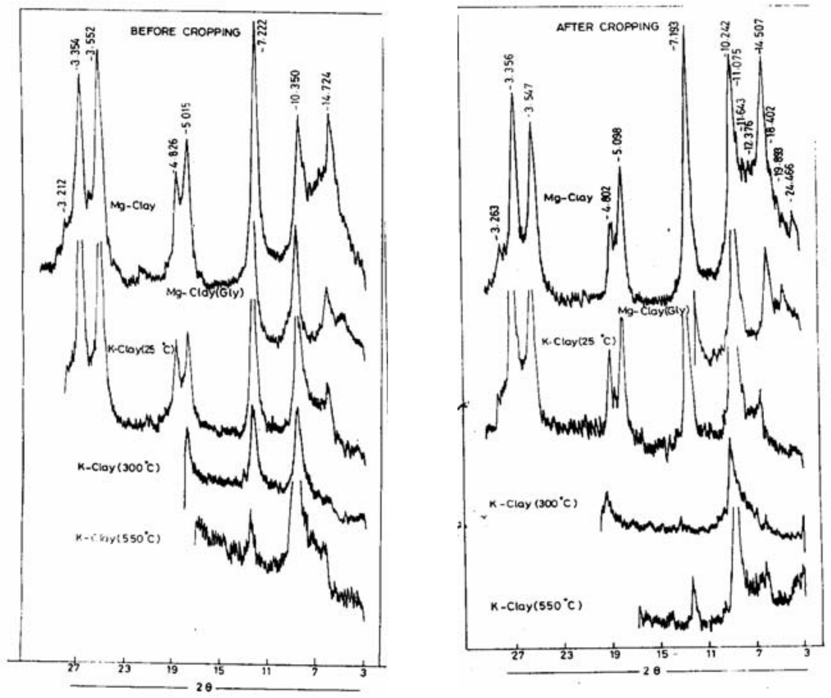
(c)


BEFORE CROPPING
Mg-Clay
Mg-Clay(Gly)
K-Clay(25 °C)
K-Clay(300 °C)
K-Clay(550 °C)
AFTER CROPPING
Mg-Clay
Mg-Clay(Gly)
K-Clay(25 °C)
K-Clay(300 °C)
K-Clay(550 °C)
2 θ

(d)


BEFORE CROPPING
Mg-Clay
Mg-Clay(Gly)
K-Clay(25 °C)
K-Clay(550 °C)
AFTER CROPPING
Mg-Clay
Mg-Clay(Gly)
K-Clay(25 °C)
K-Clay(300 °C)
K-Clay(550 °C)
2 θ

(e)



(f)

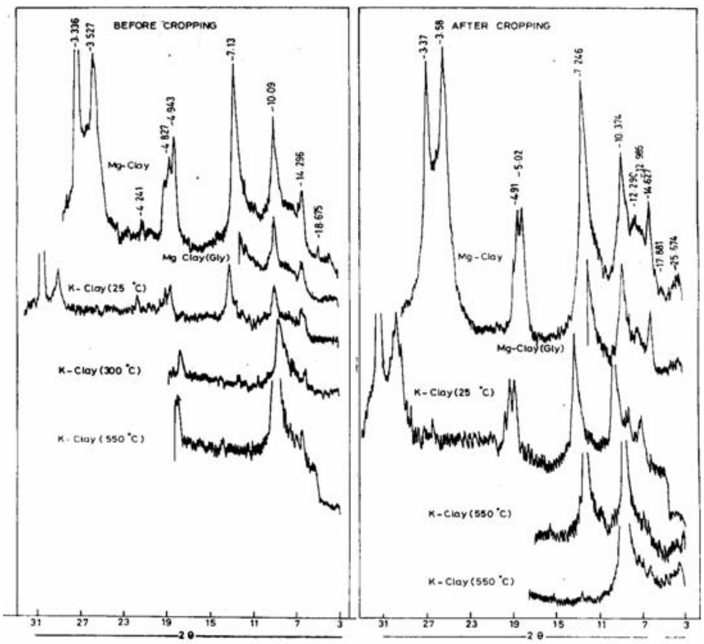


Fig. 1. X-ray diffractograms of clay fraction (before and after cropping) of the selected soils (a) Palwal (b) Sonepat (c) Karnal (d) Jorhat (e) Kokila (f) Chatia.

Mg-clay – magnesium saturated clay, Mg-clay (Glv) – magnesium saturated and glycerol saturated, K-clay (25°C) – potassium saturated and heated at 25°C, K-clay (300°C) – potassium saturated and heated at 300°C, K-clay (550°C) – potassium saturated and heated at 550°C.

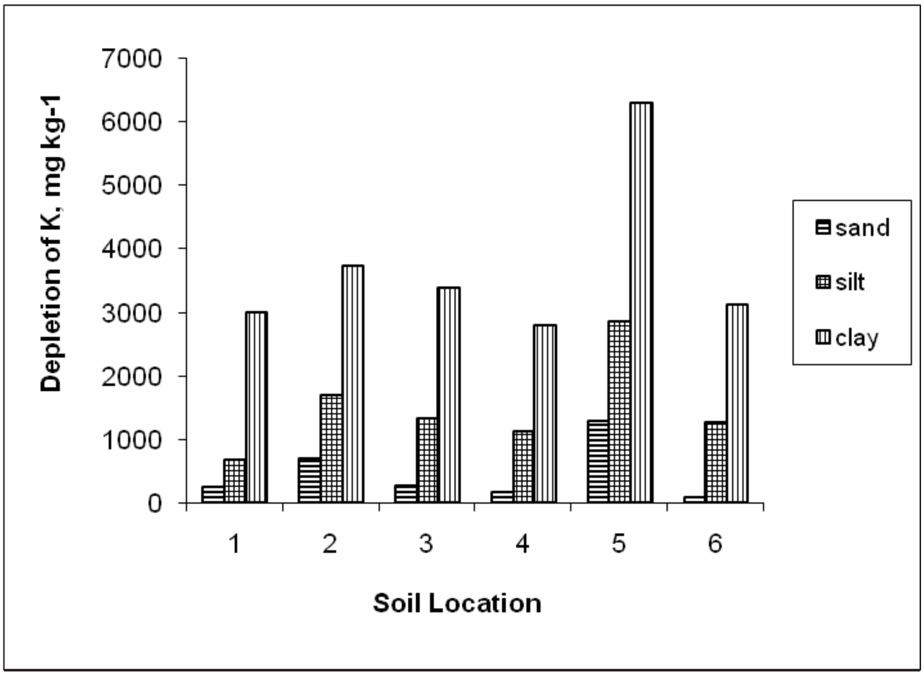


Fig. 2. Depletion of mineral K from sand, silt and clay

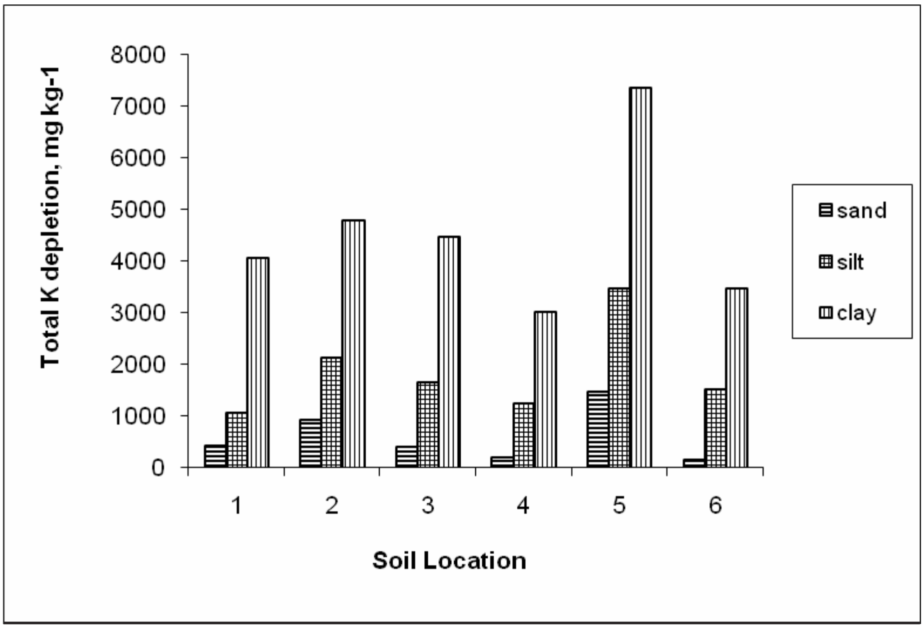


Fig. 3. Depletion of total K from sand, silt and clay

The growing plants developed a dense network of roots and produced a large feeding zone within a very small area, which was capable of extracting enough K in order to meet their requirements. Uptake of K in excessive quantity by plants causes a shift in the exchange equilibrium between the internal and external K at mica solution interface because of decrease in K concentration in the rhizosphere. Under such circumstances, K from the interlayer spaces of micas, primarily from trioctahedral micas, that are present in appreciable quantity as indicated by the differences between the first and second order peak of micas in the diffractograms of the clay fraction of semiarid region (Fig. 1a-c), comes out to meet the excess K requirement of plant resulting in changes in the original mineral structures. The occurrence of bio induced weathering of primary phyllosilicates in the rhizosphere of plant has also been earlier reported by Robert and Berthelin (1986). The exchange release of interlayer potassium and concomitant vermiculitization of micas was indicated by broadening of 14 Å peak in Mg clay of the diffractograms of Sonepat, Karnal, Kokila and Chatia obtained after cropping (Fig. 1b, 1c, 1e and 1f). The exchange release of interlayer K of micas is only possible when K concentration in the solution phase falls below a threshold level of 3 to 8 ppm in case of trioctahedral mica (Fanning and Keramidas,1982). The root system produced by the crops in pot might be effective in reducing the solution K concentration below the threshold level. The detection of vermiculitization process in the clay fraction of Kokila and Chatia soils of humid region indicated the presence of few trioctahedral micas in the finer fraction. The presence of this type of mineral in these soils was related to its source of alluvium (Dutta and Shanwal 2006).

Differences were observed in the final diffractograms of the clay fractions of Sonepat, Karnal and Kokila soils (Fig. 1b, 1c and 1e) particularly in Mg saturated glycerol solvated clays. There was a slight shifting of 14 Å peak to 18 Å in Mg-glycolated clays in these soils. The 18 Å peak was however disappeared on K saturation and heating up to 550^{o}C. This change of peak intensities might be attributed to smectitization of micas. The low concentration of K in the soil solution during the experimental period along with low Al content and high pH, Ca and Mg content of the soils of semiarid region might have favour the process of smectitization. The observation is in good agreement with the findings of Roushani (2010) and Tributh *et al.* (1987). The transformation of micas to smectite could be attributed to the process of edge weathering when simultaneous opening of most of or all the layers take place from the edges of the mica particles due to excessive removal of interlayer K. Depletion of K together with oxidation of Fe^{2+} and subsequent movement of Fe^{3+} from the octahedral position was found to be the main mechanism responsible for transformation of biotite to smectite through the intermediate stages of interstratifications (Kapoor *et al.* 1981).

Emergence of small peaks in the higher region of Mg saturated clay (24 to 26 Å), particularly in the clay fractions of Kokila and Chatia was noticed in the final X-ray diffractograms (Fig. 1e and 1f). Traces of these peaks were also observed in the glycerol solvated clay. The development of small peaks in the higher region of Mg saturated clay which did not decline in glycerol solvation might be ascribed to the presence of mica - vermiculite type of interstratified mineral. The formation of interstratified minerals in the clay fraction of humid region soils seems to be primarily due to partial removal of interlayer K from mica rather than uptake of K and similar ions by expanding minerals like vermiculite and smectitie in the prevailing environment. Interstratifications process might also be favoured by the low pH of the humid region soils. The observations corroborated the findings of Tributh *et al.* (1987).

Table 3. Reduction in soil potassium, total dry matter production and total K uptake by plant during the experimental period

Location	% Reduction of soil potassium			Total dry matter production ($g\ kg^{-1}$ of soil)	Total K uptake ($mg\ kg^{-1}$ of soil)
	NH_4OAc-K	Non-Exch- K	Mineral-K		
Palwal	67.0	51.0	6.0	107.2	1580
Sonepat	54.0	55.0	9.5	94.8	1204
Karnal	67.0	48.2	8.0	117.2	1664
Jorhat	64.0	37.1	13.2	105.6	1124
Kokila	78.0	45.0	11.0	148.0	2216
Chatia	56.5	30.5	11.0	107.2	1164

Changes in potassium status of soils after cropping

The content of all forms of soil potassium was reduced considerably after intensive cropping of 240 days (Table 3). On an average, 60% of NH_4OAC-K of the studied soils was depleted during the experimental period. Reduction from non-exchangeable pool was more in semi-arid soils (48-55%) compared to humid soils (31-45%) because of the presence of higher amount of prime K bearing minerals. Depletion of mineral K was found to be slightly higher in humid soils compared to semi-arid soils. The total K depletion (NH_4OAC-K, non-exchangeable and mineral K) was found significantly correlated with total K uptake (Table 3) by plants (r = 0.98**) and total dry matter yield (r = 0.85*). Significant relationship was also observed between total dry matter yield and total K uptake (r = 0.91*).

Changes in potassium content of clay fraction

During the experimental period, more than 1000 mg kg^{-1} of non-exchangeable K was depleted from the clay fraction of all the soils except the Jorhat and Chatia soils. The finer fraction exhibited 40-63% reduction, with an average value of 54% in the non exchangeable pool of K after cropping. Low release of non-exchangeable K from the clay fraction of Jorhat and Chatia soils of humid region could be attributed to the dominance of resistant dioctahedral micas which was in conformity with the observation of Chakravarty *et al.* (1992) and Pal and Durge (1993). Barring Kokila, the average depletion of mineral K during the period was 3382 and 2982 mg kg^{-1} in semiarid and humid region respectively (Fig. 2). Depletion of mineral K was exceptionally high in Kokila soil (6299 mg kg^{-1}) because of its unique mineralogical composition. It was observed that depletion of mineral K from the clay fraction of Jorhat and Chatia, was quite high compared to their reduction of non exchangeable K. Though cumulative amount was less, these two soils exhibited 13-15 % reduction in the mineral K as compared to 9-12 % in the semi arid region soils. The continuous and excessive demand of growing plants for soil K during the experimental period might have severely depleted the non-exchangeable pool of soil potassium. This situation possibly compelled the release of potassium from the structural position of minerals as the contribution from the non exchangeable pool was limited in these soils. The release of hydronium ion by the plant rootlets may also cause major release of lattice potassium under this environment (Huang *et al.*, 1968). All the three fractions have contributed to the total K supply with the demand of growing plant during the experimental period. However, the major role played by the finer fraction which was recorded for an average 67% reduction in total K (non exchangeable + mineral K) followed by the silt (26%) and sand fraction (7%) of the studied soils (Fig. 3). The considerable amount of K depletion from the finer fraction obviously resulted from the continuous plant removal of K as there was no other reason of K loss from the polyethylene lined pots. This was also supported by the statistically significant relationship between the total amount of K depleted from clay fraction and total plant K uptake (r = 0.88*). Hence, the evidence of changes found in the X-ray diffractograms of the clay fraction of the studied soil samples could be attributed to the removal of interlayer K due to continuous plant uptake. The excessive K uptake by plant roots may decrease the K^+ concentration of soil solution at the root surface and the resulted low K concentration favours the net release of non-exchangeable K, which is mainly interlayered in clay minerals. The findings of this experiment corroborated the observation of Martin and Sparks (1983) as more than 60% of the total depleted K (non-exchangeable and mineral K) was contributed by the clay fraction which further affirmed our observation on the changes in the X ray diffractograms of clay fraction after cropping.

Conclusion

Considerable depletion of different fractions of potassium was observed from various size fractions during the experiment period. The results of the present investigation also showed some changes in the X-ray diffractograms of the clay fractions of the studied soils taken after completion of 240 days of cropping without external K supplementation. The changes in the diffractograms can be considered as an evidence of vermiculitization and smectitization of micas due to excessive removal of interlayer potassium. Besides these two processes, interstratification of mica was also observed in the final diffractograms of clay fraction belonging to Brahmaputra valley soils. However, it is not possible to draw a concrete inference on the impact of plant induced depletion of soil potassium on the clay mineral structures as seen in the diffractograms with the present study. A detailed long term study will provide the desired evidence about the actual processes that lead to transformation of clay minerals owing to excessive plant removal of interlayer potassium. Such study is necessary as the exploitation of native potassium is continuously taking place in the alluvial soils under intensive cultivation practices and the condition was further aggravated by the little or no use of potassium fertilizers.

References

Chakravarty, D. N., Sehgal, J. L., Pal, D. K. and Dev G. (1992). Clay mineralogy of Assam soil developed on alluvium. *Agropedology* **2**, 45-50.

Dutta,S., and Shanwal, A.V. (2006). Potassium bearing minerals in some soils of semi-arid (Haryana) and humid (Assam) regions of India. *Agropedology* **16,** 86-91.

Fanning, D.S., and Keramidas, V.Z. (1982). Micas .In: *Minerals in Soil Environment* (J.B.Dixon and S.B.Weed, Eds), pp 195-258, *Soil Science Society of America*, Madison, USA.

Gjems, O. (1967). Studies on clay minerals and clay minerals formation in soil profiles in Scandinavian. *Meddelelser fra De Norsek Skogforsoksvesen* **21,** 303

Hinsinger, P., Elsass, F., Jaillard, B. and Robert, M. (1993). Root-induced irreversible transformation of a trioctahedral mica in the rhizosphere of rape. *Journal of Soil Science* **44,** 535-545.

Hinsinger, P. and Jaillard, B. (1993). Root-induced release of interlayer potassium and vermiculitization of phlogopite as related to potassium depletion in the rhizosphere of ryegrass. *Journal of Soil Science* **44,** 525-534.

Huang, P.M., Crosson,L.S. and Rennie, D.A. (1968). Chemical dynamics of potassium release from potassium minerals common in soils. *Trans. 9th International Congress of Soil Science.* **2,** 705-712

Jackson, M.L. (1973). *Soil Chemical Analysis*, Prentice Hall of India Pvt. Ltd., New Delhi.

Jackson, M.L. (1986) *Soil Chemical Analysis-Advance course*, Dept. of Soil Science, University of Wisconsin, Madison.

Kapoor, B.S., Singh, H.B., Goswami, S.C., Abrol, I. P., Bhargava, G.P. and Pal. D.K. (1981). Weathering of micaceous minerals in some salt affected soils. *Journal of the Indian Society of Soil Science* **29,** 486-492.

Knudsen, D., Peterson, G.A. and Pratt. P.F. (1982). Lithium, Sodium and Potassium. In: *Method of Soil Analysis*, Part 2, Second Edition (Page, A.L., ed.), *American Society of Agronomy, Inc. and Soil Science Society of America, Inc.*, Madison, Wisconsin, USA. pp.225-245

Kundu, S., Bhatnagar, V.K., Prakash, V., Joshi, H.C. and Koranne. K.D. (1990). Yield response of soybean-wheat rotation to K application in a long term field expriment. *Journal of Potassium Research* **6**, 70-78.

Lim, C.H., and Jackson, M.L. (1982). Dissolution for total elemental analysis. In: *Method of Soil Analysis*, Part 2, Second Edition (Page, A.L., ed.), *American Society of Agronomy Inc. and Soil Science Society of America Inc.,* Madison, Wisconsin, USA. pp.1-12

Martin,H.W., and Sparks, D.L. (1983). Kinetics of non-exchangeable potassium release from two coastel plain soils. *Soil Science Society of America Journal* **47,** 883-887.

Pal, D.K., Despande, S.B. and Durge, S.L. (1987). Weathering of biotite in some alluvial soils of different agro climatic zones. *Clay Research* **6,** 69-75.

Pal, D.K., and Durge, S.L. (1993). Potassium release from clay micas. *Journal of the Indian Society of Soil Science* **41,** 67-69.

Robert, M., and Berthelin, J. (1986). Role of biological and biochemical factors in soil mineral weathering. In: *Interaction of soil minerals with natural organics and microbes*, Special publication No. 17(Huang, P.M. and Schnitzer, M. eds), *Soil Science Society of America,* Madison, pp. 453-495.

Roushani, G. (2010). Effect of exhaustive cropping on potassium depletion and clay mineral transformations. In: *Proceedings of the 19th World Congress of Soil Science* Soil Solutions for a Changing World, 1-6th August, 2010, Brisbane, Australia. Pp 53-56.

Sen, U., and Ghosh, A.K. (2011). Changes in potassium forms, clay and silt mineralogy brought about by intensive cropping . *Clay Research* **30**, 29-41.

Tributh,H., Boguslawski, E.V., Lieres, A.V., Stefens, D. and Mengel, K. (1987). Effect of potassium removal by crops on transformation of illitic clay minerals. *Soil Science*. **143,** 404-409.

Received : April, 2013 *Accepted : May, 2014*