



Long-term fertilization effects on soil potassium and crop yields in a Vertisol

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ABSTRACT

Effect of long-term fertilization and manuring on soil potassium (K) fractions in black soil (Vertisol) was investigated after 42 years of cultivation. Soils from 6 treatments, viz. control (unfertilized), N (100% of recommended N fertilizer), NP (N+ 100% of recommended P fertilizer), NPK (NP+ 100% of recommended K fertilizer), 150% NPK (150% of recommended N, P and K fertilizer), NPK+FYM (NPK+ farm yard manure), and adjacent uncultivated land were collected from 0–15 and 15–30 cm depths. Water soluble K (WSK), exchangeable K (EK) and non-exchangeable K (NEK) in soil; grain yields and K uptakes of soybean and wheat; and annual apparent K balances for different treatments were determined. Long-term variation in fertilization significantly altered the WSK, EK and NEK fractions in the soil. Cropping with K fertilizer resulted in higher WSK and EK than cropping without K fertilizer. Non-exchangeable K estimated by boiling nitric acid extraction showed higher values than that extracted by sodium tetraphenyl boron for five minutes. Wheat grain yield and total K uptake by the two crops showed positive response to K fertilization. Apparent annual K balances for 2013-14 crop cycle were negative irrespective of nutrient supply options. In general, all the K fractions and especially the exchangeable and interlayer K showed decline over uncultivated (or initial) soil. Findings of the present study, thus, highlight the need to develop a more pragmatic K fertilization approach based on exchangeable and non-exchangeable K reserves so as to minimize the decline in soil K-fertility under intensive cultivation.

Key words: Exchangeable potassium, Long-term experiment, Non-exchangeable potassium, Potassium balance, Potassium uptake, Vertisol

Potassium (K) is one of the essential nutrient elements required in large quantities by plants for a number of physiological processes (Epstein and Bloom 2005, Pettigrew 2008). Reports show that K fertility in many agricultural soils throughout the world is declining with time (Dobermann *et al.* 1998, Malo *et al.* 2005). Crop K requirement is generally at par to or even greater than nitrogen (N) requirement; despite that K fertilization remained largely neglected as compared to N and phosphorus (P) fertilizations in most of the intensively cropped soils of India (Sanyal 2014), as evidenced by the skewed N: P₂O₅: K₂O consumption ratio, which was 7.5: 3: 1 in 2015-16 (FAI 2017). Inadequate K fertilization leads to overdependence on soil's native K

reserves. During 2015-16, almost 15 million tonnes of K₂O was mined from Indian soils by crop cultivation (Tewatia *et al.* 2017). Long-term cropping with N or N and P without K fertilizers have been found to adversely affect a soil's K supplying capacity (Das *et al.* 2018, 2019). For easy understanding of the relatively complicated soil K dynamics, soil K is categorized into four different classes based on their availability to plants, viz. soil solution K (mostly measured as water soluble K, WSK), exchangeable K (EK), non-exchangeable K (NEK) and structural K (Sparks and Huang 1985). Plant uptake and/or leaching depletes the WSK, which is then replenished by the EK, which in turn gets replenished by NEK. Black soils of central India have large amounts of smectite clays and are generally high in exchangeable K. However, long-term intensive cultivation without adequate K additions through fertilizer or manure might adversely affect the non-exchangeable K reserves of this soil.

Considering the above facts, the present study was conducted with a black soil (taxonomically, Typic Haplustert) after 42 years of cultivation. The objectives were to observe the effects of long-term cropping with different nutrient supply options on soil K fractions and crop yields and to find out whether crops are responding

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to applied K or not.

MATERIALS AND METHODS

Long-term fertilizer experiment (LTFE) located at Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh (23°10'N, 79°57'E and 393 m above mean sea level) continuing since 1972-73, was chosen for present study. The site has a humid subtropical climate with mean minimum temperature 18°C and mean maximum temperature 32°C. Mean annual precipitation was 1386 mm. The experiment started with soybean-wheat-maize (fodder) cropping system, which was continued up to 1993-94. From 1994-95, summer maize was discontinued and soybean-wheat cropping sequence was maintained. Recommended rates of N-P-K for soybean and wheat were 20-35-17 kg/ha and 120-35-33 kg/ha, respectively. Urea, single superphosphate (SSP) and muriate of potash (MOP) were used as the sources of N, P and K, respectively. Farm yard manure (FYM) (15 Mg/ha/year up to 2012-13; 5 Mg/ha/year from 2013-14) was applied to soybean crop only during *kharif* season. Individual plot size was 17 m × 10.8 m. The soil of this site is named as Typic Haplustert. At the beginning of the experiment the soil (0-15 cm) had pH 7.6, EC 0.18 dS/m, CEC 49 cmol[p+]/kg, and organic C 0.57%.

A total of 10 treatments, comprising sub-optimal (50% of recommended rate) to super-optimal (150% of recommended rate) NPK, N, NP, NPK in combination with FYM, S, Zn, or lime and control (unfertilized) were being evaluated in a completely randomized block design in this LTFE. For the present study, soil samples were collected from three replications of six treatments (Table 1). Along with that soil samples from adjacent uncultivated land were also collected, which were treated as initial or reference soil. Soil samples (0-15 and 15-30 cm) were collected from each replicated plot after the harvest of wheat crop of 2013-14. The soil was air-dried, ground and passed through a 2-mm sieve before analysis.

Water soluble K (WSK) was determined by shaking 2.5 g soil with 25 mL distilled water for 1 hour. Ammonium acetate extractable (NH₄OAc-K) was determined by 1 N NH₄OAc (pH 7) method of Hanway and Heidel (1952).

Table 1 Details of the six treatments chosen for the study

Treatment code*	Treatment details
Control	No fertilization in <i>kharif</i> or <i>rabi</i>
N	N at recommended rate through fertilizer in both <i>kharif</i> and <i>rabi</i>
NP	N and P at recommended rates through fertilizers in both <i>kharif</i> and <i>rabi</i>
NPK	N, P and K at recommended rates through fertilizers in both <i>kharif</i> and <i>rabi</i>
150% NPK	N, P and K at 150% of recommended rates through fertilizers in both <i>kharif</i> and <i>rabi</i>
NPK+FYM	N, P and K at recommended rates through fertilizers in both <i>kharif</i> and <i>rabi</i> + 10 Mg FYM/ha only in <i>kharif</i>

The WSK was subtracted from NH₄OAc-K to obtain the exchangeable K (EK). The HNO₃ extractable K (HNO₃-K) was determined by boiling 2.5 g soil in 25 mL of 1 N HNO₃ for 10 min (Page *et al.* 1982). The NH₄OAc-K was deducted from HNO₃-K to obtain the non-exchangeable K based on boiling nitric acid (NEK_{nitric}). Soil K was also extracted with 0.03 M NaTPB for five minutes following the procedure described by Jackson (1985). The NH₄OAc-K was deducted from NaTPB extractable K to get the NEK based on NaTPB (NEK_{NaTPB}). The K concentration in aliquots was determined in a flame photometer (Systronics Flame Photometer 128).

Plot-wise grain and stalk/straw samples of soybean and wheat (2013-14) were collected at harvesting for yield estimation. Plant samples were cleaned once with tap water, and twice with distilled water. Cleaned plant samples were dried in a hot-air oven at 65±5°C, ground in a Wiley mill, and digested in concentrated HNO₃ for total K determination. The K uptake by grain or stalk/straw was calculated by multiplying their K contents with respective yields. Apparent K-balances for 2013-14 crop cycle under different treatments were computed using following formula:

$$\text{Apparent K-balance (kg/ha)} = F_K + M_K - C_K$$

where, F_K –K addition through fertilizer (kg/ha), M_K –K addition through FYM (kg/ha), C_K –K removal through harvested portion of crop (kg/ha)

The data generated were processed for analysis of variance as applicable to randomized block design to test differences among the treatment means as described by Gomez and Gomez (1984). The data were analysed using the software SAS 9.2.

RESULTS AND DISCUSSION

The surface (0-15 cm) soil contained 25.1% sand, 17.6% silt and 57.3% clay, and the sub-surface (15-30 cm) soil contained 23.7% sand, 17.8% silt and 58.5% clay. Both surface and sub-surface soils were clay textured. The soil was neutral to slightly alkaline (pH 7.31-7.78 at 0-15 cm and 7.44-7.73 at 15-30 cm) and non-saline. Cation exchange capacity was quite high (41.2-42.9 cmol[p+]/kg at 0-15 cm and 36.7-39.9 cmol[p+]/kg at 15-30 cm).

Grain yields, aboveground K uptakes and apparent K balances under different nutrient supply options for 2013-14 crop cycle are presented in Fig. 1 (a-c). Grain yields of soybean and wheat ranged from 0.75 to 1.5 Mg/ha, and 1.47 to 5.29 Mg/ha, respectively (Fig. 1a). Application of K along with NP significantly increased the grain yields of both crops over NP. Singh *et al.* (2017) also observed substantial yield responses to K fertilization in Vertisols. In the present study, highest grain yields were recorded with NPK+FYM for soybean as well as wheat. Application of FYM provides additional nutrients and also improves overall soil health by improving the biological activity (Das *et al.* 2015, 2017), so had a beneficial impact on crop yields.

The K uptake by the crops was significantly greater in treatments with added K fertilizer than those without added

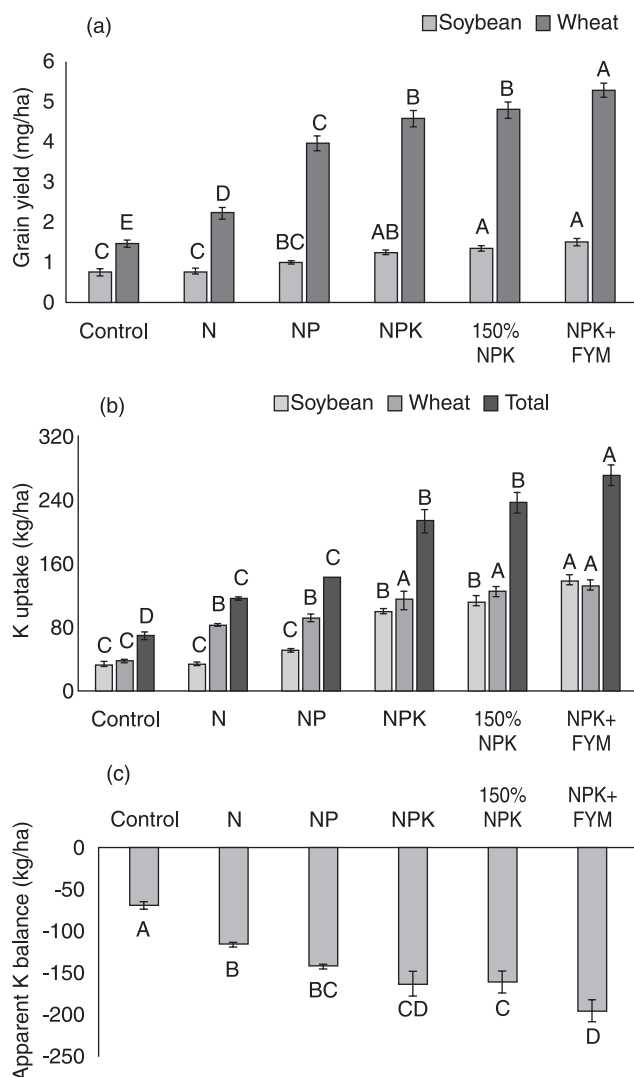


Fig 1. (a) Grain yield, (b) above-ground K uptake and (c) apparent K balance for 2013-14 crop cycle; in each figure, columns with no common letters indicate significant difference at $P < 0.05$; error bars represent standard error of mean (SEm, $n=3$)

K (Fig. 1b). The annual total K uptake by the system was significantly greater under NPK+FYM than other treatments. Aboveground K uptakes by soybean and wheat under NPK were significantly greater than those under NP. Significant positive response of grain yield of wheat and K-uptake of both crops towards K application underlined the importance of K-fertilization for attaining higher crop yields.

Control showed the lowest negative K balance, whereas the same was highest under NPK+FYM (Fig. 1c). Irrespective of treatments, apparent K balances for 2013-14 crop cycle were negative. This indicated that applications of K fertilizer even at greater than recommended rates were not able to compensate for the K removal from the crops. Hence, the crop-K requirement in excess of that supplied through fertilizer with or without manure was met by K input through irrigation water (not estimated in the present study) and soil K reserves. The negative

apparent K balances computed across the treatments were not necessarily culminated into lowering of different pools of soil K owing to K input to the studied soil layers (0–15 and 15–30 cm) through capillary-rise and irrigation, which remained largely unaccounted in the present study.

Across the treatments, WSK was in the range of 16.5 to 24.5 and 15.1 to 29.9 kg/ha at 0–15 and 15–30 cm soil depths, respectively (Fig. 2). At 0–15 cm, the K-fertilized treatments showed significantly higher WSK than the unbalanced fertilization options, i.e. N and NP. At 15–30 cm depth, WSK in NPK was at par with unfertilized-control, N and NP. Unlike the surface layer, application of FYM along with recommended NPK significantly increased the WSK content over NPK alone in the sub-surface layer. Solubilizing and chelating effect of FYM could be responsible for increase in WSK. No K input through fertilizer or manure resulted in lower WSK under N and NP treatments. However, all the treatments showed lower WSK than uncultivated soil at surface layer.

Across the treatments, EK varied from 169 to 257 and 166 to 254 kg/ha at 0–15 and 15–30 cm soil depths, respectively (Fig. 3). The K-fertilized treatments showed significantly greater EK contents as compared to unfertilized-control and imbalanced fertilization practices (i.e. N and

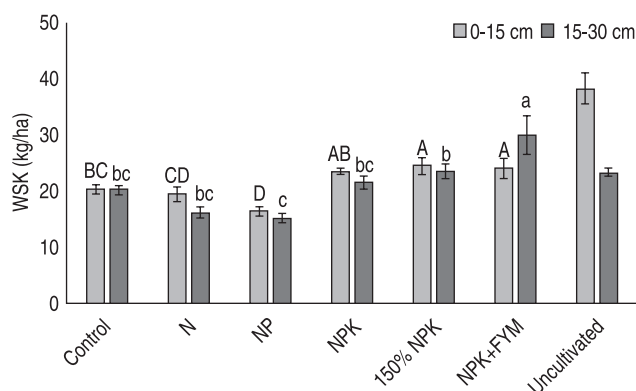


Fig 2. Water soluble K under different nutrient supply options after 42 years of intensive cultivation; for a particular depth, columns with no common letters indicate significant difference at $P < 0.05$; error bars represent SEm ($n=3$)

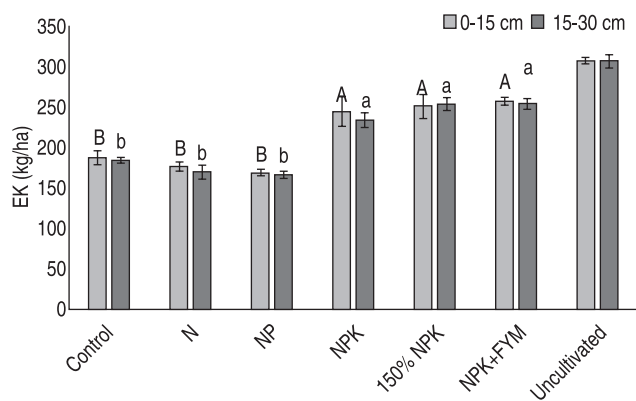


Fig 3. Exchangeable K under different nutrient supply options after 42 years of intensive cultivation; for a particular depth, columns with no common letters indicate significant difference at $P < 0.05$; error bars represent SEm ($n=3$)

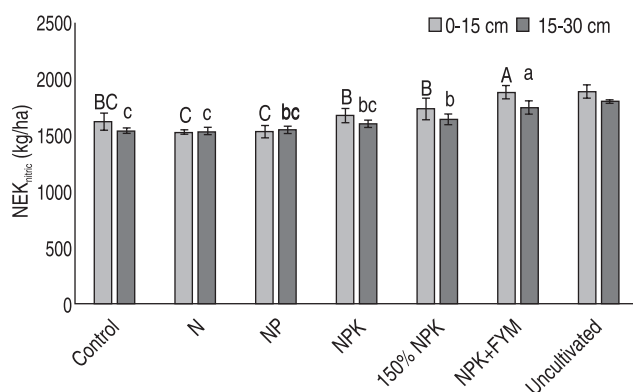


Fig. 4. Non-exchangeable K based on boiling nitric acid extraction under different nutrient supply options after 42 years of intensive cultivation; for a particular depth, columns with no common letters indicate significant difference at $P < 0.05$; error bars represent SEM ($n=3$).

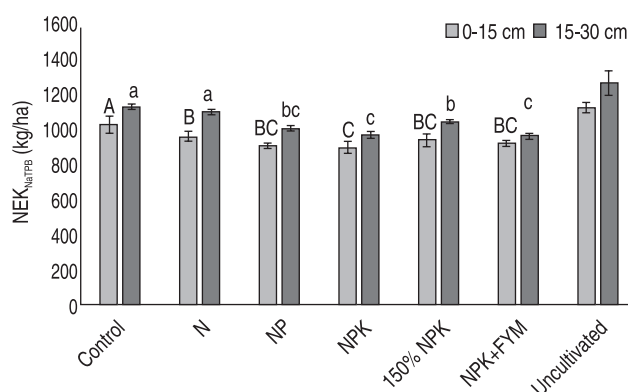


Fig. 5. Non-exchangeable K based on NaTPB extraction under different nutrient supply options after 42 years of intensive cultivation; for a particular depth, columns with no common letters indicate significant difference at $P < 0.05$; error bars represent SEM ($n=3$).

NP) in both soil depths. Interestingly, application of more than recommended K through fertilizer alone (i.e. 150% NPK) or in combination with manure (i.e. NPK+FYM) did not increase the EK over NPK. This could be attributed to the additional K uptake under 150% NPK and NPK+FYM as compared to NPK. Das *et al.* (2018) also observed non-significant increase in EK with NPK+FYM over NPK-alone in an Inceptisol after more than four decades of double-rice cropping. However, averaged over the treatments, cultivated soil showed 30.5% and 31.4% lower EK contents than uncultivated soil in surface and sub-surface layer, respectively. Hence, the K-fertilization even at recommended rate was not able to maintain EK at levels similar to that of uncultivated (or initial) soil. A few long-term studies with rice-wheat system at different locations in the Indo-Gangetic Plains showed a decrease in NH_4OAc extractable K despite K fertilization at recommended rate (Yadav *et al.* 2000).

Across the six treatments, $\text{NEK}_{\text{nitric}}$ varied from 1530 to 1883 kg/ha in surface layer and 1540 to 1751 kg/ha sub-surface layer of the Vertisol (Fig. 4). In both soil layers, NPK+FYM showed the highest contents of $\text{NEK}_{\text{nitric}}$, which were significantly greater than the rest of the treatments at each depth. In surface soil layer, all the K-fertilized treatments showed significantly greater $\text{NEK}_{\text{nitric}}$ than the imbalanced fertilization practices (i.e. N and NP), however NPK and 150% NPK were at par with control. Cultivated soil (mean of six treatments) showed 12% and 10.7% lower $\text{NEK}_{\text{nitric}}$ than uncultivated soil at 0–15 and 15–30 cm depths, respectively.

Amounts of NEK extracted by NaTPB for five min ($\text{NEK}_{\text{NaTPB}}$) ranged between 907 and 1036 kg/ha at 0–15 cm, and 971 and 1140 kg/ha at 15–30 cm (Fig. 5). Treatment-wise trend of $\text{NEK}_{\text{NaTPB}}$ was different from $\text{NEK}_{\text{nitric}}$. Among the six treatments, unfertilized-control showed the highest $\text{NEK}_{\text{NaTPB}}$ at both soil depths. The K-fertilized treatments did not show any increase in $\text{NEK}_{\text{NaTPB}}$ over imbalanced fertilization practices. Similar to other K pools, $\text{NEK}_{\text{NaTPB}}$ also showed higher values in uncultivated soil than the cropped soils.

Most of the K requirement of crops come from soil K reserves under inadequate external K inputs (Sheldrick *et al.* 2003). Das *et al.* (2018) observed highest decline in $\text{NEK}_{\text{nitric}}$ under NP treatment after 45 years of rice-rice cropping in an Inceptisol, where recommended K-fertilization along with FYM maintained relatively higher $\text{NEK}_{\text{nitric}}$. In the present study, though $\text{NEK}_{\text{nitric}}$ showed positive influence of K-fertilization along with manuring, such effects were not seen in case of $\text{NEK}_{\text{NaTPB}}$. Soil K extracted by boiling nitric acid consists largely of K from interlayers of 2:1 phyllosilicates and a small part of structural K released due to dissolution of tectosilicates, apart from entire amount of EK. Now, subtracting EK from HNO_3 extracted K gives the $\text{NEK}_{\text{nitric}}$, which is neither exclusively non-exchangeable K, nor includes the entire amount of non-exchangeable K of a soil (Li *et al.* 2015, Wang *et al.* 2016). On the other hand, NaTPB typically does not extract K by breaking the mineral structures (Li *et al.* 2015), and is more specific to K present in the interlayers only. The $\text{NEK}_{\text{NaTPB}}$ values in the present study does not represent the entire amount of NEK present in the soil, as only 5 min of extraction time was provided. Extraction of entire amount of non-exchangeable K from a soil by NaTPB seems to require multiple days (may be more than 10 days) of contact time (Wang *et al.* 2016). However, $\text{NEK}_{\text{NaTPB}}$ is more exclusive to interlayer K than $\text{NEK}_{\text{nitric}}$, and in the present case, control soils retained the highest interlayer K among the different treatments. Lowest crop yields associated with lower K removals under control might be the reason for higher interlayer K under this treatment. No disturbance since last four decades in the uncultivated soil helped in maintaining higher interlayer K as compared to the cropped soils.

Four decades of intensive cropping with varying nutrient management options resulted in significant changes in water soluble, exchangeable and non-exchangeable K pools ($\text{NEK}_{\text{nitric}}$ and $\text{NEK}_{\text{NaTPB}}$). Positive influence of K-fertilization was clearly observed on grain yield of wheat and total K uptake by the two crops. The labile fractions of soil K were also higher under treatments with added

K fertilizer with or without manure. However, apparent K balances were negative irrespective of nutrient supply options. In general, all the K fractions and especially the exchangeable and interlayer K fractions showed decline over uncultivated (or initial) soil. Findings of the present study, thus, highlight the need to come out with a more pragmatic K fertilization approach based on exchangeable and non-exchangeable K reserves so as to minimize the decline in K-fertility under intensive cultivation.

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