



Influence of production systems on potassium fractions and release of non-exchangeable potassium in Kalyana Karnataka, India

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Abstract

Soil potassium (K) dynamics are governed by the distribution of K among soluble, exchangeable, non-exchangeable and mineral pools, as well as by the capacity of soil to release reserve K. A study was conducted to characterize soil K fractions and to determine the release characteristics of non-exchangeable K under natural farming (NFS), organic farming (OFS), conventional farming (CFS) and integrated farming systems (IFS) across the North East Transition, North Eastern Dry and Northern Dry zones of Kalyana Karnataka, India. Forty-eight soil samples were collected from surface (0-15 cm) and subsurface (15-30 cm) layers under established production systems and analysed using standard procedures. Potassium fractions followed the order total K > mineral K > non-exchangeable K > exchangeable K > water-soluble K. Total K ranged from 3286 to 3980 mg kg⁻¹ in surface soil and 3427 to 4122 mg kg⁻¹ in subsurface soil. Sequential extraction with boiling 1 N HNO₃ showed rapid K release during the first seven extractions, followed by a gradual decline and a near-constant release during the later extractions. Total step-K ranged from 652 to 748 mg kg⁻¹ in surface soil and 740 to 939 mg kg⁻¹ in subsurface soil. Cumulative K release ranged from 671 to 825 mg kg⁻¹ in surface soil and 820 to 1051 mg kg⁻¹ in subsurface soil. Constant-rate K ranged from 2 to 6 mg kg⁻¹ in surface soil and 7 to 9 mg kg⁻¹ in subsurface soil.

Keywords: Agro-climatic zones, potassium fractions, non-exchangeable potassium, sequential extraction, soil fertility

Introduction

Potassium (K) is an essential plant nutrient involved in enzyme activation, photosynthesis, osmoregulation, protein synthesis and assimilate translocation. In soil, K occurs in water-soluble, exchangeable, non-exchangeable and mineral forms that differ in their availability to plants. These pools are dynamically linked: solution K can be replenished from exchangeable K, while non-exchangeable and mineral pools may contribute K over time through release and weathering processes.

The distribution and transformation of soil potassium are influenced by soil texture, mineralogy, organic matter, moisture regime, cropping pattern and nutrient management. Farming systems that differ in organic inputs, fertilizer use and residue recycling can therefore influence both readily available K and reserve pools. Assessing only extractable K may not fully describe the soil's capacity to supply K, particularly where crops draw on non-exchangeable reserves. Kalyana Karnataka region includes the North East Transition Zone, North Eastern Dry Zone and Northern Dry Zone, which differ in climate, soils and cropping patterns. These variations, together with differences in natural, organic, conventional and integrated farming practices, may influence soil physico-chemical properties and the distribution of potassium fractions across soil depths. A comparative assessment across these zones and production systems can help characterize soil fertility and the potential contribution of reserve K to plant nutrition.

Understanding potassium dynamics requires the assessment of individual K fractions and the release of non-exchangeable K, which serves as a potential source of plant-available potassium when readily available pools become depleted. In this context, the present study addressed two

objectives: (i) to characterize physico-chemical properties and potassium fractions of soils under different production systems; and (ii) to determine the release characteristics of non-exchangeable potassium in soils under different production systems.

Material and Methods

The investigation covered three agro-climatic zones of the Kalyana Karnataka region: the North East Transition Zone (Zone I; Bidar), the North Eastern Dry Zone (Zone II; Kalaburagi and parts of Raichur and Yadgir), and the Northern Dry Zone (Zone III; Koppal), encompassing four production systems, namely natural farming, organic farming, conventional farming and integrated farming, under cropping systems involving chickpea, redgram, paddy, pearl millet and groundnut. A total of 48 soil samples were collected from surface (0-15 cm) and subsurface (15-30 cm) depths, air-dried, ground and passed through a 2-mm sieve before analysis. Water-soluble K was determined by 1:5 soil-to-water extraction, exchangeable K by neutral normal ammonium acetate extraction, and non-exchangeable K by boiling with 1 N HNO₃; mineral K was calculated as the difference between total K and the sum of water-soluble, exchangeable and non-exchangeable K.

The release characteristics of non-exchangeable K were assessed through successive extraction with boiling 1 N HNO₃ after removing exchangeable K, following Haylock (1956) [4]. Potassium released during each extraction was recorded, and cumulative K release was calculated by summing the K released across successive extractions. Total step-K represented cumulative K release excluding the later constant-rate portion, while constant-rate K (CR-K) was estimated from the K released during the final successive

extractions, when the release rate remained nearly constant. The data were subjected to analysis of variance using Fisher's method, as described by Gomez and Gomez (1984) [1], to assess variations in soil potassium fractions and K release characteristics among production systems, agro-climatic zones and soil depths.

Results and Discussion

Potassium fractions

Potassium fractions showed considerable variation among production systems, agro-climatic zones and soil depths. In surface soil, the maximum mineral K (3344.0 mg kg⁻¹) and total K (3980 mg kg⁻¹) were observed under integrated farming with chickpea in the North Eastern Transition Zone, which may be attributed to the presence of K-bearing minerals and efficient nutrient recycling under integrated management. Similar trends were reported by Rao *et al.* (2013) and Yadav *et al.* (2019) [6, 8], respectively. Non-exchangeable K reached its highest value (412.5 mg kg⁻¹) under integrated farming with redgram in the North Eastern Transition Zone zone, possibly due to K retention within clay mineral interlayers and the gradual replenishment of reserve potassium through mineral weathering. These observations are consistent with Laalithya *et al.* (2022) [5]. Exchangeable K was also highest under integrated farming with redgram (237.5 mg kg⁻¹), which may be related to the addition of organic materials and residue recycling that help replenish potassium on soil exchange sites, as reported by Habib *et al.* (2014) [3]. The highest water-soluble K (11.3 mg kg⁻¹) was recorded under integrated farming

chickpea, potentially due to the release of potassium during residue decomposition and its movement into the soil solution, in agreement with Gurumurthy and Prakash (2011) [2].

Release of non-exchangeable potassium

Sequential extraction with boiling 1 N HNO₃ revealed a rapid release of non-exchangeable K during the first seven extractions, followed by a gradual decline from the eighth to tenth extractions and a nearly constant release during the eleventh to thirteenth extractions. This pattern indicates the progressive depletion of readily releasable potassium reserves, followed by the slower release of K from minerals. A comparable decline in potassium release with successive extractions was documented by Sinha *et al.* (2024) [7]. Total step-K ranged from 652 to 748 mg kg⁻¹ in surface soil and from 740 to 939 mg kg⁻¹ in subsurface soil, whereas cumulative K release varied from 671 to 825 mg kg⁻¹ and 820 to 1051 mg kg⁻¹, respectively. Constant-rate K (CR-K) ranged from 2 to 6 mg kg⁻¹ in surface soil and from 7 to 9 mg kg⁻¹ in subsurface soil. Integrated farming generally recorded higher K release values, possibly due to greater replenishment of potassium reserves through nutrient recycling and organic amendments, while natural farming exhibited comparatively lower values. The higher cumulative K release and CR-K in subsurface soil may be associated with greater reserves of K-bearing minerals and clay minerals capable of releasing potassium under successive extraction conditions.

Table 1: Water soluble and exchangeable potassium content of soils under different production systems across various agro-climatic zones

Production System	Water soluble K (mg kg ⁻¹)						Exchangeable K (mg kg ⁻¹)					
	NE Transition Zone		NE Dry Zone		Northern Dry Zone		NE Transition Zone		NE Dry Zone		Northern Dry Zone	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Crop	Chickpea		Paddy		Paddy		Chickpea		Paddy		Paddy	
NFS1	10.7	8.7	10.5	9.4	10.2	9.1	216.9	187.6	211	166.8	176.1	147.6
OFS1	11.1	9.6	10.8	10.4	10.4	10	228.5	203.1	223.6	199.3	212.5	193.5
CFS1	9.6	9.2	9.4	9.2	9.2	9.0	197.4	158.5	194.1	149.8	163.2	135.3
IFS1	11.3	10.7	10.8	10.5	10.5	10.2	234.5	221.3	226.9	219.8	216.7	187.6
Crop	Redgram		Redgram		Pearlmillet/Groundnut		Redgram		Redgram		Pearlmillet/Groundnut	
NFS2	11.0	9.0	10.7	9.2	10.3	9.8	218.1	196.4	216	182.3	209.5	188.1
OFS2	11.2	9.9	11.0	10.2	10.5	10.5	237.1	213	234.4	200.5	223.4	206.3
CFS2	9.7	9.6	9.5	9.4	9.6	9.2	197.4	170.9	200.1	166.6	188	162.8
IFS2	11.2	10.9	11	10.7	10.6	10.3	237.5	223	235	213.5	222.0	213.7
Range	9.6-11.3	8.7-10.9	9.4-11.0	9.2-10.7	9.2-10.6	9.0-10.5	197.4-237.5	158.5-223.0	194.1-235.0	149.8-219.8	163.2-223.4	135.3-213.7
Mean	10.73	9.70	10.46	9.88	10.16	9.76	220.92	196.73	217.64	187.33	201.43	179.36

Table 2: Non-Exchangeable and mineral potassium content of soils under different production systems across various agro-climatic zones

Production System	Non-Exchangeable K (mg kg ⁻¹)						Mineral K (mg kg ⁻¹)					
	NE Transition Zone		NE Dry Zone		Northern Dry Zone		NE Transition Zone		NE Dry Zone		Northern Dry Zone	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Crop	Chickpea		Paddy		Paddy		Chickpea		Paddy		Paddy	
NFS1	320.4	350.1	305.4	405.2	295.6	325.4	3077	3235.5	2798	2889.6	3004	3152.9
OFS1	375.2	405.2	360.8	388	348.2	378.9	3245.2	3399	2973.8	3154.3	3156.8	3304.5
CFS1	352.9	388	340.2	372.6	330.7	360.8	3182.1	3339.3	2908.3	3070.3	3097.9	3256.9
IFS1	390.3	410.5	371	398.3	360.4	388.1	3344	3479.4	3071.3	3217.4	3257.3	3416
Crop	Redgram		Redgram		Pearlmillet/Groundnut		Redgram		Redgram		Pearlmillet/Groundnut	
NFS2	335.6	370.5	310.1	340.8	299.4	329.6	3020.3	3150.1	2749.2	2894.6	2940.7	3077.6
OFS2	380.5	410.7	350.7	397.3	335.2	365.5	3197.2	3343.4	2929	3071.9	3135.8	3273.7
CFS2	360.2	402.6	330.5	380.5	312.2	375.6	3133.6	3269	2866.8	2995.5	3076.1	3180.2
IFS2	412.5	425.1	380.1	395.2	356.5	390.3	3286.8	3421.9	3016.8	3183.6	3232.8	3372.6
Range	320.4-412.5	350.1-425.1	305.4-380.1	340.8-405.2	295.6-360.4	325.4-390.3	3020.3-3344.0	3150.1-3479.4	2749.2-3071.3	2889.6-3217.4	2940.7-3257.3	3077.6-3416.0
Mean	365.95	395.34	343.60	384.74	329.78	364.28	3185.78	3329.70	2914.15	3059.65	3112.68	3254.3

Table 3: Total potassium content of soils under different production systems across various agro-climatic zones

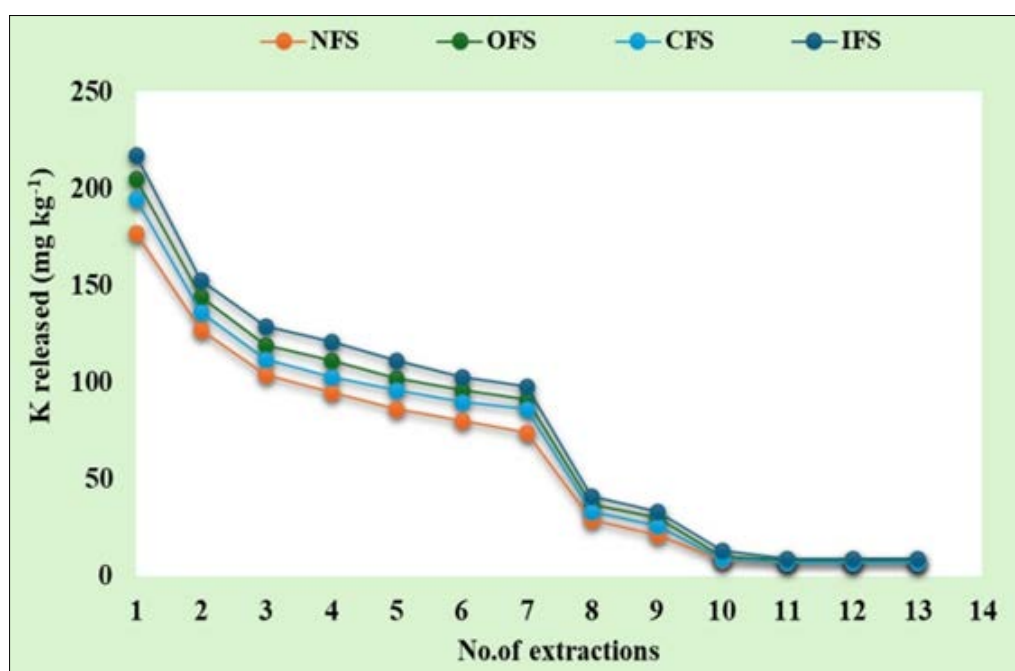
Total K (mg kg ⁻¹)						
Zone	NE Transition Zone		NE Dry Zone		Northern Dry Zone	
Production System	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Crop	Chickpea		Paddy		Paddy	
NFS1	3625	3782	3325	3471	3486	3635
OFS1	3860	4017	3569	3752	3728	3887
CFS1	3742	3895	3452	3602	3601	3762
IFS1	3980	4122	3680	3846	3845	4002
Crop	Redgram		Redgram		Pearlmillet/Groundnut	
NFS2	3585	3726	3286	3427	3460	3605
OFS2	3826	3977	3525	3680	3705	3856
CFS2	3701	3852	3407	3552	3586	3728
IFS2	3948	4081	3643	3803	3822	3987
Range	3585–3980	3726–4122	3286–3680	3427–3846	3460–3845	3605–4002
Mean	3783.38	3931.5	3485.88	3641.63	3654.13	3807.75

Table 4: Release characteristics of non-exchangeable potassium in surface soil (0-15 cm) under different production systems (mean value across the agro-climatic zones)

Production system	Successive extraction (number) with 1N HNO ₃													Cumulative K release (mg kg ⁻¹)	Total step-K	CR-K
	1	2	3	4	5	6	7	8	9	10	11	12	13			
NFS	172	111	86	81	70	66	62	25	13	2	2	2	2	671.0	652.0	2
OFS	190	124	96	91	83	76	71	30	19	5	4	4	4	783.0	731.0	4
CFS	189	117	90	85	81	73	68	27	16	4	3	3	3	740.0	700.0	3
IFS	207	120	101	94	85	79	76	34	22	7	6	6	6	825.0	748.0	6
Mean														754.8	707.75	3.75
Range														671-825	652-748	2-6

Table 5: Release characteristics of non-exchangeable potassium in subsurface soil (15-30 cm) under different production systems (mean value across the agro-climatic zones)

Production system	Successive extraction (number) with 1N HNO ₃													Cumulative K release (mg kg ⁻¹)	Total step-K	CR-K
	1	2	3	4	5	6	7	8	9	10	11	12	13			
NFS	177	127	104	95	86	80	74	29	21	8	7	7	7	820.0	740.0	7
OFS	205	144	119	111	102	96	91	37	30	10	8	8	8	970.0	870.0	8
CFS	195	136	112	103	96	90	86	33	26	9	7	7	7	907.0	819.0	7
IFS	217	153	129	121	111	103	98	41	33	13	9	9	9	1051.0	939.0	9
Mean														937	842	7.75
Range														820-1051	740-939	7-9

**Fig 1:** Non-exchangeable potassium release pattern in surface soil (0-15 cm) under different production systems (mean value across the agro-climatic zones)

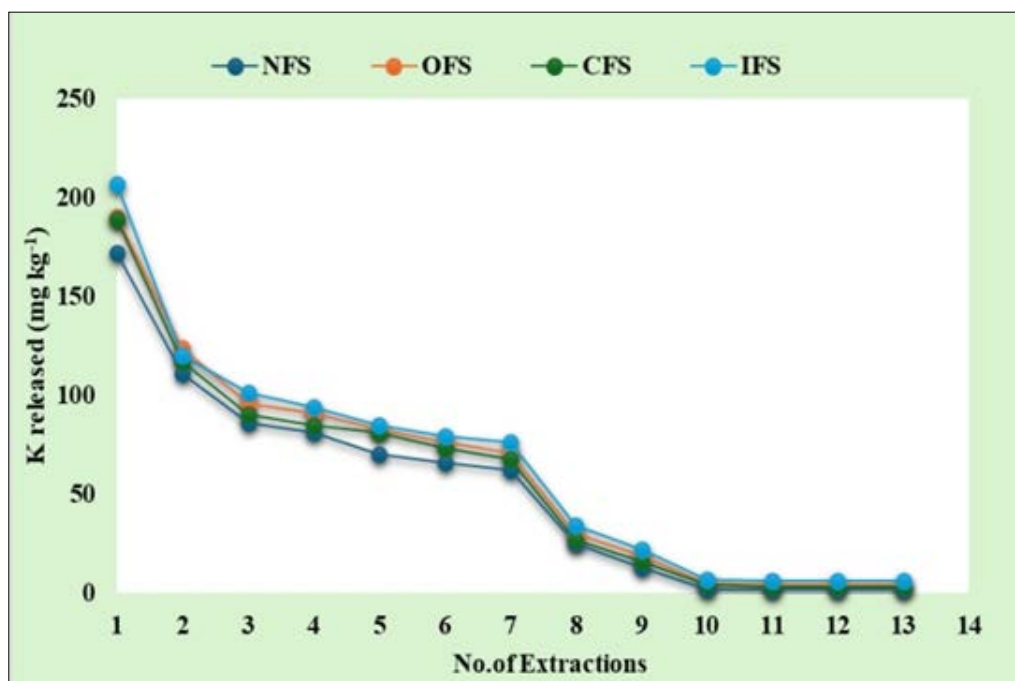


Fig 2: Non-exchangeable potassium release pattern in subsurface soil (15-30 cm) under different production systems (mean value across the agro-climatic zones)

Conclusion

Soil potassium fractions varied among production systems, agro-climatic zones and soil depths in Kalyana Karnataka region. Potassium fractions followed the order total k > mineral k > non-exchangeable k > exchangeable k > water-soluble k, with mineral k accounting for the largest proportion of total k. Sequential extraction showed rapid non-exchangeable k release during early extractions, followed by a decline and a near-constant release at later stages. Integrated farming generally showed higher k release than natural farming. As the study compared established production systems across locations, further replicated, long-term studies would be needed to separate management effects from inherent site differences.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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Competing Interests

The authors declare that they have no competing interests.

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