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Short Communication

Impact of NPK Fertilizer Levels on Soil Properties and Potassium Fractions in Lateritic Soil of Coastal Maharashtra

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An investigation was carried out in cluster bean during the *Rabi* season of 2021-2022 in the lateritic soil of coastal Maharashtra to assess the changes in soil properties, potassium (K) balance and K content as influenced by different fertilizer doses. The experiment involved nine treatments that were replicated three times in a randomized block design. The findings demonstrated that application of 40:60:60 NPK (kg ha^{-1}) significantly enhanced availability of K in soil *i.e.*, exchangeable K (85.70 mg kg^{-1}) as well as non-exchangeable K (243.44 mg kg^{-1}), whereas highest water-soluble K (5.12 mg kg^{-1}), lattice K (4862.26 mg kg^{-1}) and total K (5183.00 mg kg^{-1}) was observed with 60:40:60 NPK (kg ha^{-1}) fertilizer dose. The dominance sequence of the various K fractions was as follows: total K > lattice K > non-exchangeable K > available K > exchangeable K > water-soluble K. The results showed that available nitrogen, phosphorus, and potassium had a positive and significant relationship with organic carbon. The results indicated that applying balanced potassic fertilizers can improve the chemical properties of soil. Moreover, highly significant and positive correlations have been noted between water-soluble, exchangeable, non-exchangeable, lattice and total K, suggesting dynamic equilibrium among the different fractions of K. The application of 40:60:60::N:P_2O_5:K_2O (kg ha^{-1}) proved to be most helpful in enhancing K fractions in lateritic soil of the coastal region of Maharashtra, considering the most available potassium forms as well as improvement in the availability of nutrients.

(***Key words:*** *Coastal Maharashtra, Exchangeable K, Laterite soil, Potassium fractions*)

Potassium (K), a vital plant nutrient is involved in a variety of plant metabolic processes, including cellular osmoregulation, protein synthesis, ion absorption, and transport, photosynthesis and respiration, resistance to both biotic and abiotic stresses, and improving nutrient use efficiency (Singh *et al.,* 2021), and is needed in relatively large amounts like nitrogen and phosphorus nutrients. Additionally, it also stabilizes the relationship between monovalent and divalent cations in the water transport process through stomatal movement (Dhillon *et al.,* 2019). Potassium constitutes an average of 1.9% of the earth's crust (Tisdale *et al.,* 1985) and can exists in four different forms in dynamic equilibrium *viz.*, soil solution (0.1-0.2%), exchangeable-K (1-2%), fixed or non-exchangeable K (1-10%), and lattice K (90-98%) (Sparks, 1987) of which microbes and higher plants both depend on the soil solution and exchangeable-K for their growth (Singh *et al.,* 2010). The availability of K varies with the physical, chemical, and biological properties of soil, parent material, weathering rate, addition of organic, and inorganic fertilizers, leaching, erosion, and plants translocation (Dhillon *et al.,* 2019). Also, the availability of K is determined by the textural composition of soil and presence of 2:1 type of clay minerals such as mica, biotite, muscovite and illite (Sparks, 1987).

The majority of farmers apply higher dose of nitrogen in comparison to the application of phosphorus and potassium which has resulted in nutrients imbalance. In India, the net K balance for majority

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of crops and cropping systems remains negative as farmers primarily apply only nitrogen and phosphorus, but little to no K (Das *et al.,* 2022). This imbalanced use of fertilizers affects the crop production and soil fertility of agricultural sector (Jothi and Murugan, 2019). Under the current system, cultivation of high-yielding varieties without sufficient K fertilization leads to all forms of K to be depleted at faster rate (Srinivasa and Chikkaramappa, 2019) and subsequent degradation of silt and clay minerals (Sen and Ghosh, 2011). Also, due to predominance of kaolinitic clay minerals and low CEC, red and lateritic soils normally have the lowest amounts of all K fractions (Ravichandran and Sriramachandrasekharan, 2011). In contrast to using NP alone, balanced NPK fertilizers have been demonstrated in long-term fertilizer trials to produce a somewhat higher crop yield (Dutta *et al.,* 2015). In light of this, the current study was carried out in lateritic soil of coastal region of Maharashtra with the aim of evaluating the effects of varying fertilizer dosages on potassium fractions and the correlations between various forms of K with some relevant soil parameters under cluster beans.

Field investigation was conducted at the Research Farm, Department of Agronomy, College of Agriculture, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra (17°45’ N and 73°11’ E, 244.0 m AMSL) during *Rabi* season of 2021-2022. Taxonomically the soil is classified as *fine, mixed, isohyperthermic* family of *Fluventic Ustropepts* (Bhattacharjee *et al.,* 1978). The study area has a hot, humid climate with a mean annual rainfall of above 2700-3500 mm of which 90-95% is received in June to September (Bhattacharyya *et al.*, 2019). An initial soil sample was collected and analyzed for various physico-chemical parameters based on standard laboratory procedures. The potassium fractions such as water-soluble K were determined by Grewal and Kanwar (1966), exchangeable K by Hanway and Heidel (1952), non-exchangeable K by Wood and Deturk (1941), lattice K was obtained by the difference between total K and the sum of water-soluble, exchangeable and non-exchangeable K (Wiklander, 1954) and total K by Jackson (1973).

Nine treatments were applied to the cluster bean (*Cyamopsis tetragonoloba* (L.) Taub) cv Pusa Navbahar *viz.*, T_1-Absolute control (No Fertilizers), T_2- 20:40:00::N:P_2O_5:K_2O kg ha^{-1}, T_3 - 20:40:40::N:P_2O_5:K_2O kg ha^{-1}, T_4-40:40:40::N:P_2O_5:K_2O kg ha^{-1}, T_5- 40:40:60::N:P_2O_5:K_2O kg ha^{-1}, T_6 - 40:60:40::N:P_2O_5:K_2O kg ha^{-1}, T_7- 40:60:60::N:P_2O_5:K_2O (kg ha^{-1}), T_8- 60:40:40::N:P_2O_5:K_2O kg ha^{-1}, and T_9- 60:40:60::N:P_2O_5:K_2O kg ha^{-1} in a randomized block design replicated thrice. Farm yard manure (FYM) was added at a rate of 10 t ha^{-1} in all treatments (from T_2 to T_9), excluding the absolute control (T_1).

The required amount of N, P, and K was applied through urea, single super phosphate, and muriate of potash, respectively. At the time of sowing P and K were applied in a basal dose as per the treatment, while nitrogen was applied in two splits, with the basal dose of 50% N, and the remaining 50% N at the flowering stage (*i.e.*, at 30 days after sowing). Throughout the experiment, all suggested cultural techniques for cluster bean production were followed. Following the harvest of the cluster bean, soil samples were taken from each plot at a depth of 0-30 cm and soil physico-chemical properties were analyzed using standard procedures. Statistical analysis of the data was done using a standard statistical method of analysis of variance (Panse and Sukhatme, 1967) using MS Exel software.

After crop harvest, the physico-chemical properties of soils indicated considerable variation among the fertilizer treatments (Table 1). With varying fertilizer treatments, neither soil pH nor its electrical conductivity was significantly affected. The soil organic carbon (12.44 g kg^{-1}), available phosphorus (11.50 kg ha^{-1}), and available potassium (243.86 kg ha^{-1}) were influenced significantly in the treatment T_7 with the application of NPK @ 40:60:60 kg ha^{-1}. The build-up of organic carbon content could be reasoned by several factors such as the addition of manures (FYM), litter fall, fine root biomass recycled and root exudates and its reduced oxidation of organic matter. These results are in agreement with Bhuvad (2023) in lateritic soils of Konkan. The direct addition of phosphatic fertilizer may be the cause of increased phosphorus content in soil. The increased potassium availability may be due to synergistic effect of K and N (Shrivastava, 2002). Further, Sumita *et al.* (2018) also observed that addition of fertilizers caused build-up of available P and K content in different cropping systems. In this study, significantly higher available nitrogen (265.52 kg ha^{-1}) was recorded in the treatment T_9 with the application of NPK @ 60:40:60 kg ha^{-1} over all treatments. The direct addition of nitrogen through fertilizer may have led to an increase in available nitrogen. Wahane *et al.* (2022) indicated an increase in soil organic carbon, and available N, P, and K with the application of integrated nutrient management practices in groundnut grown on alfisols in the Konkan area of Maharashtra.

The data (Table 1) showed that different fertilizer doses had a significant impact on water-soluble potassium in the soil after the harvest of cluster bean. Water soluble K varied from 3.44 mg kg^{-1} in absolute control (T_1) to a maximum of 5.12 mg kg^{-1} in the treatment receiving 60:40:60 NPK (kg ha^{-1}) fertilizer dose. The direct addition of potash via fertilizer application may be the reason for the increase in water-soluble K. The increase in water-soluble K with an increasing rate of potassium application was also reported by Jadhao *et al.* (2018) and Dotaniya *et al.* (2023). The exchangeable K content varied from 52.52 to 85.70 mg kg^{-1} with different treatments and significantly maximum exchangeable K (85.70 mg kg^{-1}) was recorded with NPK @ 40:60:60 kg ha^{-1} fertilizer dose. Yaduvanshi and Swarup (2006) observed an increase in exchangeable K in the FYM-treated plots over time. This may be attributed to the addition of FYM, which likely enhanced the soil's cation exchange capacity (CEC), thereby facilitating the release of exchangeable K from the non-exchangeable pool. Similar results were also documented by Dotaniya *et al.* (2023). Non-exchangeable K content in soil varied from 180.97 to 243.44 (mg kg^{-1}) and exhibited a maximum (243.44 mg kg^{-1}) and significantly higher content with application of NPK @ 40:60:60 kg ha^{-1}) fertilizer dose compared to other treatments. Non-exchangeable K may have increased due to several factors, including conversion of extra water-soluble K into non-exchangeable forms, and increased fixation caused by a higher amount of K fertilization that may have decreased the use of non-exchangeable K and caused its accumulation. Significant increases in non-exchangeable K with various fertilizer treatments were also reported by Talashikar *et al.* (2006) and Jadhao *et al.* (2018).

Lattice potassium fraction increased significantly with application of different NPK fertilizer doses, as was the case with other K fractions. Significantly maximum lattice K of 4862.26 mg kg^{-1} was registered in the treatment T_9 where fertilizer dose of NPK @ 60:40:60 kg ha^{-1} was applied. The fairly high value of lattice K in the soils is indicative of high K supplying power to crops over a longer period of time especially when K level reach at threshold level, although the availability of this form of K to plants is meager at any specified time. The mineral K is bound within the crystal structure of soil mineral particles between adjacent tetrahedral layer of micas, vermiculites, and intergrades clay minerals (Sparks, 1987). The results are in accordance with the finding of Jadhao *et al.* (2018) who found that application of 100% NPK + FYM @ 5 t ha^{-1} considerably increased lattice K in 0-15 cm depth in Vertisols of central India.

In the present study, the total potassium ranged from 4105.33 mg kg^{-1} to 5183.00 mg kg^{-1}. Significantly maximum total K to the tune of 5183.00 mg kg^{-1} was recorded with application of NPK @ 60:40:60 kg ha^{-1}. The increased in total potassium was observed possibly because of K supply through organic residues as FYM helps retaining the K+ ion on exchange sites thereby reducing leaching losses. These findings are in agreement with those reported by Talashikar *et al.* (2006) and Dotaniya *et al.* (2023).

The correlation coefficient between different forms of potassium and soil properties (Table 2) revealed a significant negative correlation between soil pH and all K fractions. The electrical conductivity and organic carbon exhibited strong and positive correlation with all K fractions. A significant and positive correlation was also found between available nitrogen and all K fractions, however, available phosphorus showed significant and positive correlation with water soluble K (r = 0.606*), exchangeable K (r = 0.580*), and non exchangeable K (r = 0.544*). The data presented in Table 3 indicated that, water soluble K had significant and positive correlations with exchangeable K (r = 0.916**), non-exchangeable K (r = 0.880**), lattice K (r = 0.771**), and total K (r = 0.797**) suggesting a rapid replenishment of equilibrium between these forms of K. Exchangeable

Table 2. *Soil characteristics as influenced by different fertilizer doses of NPK under cluster bean*

Treatment	pH (1:2.5)	EC (dS m^{-1})	Organic carbon (g kg^{-1})	Available N	Available P_2O_5	Available K_2O	Water soluble K	Exchangeable K	Non-exchangeable K	Lattice K	Total potassium
				--------------(kg ha^{-1})-----------			----------------------------(mg kg^{-1})----------------------------				
T_1 - 00:00:00 NPK (kg ha^{-1})	5.34	0.070	10.47	207.77	8.92	150.40	3.44	52.52	180.97	3869.09	4105.33
T_2 - 20:40:00 NPK (kg ha^{-1})	5.33	0.072	11.32	223.86	10.13	153.32	3.57	53.47	185.21	3931.80	4173.33
T_3 - 20:40:40 NPK (kg ha^{-1})	5.44	0.076	12.42	228.09	10.34	188.80	4.10	66.13	208.57	4370.34	4648.33
T_4 - 40:40:40 NPK (kg ha^{-1})	5.37	0.071	12.07	234.18	10.48	199.91	4.19	70.18	210.54	4493.25	4777.33
T_5 - 40:40:60 NPK (kg ha^{-1})	5.32	0.086	12.39	238.99	10.53	226.84	4.83	79.57	232.66	4592.24	4908.33
T_6 - 40:60:40 NPK (kg ha^{-1})	5.34	0.084	11.47	237.74	10.75	190.75	4.23	66.73	213.96	4670.59	4954.67
T_7 - 40:60:60 NPK (kg ha^{-1})	5.25	0.107	12.44	254.54	11.50	243.86	5.03	85.70	243.44	4648.17	4981.33
T_8 - 60:40:40 NPK (kg ha^{-1})	5.35	0.120	11.85	261.62	10.51	194.30	4.47	67.82	218.41	4447.87	4737.67
T_9 - 60:40:60 NPK (kg ha^{-1})	5.36	0.105	11.94	265.52	10.69	235.08	5.12	82.33	234.49	4862.26	5183.00
SE (m) ±	0.05	0.02	0.28	3.83	0.42	9.40	0.10	3.45	4.01	119.65	120.11
CD @ 5%	NS	NS	0.85	11.47	1.25	28.19	0.30	10.34	12.03	358.7	360.09

K was also positively and significantly correlated with non-exchangeable K (r = 0.851**), lattice K (r = 0.757**), and total K (r = 0.786**). The strong significant and positive correlation between non-exchangeable K with lattice K (r = 0.716**), and total K (r = 0.750**) indicates a substantial replenishment of non-exchangeable K pool from mineral or lattice K. Similarly, highly significant positive correlation between lattice K and total K (r = 0.999**) highlights the dominant contribution of lattice K to total K (98.4-98.8%) (Patil and Sonar, 1993). The significant and positive correlations among various forms of soil K thus indicates the existence of a dynamic equilibrium among the different forms of K, where reserve and non-exchangeable K forms are slowly released to the available pool upon depletion due to intensive cropping and/or leaching in the lateritic soils of coastal region of Maharashtra. Similar findings were also reported by Talashikar *et al.* (2006) and Jadhao *et al.* (2018).

Based on the results of the experiment, it can be concluded that application of NPK @ 40:60:60 kg ha^{-1} enhanced potassium fractions such as water-soluble, exchangeable, and non-exchangeable K, while the application of 60:40:60 NPK kg ha^{-1} resulted in significantly higher levels of lattice and total potassium in cluster bean over the control. The contribution of various K fractions followed the order as total K > lattice K > non-exchangeable K > available K > exchangeable K > water-soluble K. The different forms of potassium were positively and significantly correlated with each other, indicating the existence of a dynamic equilibrium among different forms. Thus, in the lateritic soil of coastal region of Maharashtra, application of $N:P_2O_5:K_2O$ @ 40:60:60 (kg ha^{-1}) to cluster beans was found beneficial.

Table 3. *Relationship between various forms of potassium and soil characteristics under cluster beans*

Soil characteristics	Water soluble-K	Exchangeable-K	Non exchangeable-K	Lattice-K	Total-K
	(mg kg^{-1})				
pH	-0.163	-0.145	-0.216	-0.008	-0.024
EC(ds m^{-1})	0.440*	0.346	0.393*	0.075	0.103
Organic carbon (g kg^{-1})	0.466*	0.379	0.433*	0.402*	0.412*
Av. nitrogen (kg ha^{-1})	0.780**	0.651**	0.694**	0.644**	0.661**
Av. phosphorus (kg ha^{-1})	0.606**	0.580**	0.544**	0.351	0.376

**Significant at the 0.01 level * Significant at the 0.05 level

Table 3. *Inter-relationship among the various forms of potassium (mg kg^{-1}) under cluster bean*

Different forms of potassium	Water Soluble-K	Exchangeable-K	Non Exchangeable-K	Lattice-K	Total-K
Water Soluble-K	1.000				
Exchangeable-K	0.916**	1.000			
Non-Exchangeable-K	0.880**	0.851**	1.000		
Lattice-K	0.771**	0.757**	0.716**	1.000	
Total-K	0.797**	0.786**	0.750**	0.999**	1.000

**Significant at the 0.01 level * Significant at the 0.05 level

CONFLICTS OF INTEREST

Authors declare no conflict of interest.

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