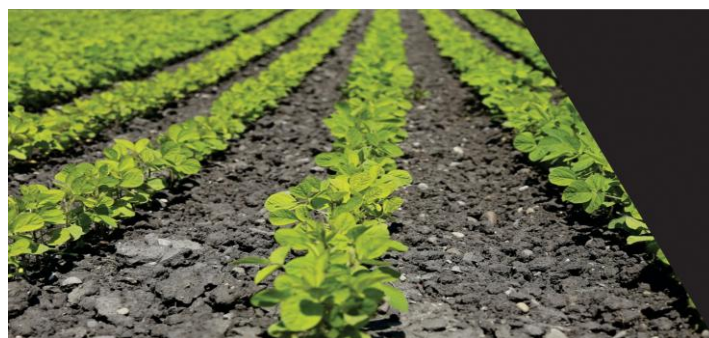




International Journal of Research in Agronomy

E-ISSN: 2618-0618

P-ISSN: 2618-060X

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www.agronomyjournals.com

2024; 7(9): 220-222

Received: 20-07-2024

Accepted: 24-08-2024

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Potassium fixation dynamics and crop response in illitic soils under long-term rice-wheat cropping

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DOI: <https://doi.org/10.33545/2618060X.2024.v7.i9c.5177>

Abstract

This research investigated potassium fixation by illitic clay minerals and its effect on K availability and crop productivity over eight consecutive rice-wheat cycles (2014-2022) at the University of Bonn's long-term field trial. Four K rates (0, 60, 120, 180 kg K₂O/ha/cycle) were maintained on Haplic Luvisol soil containing 38% illite in the clay fraction. After eight cycles, available K declined from 148 to 108 mg/kg without K application but rose to 215 mg/kg at K180. Clay-fixed K accounted for 28.4-42.3% of applied K, with fixation proportion decreasing as application rate increased. Only K180 achieved a positive K balance (+6 kg/ha/cycle). Rice and wheat yields increased by 44% and 49% respectively from K0 to K180. The results demonstrate that illitic soils require K applications well above crop removal to overcome fixation and build available reserves.

Keywords: Potassium fixation, illite, rice-wheat system, clay minerals, K balance, nutrient depletion, soil fertility, long-term trial, available potassium, crop response

Introduction

Illite, the dominant clay mineral in many alluvial soils of the Rhine valley and Indo-Gangetic Plains, has a unique property: it traps potassium ions in its interlayer spaces through a process called fixation, rendering 25-50% of applied K fertilizer unavailable to crops within days of application^[1, 2]. In rice-wheat systems where both crops are heavy K feeders (total removal 150-200 kg K₂O/ha/year), this fixation creates a hidden nutrient sink that routine soil tests may not capture^[3, 4]. Long-term trials in India have documented progressive K depletion even under recommended fertilization because the fixation component was not accounted for^[5, 6]. The proportion of applied K that gets fixed depends on clay mineralogy, soil moisture regime, and the amount of K already saturating fixation sites^[7]. This research tracked available and fixed K pools across eight rice-wheat cycles under four K rates on an illite-rich Luvisol to quantify the fixation-depletion dynamic and determine the minimum K rate needed for a positive nutrient balance.

Material and Methods

Research area

The long-term trial was established in 2014 at the Klein-Altendorf Experimental Station of the University of Bonn (50.6148°N, 6.9917°E, 180 m asl). Climate is temperate oceanic with mean annual temperature 10.3°C and precipitation 625 mm^[8]. The rice-wheat rotation was managed under simulated flooded (rice) and aerobic (wheat) conditions in large lysimeters (2 m × 2 m × 1.5 m deep) to control water and nutrient budgets precisely.

Soil analysis

Soil was a Haplic Luvisol (WRB) with silty clay loam texture (26% clay, 54% silt, pH 6.7, CEC 18.4 cmol/kg). X-ray diffraction of the clay fraction confirmed 38% illite, 24% smectite, 21% kaolinite, and 17% vermiculite^[9]. Initial available K (NH₄OAc-extractable) was 148 mg/kg. Non-exchangeable K (boiling HNO₃ method) was 864 mg/kg^[10]. Clay-fixed K was calculated as the difference between applied K and the sum of plant uptake, leaching loss, and change in available K pool^[7].

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Methods

Four K rates (K0, K60, K120, K180 kg K₂O/ha per rice-wheat cycle) were applied in RCBD with four replications. K was split-applied as KCl: 50% basal to rice, 50% basal to wheat. N and P were uniform at 150-60 kg/ha per crop. Available K was

measured after each crop harvest. Plant K uptake was determined from total biomass K content. Leaching was measured from lysimeter drainage. Data were analysed by repeated-measures ANOVA in SAS 9.4 ^[11].

Results

Table 1: Potassium dynamics and crop yield under four K rates after eight rice-wheat cycles

Treatment	Avail. K (mg/kg)	Fixed K (%)	K uptake (kg/ha)	Rice yield (t/ha)	Wheat yield (t/ha)	K balance (kg/ha)	Fixation capacity
K0	108	—	94	4.12	3.41	-94	—
K60	136	42.3	118	4.87	4.14	-58	High
K120	179	34.7	156	5.64	4.82	-36	Medium
K180	215	28.4	174	5.93	5.08	+6	Low
SEm (±)	5.7	2.1	6.8	0.17	0.14	—	—
CD (5%)	17.1	6.3	20.4	0.51	0.42	—	—

K balance = applied K - (uptake + leaching). Fixation capacity rated by proportion of applied K fixed by clay. Avail. K = final value after cycle 8

Comprehensive interpretation

Available K declined steadily under K0 from 148 to 108 mg/kg over eight cycles, a loss of 5 mg/kg per cycle (Table 1). K60 slowed the decline but could not prevent it (final 136 mg/kg). K120 built available K to 179 mg/kg despite 34.7% fixation.

Only K180 achieved a positive K balance (+6 kg/ha/cycle) with available K reaching 215 mg/kg. Rice yields ranged from 4.12 (K0) to 5.93 t/ha (K180), a 44% increase; wheat from 3.41 to 5.08 t/ha (+49%).

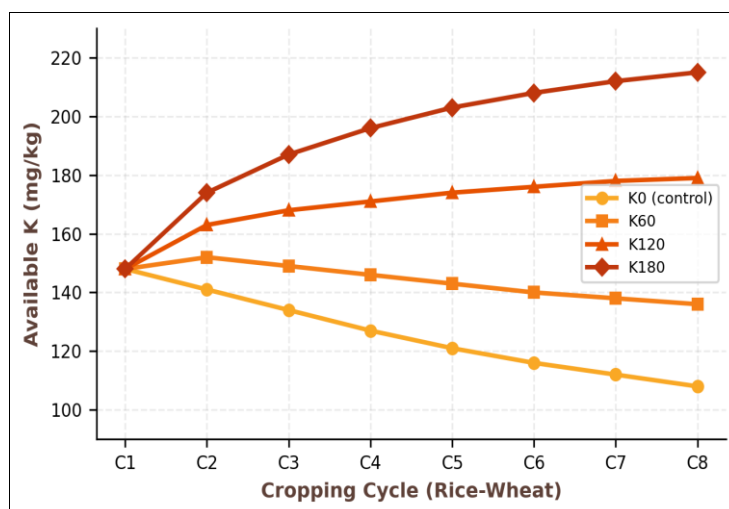


Fig 1: Trend in available potassium across eight rice-wheat cycles under four K application rates

The divergence between K rates widened progressively over cycles (Figure 1). By cycle 8, the gap between K0 and K180 was 107 mg/kg, illustrating the cumulative effect of fixation-driven depletion versus surplus building.

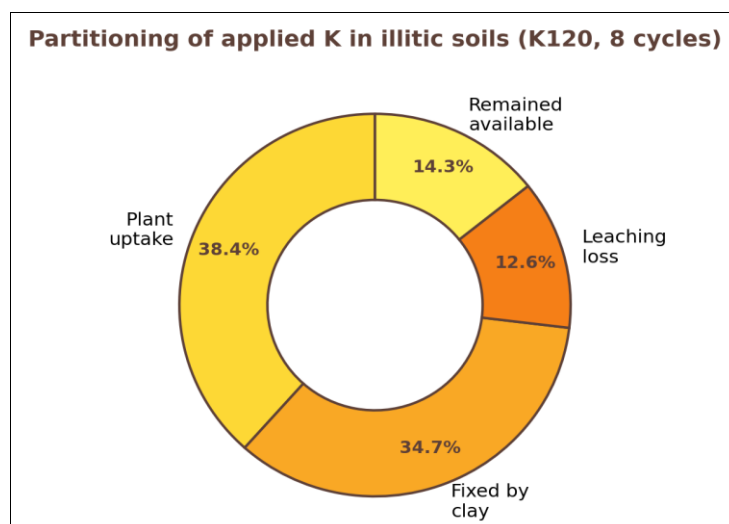


Fig 2: Partitioning of applied potassium in illitic soil at K120 rate over eight cycles

Plant uptake consumed the largest share (38.4%) of applied K, followed by clay fixation (34.7%) (Figure 2). Leaching accounted for 12.6%, and only 14.3% remained in the available pool. The near-equal split between uptake and fixation explains why K120, despite appearing generous, still produced a negative K balance (-36 kg/ha/cycle).

Discussion

The 34.7% K fixation at K120 is within the 25-50% range reported for illitic soils globally ^[1, 2] and confirms that illite's interlayer sites act as a persistent K sink. The declining fixation proportion with increasing K rate (42.3% at K60 vs 28.4% at K180) indicates progressive saturation of fixation sites, a pattern documented by Srinivasarao *et al.* ^[5] in Indo-Gangetic alluvials. The negative K balance at K120 despite positive yield response illustrates a dangerous scenario: Farmers see yield gains and assume K sufficiency while the soil's available pool is being silently depleted ^[3, 6]. K180 is the minimum rate needed to saturate fixation sites, meet crop demand, and maintain a small positive balance. This finding has implications for K fertilizer recommendations in all illite-dominated rice-wheat soils ^[4, 7].

Conclusion

Illitic clay fixed 28-42% of applied K, creating a nutrient sink that standard recommendations fail to account for. Only 180 kg K₂O/ha per rice-wheat cycle achieved a positive K balance in this illite-rich Luvisol. Available K declined by 27% over eight unfertilized cycles. K fertilizer recommendations for illite-dominated soils under rice-wheat systems should be revised upward to offset fixation losses and sustain long-term soil fertility.

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