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Research paper

Assessment of potassium release threshold levels of Vertisols (shrink-swell soils) in different agro-ecological regions of India

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ABSTRACT

Studies to evaluate the release threshold level of potassium in Vertisols (shrink-swell soils) in different agro-ecological regions of India and how that may help in K fertility interpretations are rare. Thus the objectives of this study were (i) to evaluate the K status of Vertisols through release threshold levels and (ii) to relate the findings with soil K release and fertilizer management. Three established soil series samples were collected from Vertisols of different agro-ecological regions of India. Release threshold level (RTL) was assessed after equilibrating soil with 0.01 M $CaCl_2$ solution having series of soil: solution ratio, after which the remaining amount of exchangeable K was extracted with 1 N NH_4OAc (pH 7). Total amount of K extracted (K_T = K desorbed in $CaCl_2$ solution plus K extracted with 1 N NH_4OAc) remained more or less constant with decreasing K-level up to a certain value (say threshold value) below which K_T increased sharply indicating K release from non-labile form. The threshold value in terms of K concentrations (Release Threshold Concentration) of Panjari, Nagpur, Maharashtra (Typic Haplusterts, Sub-humid dry), Teligi, Bellary, Karnataka (Sodic Haplusterts, Semi-arid dry) and Kheri, Jabalpur, Madhya Pradesh (Typic Haplusterts, Sub-humid moist) soils were 0.044–0.049, 0.034–0.062 and 0.043–0.11 mm, respectively. The high release threshold K levels in terms of concentration and activity ratio (AR) were observed in soils of Teligi and Kheri series as compared to soils of Panjari series due to high content of trioctahedral mica in the former two soils. The relationships between clay minerals, release threshold level, exchangeable potassium and non-exchangeable potassium determined by 1 N HNO_3 and sodium tetra-phenyl borate ($NaBPh_4$) have been discussed.

1. Introduction

In the present agriculture scenario, the net negative NPK balance is 19% N, 12% P and 69% K. The current estimated average net depletion per ha from India's 143 M ha of net sown area comes to 16 kg N, 11 kg P_2O_5 and 42 kg K_2O. The large proportion for K is partly because crops remove an average of 1.5 times more K than N, and K application through fertilizer is much lower than that of N or P (Tandon, 2007). In India, the entire requirement of K fertilizer is met through imports. Therefore, there is need to optimize the efficiency of native soil K as well as added fertilizer K for better plant uptake and proper management of this nutrient. For judicious use of K fertilizer there is need to have prior knowledge about the potassium supplying capacity of soil to the plant available pool is also necessary (Ghosh and Debnath, 2010). Release threshold level (RTL) is defined as that solution concentration below which labile K starts releasing (Datta, 2010). It depicts the capacity of soil system to maintain a certain level of K in solution and gives a visual representation of how the level of K in solution is related to the total amount of K available in the exchangeable and soluble form (Evangelou et al., 1994; Schindler et al., 2005).

When soil labile K is depleted to “steady state”, non-exchangeable soil K becomes a more important source of plant available K. The concept of “intermediate K” (Beckett, 1971) refers to the fraction of non-exchangeable K (NEK) that is held around the edge and wedge zones of micaceous minerals and is released in the soil solution below a certain critical level of K concentration in soil solution, called the threshold concentration (Scott and Smith, 1966; Datta and Sastry, 1988, 1989; Datta, 2010). The significant contribution of intermediate K to crop uptake in K depleted soils has been reported (Mengel and Wiechens, 1979; Datta and Sastry, 1988, 1989; Mengel, 1985; Dhar and Sanyal, 2000; Ghorban, 2007; Ghosh and Debnath, 2010). Simonson et al. (2007) studied the K release and fixation as a function of fertilizer

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application rate and soil parent material and concluded that release and fixation rates were greatly dependent on the soil K balance, confirming that these are reversible processes that depend on plant uptake and fertilizer input. Further, when a soil sample is equilibrated with a definite volume of 0.01 M $CaCl_2$ solution, a portion of K, depending on the K status and buffering capacity of the soil, is desorbed from the exchangeable phase to solution phase. The remainder of exchangeable K exists in equilibrium with K—Ca activity ratio of the equilibrated solution. If a larger volume of $CaCl_2$ solution is used for the said equilibration, a greater amount of K from exchangeable phase will be desorbed and consequently both the amount of K in the exchangeable phase and K—Ca activity ratio in equilibrium solution will decrease. However, the amount of K in the exchangeable phase, if added to that desorbed in the solution phase after equilibration, is expected to give a constant value of total K extracted for both the soil: solution ratios, with the assumption that no K had been released from the non-exchangeable forms. This assumption fails at a very high solution: soil ratio of equilibration, because of a plausible release of K from the non-exchangeable forms at reduced activity ratios of K: Ca in the equilibrated solution phase. The level of K at which this occurs may be found by plotting total K extracted against K—Ca activity ratio in the equilibrated solution of a series of soil: solution ratios (Datta and Sastry, 1988, 1989; Datta, 1996).

Reports on K response in Vertisols (shrink-swell soils) have been increasing markedly over the past decades across the black soil regions of India. No studies have been done to investigate the natural K status of Vertisols as it relates to release threshold level. The current study provides the valuable information regarding soil K dynamics in Vertisols of different agro-ecological regions of India and provides preliminary data that suggest more rigorous evaluations of the K release of these soils.

2. Material and methods

2.1. Collection and preparation of soil samples

Profile soil samples were collected from three benchmark Vertisol series representing different agro-ecological zones and variation in soil characteristics, viz. Panjari series, Teligi series and Kheri series of India. Soil samples of Ap plus Bss4 horizons to a depth of nearly 150 cm from Panjari series, (21°01′ N, 79°03′ E) Nagpur, Maharashtra (Typic Haplusterts) were collected which represent sub-humid dry agro-ecological region. Soil samples of Ap plus CrK horizons to a depth of nearly 157 cm from Teligi series, (15°37′ N, 76°54′ E), Bellary, Karnataka (Sodic Haplusterts) were collected which represent semi-arid dry agro-ecological region and soil samples of Ap plus R/Cr horizons to a depth of nearly 141 cm from Kheri series (23°14, N, 79°56, E), Jabalpur, Madhya Pradesh (Typic Haplusterts) which represent sub-humid moist agro-ecological region were compositely collected. From the three Vertisols profiles, total 20 soil samples were collected. The samples were air dried in shade, ground with the help of mortar and pestle, passed through a 2 mm sieve, kept in new polythene packets and stored for further soil analysis.

2.2. Soil analysis

Samples were analysed for particle size distribution by standard method. The air dried samples were treated with 1 N sodium acetate (pH 5.0) to destroy calcium carbonate. Thirty per cent H_2O_2 treatment was given to oxidize organic matter followed by citrate-bicarbonate-dithionite (CBD) treatment for the removal of free iron oxides. Sand (2000–50 μm) was separated by wet sieving. Silt (50–2 μm) and total clay (< 2 μm) fractions were separated after dispersion according to the size segregation procedure of Jackson (1979). Soil samples were analysed for important chemical properties of soils by using standard methodologies. The pH of a soil was measured by a pH meter after equilibrating the soil with water in the ratio of 1:2 soil water suspensions (Jackson, 1958). The EC of a soil: water (1:2) suspension was determined by ELICO conductivity bridge (Richards, 1954).Organic carbon was determined by modified Walkley and Black rapid titration procedure (Jackson, 1973). Cation exchange capacity (CEC) of soil was measured by ammonium acetate extraction (Richards, 1954). The general physical and chemical properties of soils are given in Table 1.

Table 1

Important physical and chemical properties of soils.

Soil parameters	Panjari, Nagpur, MH	Teligi, Bellary, KN	Kheri, Jabalpur, M.P.
Sand (%)	0.2–0.6[a]	4–10	6–18
Silt (%)	31–44	21–30	30–40
Clay (%)	55–69	61–74	45–54
pH	8.2–8.3	8.2–9.2	6.9–8.4
EC ($dS\ m^{-1}$)	0.13–0.18	0.22–0.37	0.10–0.19
OC (%)	0.4–0.7	0.3–1.5	0.2–1.3
CEC ($c\ mol\ (p^+)\ kg^{-1}$)	41–50	26–41	29–36

[a] The values in table are profile ranges.

2.3. Determination of potassium fractions in soil

2.3.1. Exchangeable potassium

It was determined by extracting K from the soil with 1 N NH_4OAc and the same was used for the determination of cation exchange capacity (Khudsen et al., 1982). The NH_4OAc method involves extracting soil K by using a 1 M NH_4OAc solution buffered at pH 7.0 with a soil/solution ratio of 1:10 (w/v), and shaking at 200 oscillations min^{-1} for 30 min.

2.3.2. Non exchangeable potassium

2.3.2.1. 1 N HNO_3 method. It was determined by using 1 N HNO_3 in 1:10 soil extractant ratio and boiling for 10 min (Wood and Deturk, 1940).

2.3.2.2. 0.2 M sodium tetra-phenyl borate method. The Sodium tetra-phenyl borate ($NaBPh_4$) extractable K was determined with a procedure similar to that used by Schulte and Corey (1965). One g soil was weighed into Folin Wu tubes and 3 mL of extracting solution (0.2 M $NaBPh_4{}^{+}$ 1.7 M $NaCl^{+}$ 0.01 M EDTA) was added. The incubation time was 5 min and after that 25 mL of quenching solution (0.5 M NH_4Cl^{+} 0.11 M $CuCl_2$) was added to the tubes to stop K extraction. The tubes were then placed in a digestion block on a hot plate at 150 °C until the precipitate dissolved completely (40 min). The suspension in the tubes were diluted to 100 mL with deionized water, mixed, and a 40-mL aliquot of the supernatant was filtered (filter paper Whatman no. 42) into 50-mL tubes containing 4–5 drops of 6 N HCl. The acidification of the extract helps prevent precipitation of Cu^{++} and the breakdown products of $NaBPh_4$, The extract was diluted (1:10) with deionized water and K was determined by using flame photometer.

2.4. X-ray diffraction analysis

X-ray diffraction analyses of total clay fraction (< 2 μm) were done following the standard methodology of Jackson (1979). For each total clay sample, eight treatments were given, viz. as shown (a) Ca- saturated, air dried, (b) Ca- saturated and ethylene glycol solvated, (c) Ca-saturated and glycerol solvated, (d) K- saturated, air dried, (e) K- saturated and heated to 110 °C, (f) K- saturated and heated to 300 °C, (g) K- saturated, heated to 300 °C and ethylene glycol saturated, (h) K-saturated and heated to 550 °C. The X-ray diffractograms were recorded with a Philips diffractometer using Ni-filtered CuK-alpha radiation scanning speed of 2°2θ/min. Mineral identification and semi-quantification was done from X-ray diffractograms of Ca-saturated and glycerol