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Long-term integrated nutrient management on potassium balance and uptake kinetics in maize–chickpea cropping system in a Vertisol

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Abstract
Enhancing the crop yield potential of soil by mediating the soil fertility status of soil to feed the growing population. Linking potassium (K) balance to soil fertility creates a valuable indicator for sustainability assessment in agricultural land-use systems. It is crucial for the efficient use of K resources and resource sustainability to realize soil K balance status in India. Performance was evaluated in terms of soil properties and K Balance in soil under different treatments. At crop harvest, the physico-chemical characteristics of the soil were also evaluated. Among the various modules, (1) application of 75% STCR dose + FYM @ 5t ha^{-1} to maize followed by 100% P only to chickpea and (2) application of FYM @ 20t ha^{-1} to maize followed by FYM @ 5t ha^{-1} to chickpea increased the K Balance in soil and improved soil physico-chemical properties. Such studies are important for balance application of K fertilizer during the crop production.

Keywords: integrated nutrient management, soil health, K uptake, K balance, vertisol

Introduction
Long-term experiments have shown that using chemical fertilizer's to balance nitrogen (N) or nitrogen and phosphorus (P) without adding organic manures has hastened soil degradation and decreased crop output in intensive cropping systems (Bhattacharyya *et al.*, 2016 [3]; Mi *et al.*, 2018) [25] The maize-chickpea rotation is an important cropping sequence in India, accounting for 0.54 million hectares (Mha) and 0.65% of total food grain production (Yadav, 1996) [40]. Because low soil fertility is one of the most significant restrictions to agricultural productivity, improving soil fertility is essential for ensuring food security (Sanchez and Leakey 1997, Stoorvogel and Smaling 1998) [29, 36]. Regulating farmland nutrient cycles and balance by rational fertilization is the preferred method for improving soil fertility (Wang *et al.*, 2008) [37]. Not only can a well-balanced fertilizer application save resources, but it can also boost economic benefits. The difference between nutrient inputs and outputs of a system with set spatio-temporal boundaries is used to determine nutrient balances (also known as nutrient budgets) Bindraban *et al.*, (2000) [4]. As a result, they are commonly stated as nutrient amounts per unit of area and time (*e.g.*, kg ha^{-1} yr^{-1}). Negative nutrient balances suggest that a system is losing nutrients; nevertheless, nutrients may appear to accumulate in specific instances (and might lead to nutrient losses if strongly in excess).
Over the last few decades, nutrient balances have been widely used to improve natural resource management and/or provide suggestions (Smaling and Braun 1996 – Smaling and Toulmin 2000) [34]; nutrient balance in the soil is increasingly being used to assess the effects of fertilizer management and crop rotations in production systems. Calculating soil nutrient balance in agricultural production systems, gives some essential information for assessing their long-term sustainability (Lakaria *et al.*, 2005 [21] and Lakaria *et al.*, 2008). Previous research on K balance have primarily focused on individual experimental sites (Zhang *et al.*, 2010) [41] or short-term national observations (Li and Jin 2011) [23], however it is difficult to provide in-depth analyses of element balances based on single experimental sites or one-year studies (Wang *et al.*, 2008) [37]. Although a short-term negative K balance is unlikely, a long-term negative K balance is still a concern (Bučienė *et al.*, 2003) [7]. Short-term studies with limited information may be misleading because nutrient balances vary significantly from year to year (Sheldrick *et al.*, 2003); Sheldrick *et al.* (2003) [30] also emphasized the importance of using

nutrient balances at the national level to help develop national fertilizer policies, including decisions on fertiliser factory investments and the exploitation of local resources and minerals to supply nutrients. As mentioned in previous research (Sheldrick *et al.*, 2003, [30] Bach and Frede 1998–Spiess 2011) [30], information on the temporal variability of K balances in agro-ecosystems at the national level could be very useful for policymakers and farmers in developing strategies and measures for making acceptable use of K resources to maintain food security (Shen *et al.,* 2005) [31]. The difference between the amount of nutrient exported with grains and applied as fertilizer indicates the level of increase or decrease in soil nutrient content; when the outputs of a specific nutrient exceed the inputs in the farming system, the condition is one of the critical conditions for lower sustainability. In this backdrop, a field experiment was conducted to seed the K balance and uptake kinetics in under Vertisol.

Materials and Methods

A field experiment was conducted at the research farm of the ICAR-Indian Institute of Soil Science, Bhopal. The soil of the experimental site is classified as Vertisol (Typic Haplusterts) with smectite as the dominant clay mineral. Vertisols are churning heavy clay soils with a high proportion of swelling clays. These soils form deep wide cracks during the summer season. The soil of the experimental site was clayey in texture with 25.2, 18.0 and 56.8 per cent of sand, silt and clay, respectively. The soil was medium in soil organic carbon (0.53%), low in available N (68.8 mg kg^{-1}), medium in available P (12.8 mg kg^{-1}) and high in available K (237 mg kg^{-1}). The soil was normal in reaction (pH 7.76) and electrical conductivity (EC) was 0.48 dS m^{-1}. The performance of cropping system was evaluated by monitoring parameters viz., soil health and potassium balance in soil. The experiment comprised of 12 treatments (Table 1) laid out in a Randomized Blocks Design (RBD) with 3 replications. All the measurements having the mean value of three separate replicates. Data were subjected to an analysis of variance. The mean values were grouped for comparisons and the least significant differences among them were calculated at $P < 0.05$ confidence level using ANNOVA statistics (Gomez and Gomez, 1983).

Soil K balance model description

The soil K balance model included the following inputs: chemical fertilizer, organic manure, atmospheric dry and wet deposition, irrigation and crop seeds (K_2O, similarly hereinafter). The data used in this paper, such as chemical fertilizer (urea, DAP, SSP etc.), livestock numbers, crop yield, population number living in the Vertisol. In detail, the organic fertilizer resources were categorized by animal manure (FYM, vermicompost, goat manure etc.), straw and green manure. The following outputs were used: crops removal (including grain and straw uptake) and nutrient loss (leaching and runoff loss) as below:

K balance = Σ (fertilizer K + manure K + rain K + irrigation-water K + K in seedling and seeds)- Σ (K uptake + losses of K).

Table 1. Description of the treatment details in maize-chickpea cropping sequence

Treatment	Maize	Chickpea
T_1 (control)	No Fertilizer/ Manure	No fertilizer/ manure
T_2 (GRD)	120- 60- 30	20-60-20
T_3 (STCR)	135-55-50 (5 t ha^{-1})	0-0-0(1.5 t ha^{-1})
T_4	75% NPK of T_3	100% P only
T_5	75% NPK of T_3 + 5 t ha^{-1} FYM	100% P only
T_6	75% NPK of T_3 + 1 t ha^{-1} PM	100% P only
T_7	75% NPK of T_3 + 5 t ha^{-1} UC	100% P only
T_8	75% NPK of T_3 + MR incorporated	100% P only + MR mulch
T_9	1 t ha^{-1} PM + Gly 2 t ha^{-1} + MR incorporated	100% P only + MR mulch
T_{10}	5 t ha^{-1} FYM + Gly 2 t ha^{-1} + MR incorporated	100% P only + MR mulch
T_{11}	20 t ha^{-1} FYM (every season)	5 t ha^{-1} FYM (every season)
T_{12}	75% NPK of T_3 + 20 t ha^{-1} FYM (once in 4 years)	100% P only

GRD - General recommended dose (kg ha^{-1}), STCR - Soil test crop response dose, MR - Maize residues, FYM - Farm yard manure, PM - Poultry manure, UC - Urban compost, WR-Wheat Residue, Gly – Glyricidia

Results and Discussion

Potassium balance in soil

The potassium balance in soil was estimated for two year 2017-18 and 2018-19 under the maize-chickpea cropping system. The maximum amount of K added in treatment was the highest in T_{11} (350 kg ha^{-1}) followed by T_{12} (202.6 kg ha^{-1}) and T_7 (201.6 kg ha^{-1}) under different INM modules (Table 2 and Fig 1). The highest total K uptake was recorded in treatment T_5 followed by T_{11}, T_6 and T_7 (301.5, 292.0, 291.1 and 268.1 kg ha^{-1}, respectively) which was 124, 53.9 and 53.8 % higher over control. Most of the treatments showed negative balance of K except treatment T_{11}. The maximum depletion of K from T_3 (-182.6 kg ha^{-1}). Only the treatment T_{11} could maintain a positive balance of K in soil (58 kg ha^{-1} in two years). Additions of organic sources of nutrients have contributed more potassium in soil.

Table 2: Two year K balance in soil under different INM modules by maize- chickpea cropping system

Treatment	Total K added	Total K uptake	K balance
	(kg ha^{-1})		
T_1	0.0	134.5	-134.5
T_2	83.3	245.2	-161.8
T_3	83.3	265.9	-182.6
T_4	62.5	208.1	-145.6
T_5	132.6	301.5	-168.9
T_6	87.8	291.1	-203.3
T_7	201.6	268.1	-66.5
T_8	155.0	218.8	-63.8
T_9	99.6	230.2	-130.6
T_{10}	144.4	228.2	-83.8
T_{11}	350.0	292.0	58.0
T_{12}	202.6	278.3	-75.8

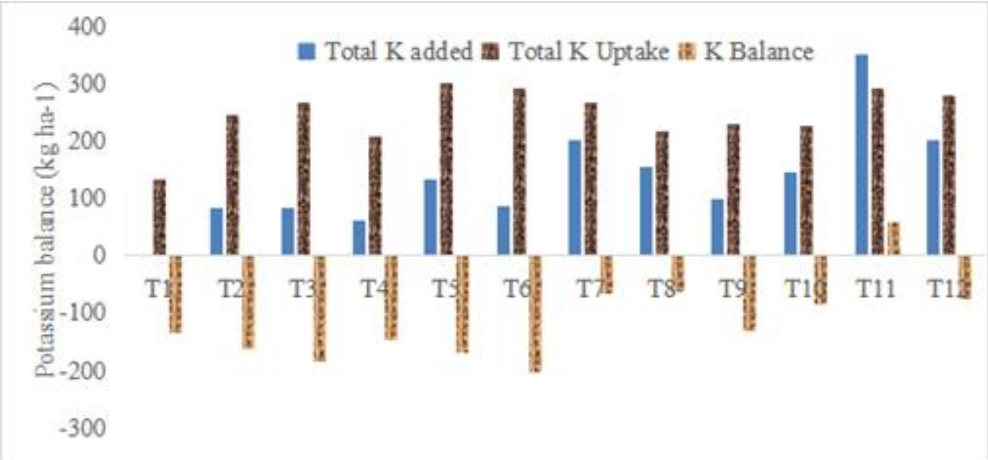

Fig 1: Two year K balance in soil under different INM modules

Potassium dynamics in soil are greatly influenced by fertilizer application rate, type, and soil properties. Maximum K (350 kg ha^{-1}) was added in this experiment via treatment T_{11}, which included 20 t ha^{-1} FYM in maize and 5 t ha^{-1} FYM in chickpea crop in each season. Organic matter improves SOC as well as soil properties such as pH, CEC, microbial population, and diversity (Dotaniya *et al.*, 2019) [10]. Blake *et al.* (1999) [5] described a treatment that incorporated a wide range of K concentrations and mediated soil cation exchange capacity. These sources contain varying amounts of K, which is solubilized during the mineralization process and improves soil solution K. Wiklander (1974) [39] reported that if there is too much K in the soil solution and the plant does not have enough K uptakes, it will leach down in the lower profile. However, the amount of clay and organic matter in the soil slows down this mechanism (Gerzabek, 1995; Dotaniya *et al.*, 2016) [14, 13]. The K dynamics in soil were mediated by a higher amount of clay in this experiment. Braunsweig (1980) [6] emphasizes the fact that sorption kinetics are heavily influenced by soil clay content. In this experiment total K uptake was highest measured in T_5, T_{11}, T_6 and T_7 by the K value 301.5, 292.0, 291.1 and 268.1 kg ha^{-1}, respectively. Among the INM module treatments showed significantly ($p=0.05$) higher K uptake by maize-chickpea crops from T_5, T_{11} and T_6 by 124 %, 53.9% and 53.8 % over control plot. Maximum uptake was observed in T_5, which was comprised with 75 % NPK of T_3 + 5 t ha^{-1} FYM. Soil available K could be increased by applying inorganic K fertilizers, and FYM mediated soil K availability. It improved the efficiency of K use and the pattern of K uptake in both crops. The amount of K uptake by maize-chickpea cropping sequence was highly dependent on soil physico-chemical properties (Singh and Goulding, 1997) [32].

The use of inorganic fertilizers during crop growth increased K availability during crop growth periods (Kandil *et al.*, 2020) [18]. Farmers prefer inorganic fertilizers to organic fertilizers such as crop residues, FYM, compost (Pettigrew 2008) [26]. Carmo *et al.* (2017) [8] reported that addition of inorganic K fertilizers containing organic components such as FYM increased total K uptake by various crops. This experiment's findings were also supported by other researchers (Rajput *et al.*, 2009 [27]; Bach and Frede 1998 [1]; Balik *et al.*, 2019; Kandil *et al.*, 2020) [18]. In K balance measurement during the experiment showed that Most of the plots showed negative balance of K except treatment T_{11}. The maximum depletion of K from T_3 plot (-182.6 kg ha^{-1}) and minimum in the treatment T_{11} (58 kg ha^{-1}). This might be due to K released kinetics under FYM taking much time than inorganic chemical fertilizers. Inorganic K fertilizers are easily taken by crop plants and the FYM treated plots are also having more microbial diversity and population. In both the conditions K balance will be more in FYM treated plots. Dotaniya *et al.* (2013) [12] reported that crop residue applied plots showed higher positive K balance than chemical fertilizers applied plots under rice-wheat cropping systems. Similar findings were also reported by different researchers (Leigh and WynJones, 1984 [22]; Wang *et al.*, 2013 [37]; Kandil *et al.*, 2020) [18].

Total potassium uptake

Maize-chickpea rotation is an important cropping sequence in Vertisol of central India. The maize total pooled K uptake was ranged between 23.85 - 80.28, during 2017, 2018 and mean of two year. The pooled data of two years revealed that the treatment T_5 (75% STCR dose + FYM @ 5t ha^{-1}) recorded highest maize stover K uptake followed by treatment T_6 (75% STCR dose + PM @ 1t ha^{-1}) and T_3 (STCR dose). Treatments T_7, T_{11} and T_{12} were found statistically at par with each other. STCR dose @ 75% (T_4) and treatments involving incorporation of maize residue and Glyricidia leaves (T_8, T_9 and T_{10}) recorded lower K uptake in maize. The unfertilized control (T_1) showed lowest K uptake by maize. A similar trend was recorded with respect to total pooled K uptake by maize. It varied between 28.85 and 80.28 kg ha^{-1}. Total pooled K uptake by chickpea was ranged between 38.53 – 79.75 kg ha^{-1} during 2017 - 18, 2018 - 19 and for pooled data of two years, respectively (Fig. 2). The average total K uptake by chickpea across the treatments was found 61.49 kg ha-1during 2017 - 18, 2018 – 19 and pooled of two years, respectively. In general, the uptake of N, P and K in maize and chickpea was found higher under the treatments receiving the integrated nutrient management modules/recommended dose of balanced chemical fertilizers (STCR). Rasool *et al.* (2008) [28] observed from a long term application of FYM and inorganic fertilizers to maize (*Zea mays* L) wheat (*Triticum aestivum* L,) cropping system that the grain yield and uptake of N, P and K by both crops were higher with the application of FYM and inorganic fertilizer than in control plots. The uptake of N, P and K increased with the application of FYM and N_{100}, P_{50}, K_{50} (Lakaria and Sharma 1995 [19]; Dotaniya and Kushwah, 2013 [11]; Jadon *et al.*, 2018a & b [16-17], Meena *et al.*, 2019 [24], Dotaniya *et al.*, 2020) [9].

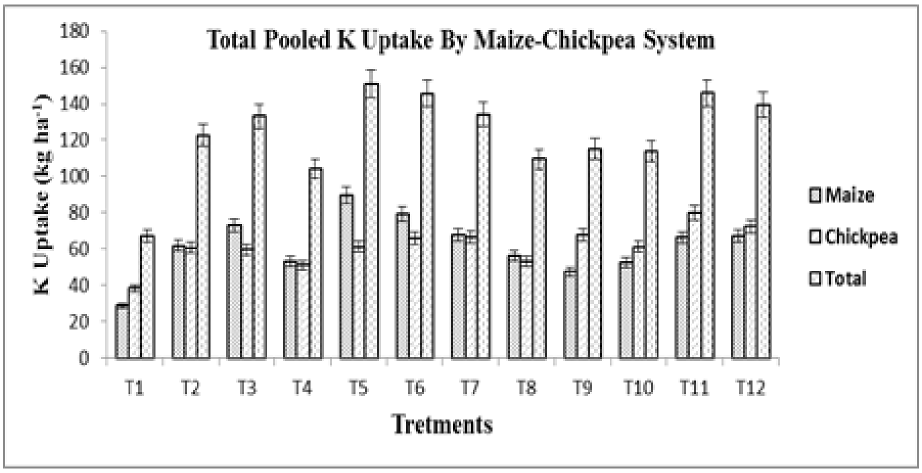

Fig 2: Maize-Chickpea total K uptake (kg ha^{-1}) under different nutrient management practices (pooled data)

Conclusion
In conclusion, the different INM modules positively influenced the performance and productivity of maize-chickpea crop as compared to the sole inorganic fertilizer application. Besides the superior crop performance, the INM modules comprised treatment T_{11} (20 t ha^{-1} FYM (every season) in maize and 5 t ha^{-1} FYM (every season in chickpea) significantly enhanced and improved soil health and potassium balance in terms of Indian Vertisol soil. To continue the application and extension of these results, the effect of K balance, soil health, and potassium uptake on crop yields under different soil fertility levels should be studied in black soil types.

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