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Nutrient use efficiency indices as influenced by nutrient management practices under cotton-green gram intercropping system in vertisols

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ABSTRACT

A field study was conducted during 2021-22 at the Research field of All India Coordinated Research Project for Dryland Agriculture (AICRPDA), Dr. Panjabrao Deshmukh Krishi Vidyapeeth, (Dr. PDKV) Akola, Maharashtra (India), on an ongoing long-term experiment initiated in 1987-88 under cotton + green gram (1:1) intercropping system in Vertisols. The eight treatments comprised of a control, sole use of organics and chemical fertilizers, and integration of organics with chemical fertilizers to partially substitute Nitrogen (N). The results after 35th cycle revealed that the uptake of N, Phosphorus (P), and Potassium (K) was significantly higher in Integrated Nutrient Management (INM) treatments, particularly the treatments T_6 and T_7 where 50 percent N was substituted by either gliricidia or Farm Yard Manure (FYM). Further, the various parameters of nutrient use efficiency of N, P, and K were also found to be significantly higher in INM treatments followed by T_2 (100% RDF). Therefore, the present investigation concludes that under the cotton + green gram intercropping system in Vertisols, INM that involves conjoint use of different nutrient sources appears to be a promising strategy for improvement in fertilizer use efficiency as a whole including Nutrient Use Efficiency (NUE).

Introduction

Cotton being an important cash crop plays a key role in the Indian economy. China and India represent around 58 percent of the world's cotton consumption. Several factors influence cotton growth, including genotype, environmental conditions, and management practices. Fertilizer is a major input in cotton production, particularly Nitrogen (N), which is one of the yield and quality limiting factors and is required more than other nutrients (Zuluaga and Sonnante, 2019). As a result, farmers tend to use a lot of N fertilizer to boost growth and productivity and ensure a high yield (Dong *et al*., 2012). Excessive N application, on the other hand, causes not only excessive cotton vegetative growth, delayed maturity, and yield and quality reductions, but also increases N release and environmental pollution (Rochester and Peoples, 2001). Nitrogen is one of the most important mineral nutrients because the production of high yields depends on its adequate supply (Zuluaga and Sonnante, 2019). The Phosphorus (P) in plants is important for root development, while Potassium (K) controls water balance, increases water uptake, and strengthens plant resistance to pests and diseases (Hartman *et al*., 2011). The efficiency of applied fertilisers is low, and the overall application efficiency has been around or less than 50 percent for N, 10–15 percent for P, and around 40 percent for K. The lower efficiencies under field conditions are associated with nutrient losses such as leaching, runoff, fixation, volatilization, etc. Furthermore, the choice of crops and cultivars also affects the use efficiency of nutrients. The Nutrient Use Efficiency (NUE) depends on the nutrient uptake, transport, assimilation, storage, remobilization, and synthesis of storage compounds during plant growth and

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development (Weih *et al*., 2018). In the literature, several site-specific management interventions have been recommended to increase the farm output per unit of input used in terms of fertilizers. A better NUE would result in lowering the need of fertilisers and associated costs. By optimizing nutrients for crop nourishment while minimizing nutrient loss to the field, nutrient use strives to improve the overall performance of cropping systems and support agricultural sustainability through contributions to soil fertility or other soil quality components (Fixen *et al*., 2015). Integrated Nutrient Management (INM) aims to improve soil health and crop productivity to make farming more sustainable (Das *et al*., 2014). A positive effect is seen on the soil properties when INM is used over other methods of nutrient management. In addition to providing nutrients to crops, organic sources of plant nutrients can improve the physical and chemical properties of soil (Sandhu *et al*., 2020). Furthermore, organic manures help increase the efficiency with which inorganic fertilizers are used. Therefore the present study has been undertaken to study the long-term effect of different nutrient management practices on nutrient use efficiency under the cotton + green gram intercropping system of Vertisol of Vidarbha region of Maharashtra.

Material and Methods

Site description

A long-term field experiment on cotton + green gram intercropping system was initiated in 1987-88 on the research field of All India Coordinated Research Project for Dryland Agriculture (AICRPDA), Dr. Panjabrao Deshmukh Krishi Vidyapeeth (Dr. PDKV), Akola. The experimental site (latitude of 20° 32' N and longitude of 77° 7' E at an elevation of 325 m above Mean Sea Level (MSL) has a hot, semi-arid ecoregion. Rainfall during *Kharif* 2021 (June-September) amounted to 741.8 mm. Most of the rainfall is received from the southwest monsoon. The maximum summer temperature is around 42°C and the winter temperature dips to 11°C. Experimental soil belongs to the Vertisols order (classified as Typic Haplusterts) with clay loam to clay texture as well as calcareous and lime concretions at varying depths. Soils have a high Available Water Holding Capacity (AWC) (180–200 mm) and are subject to drought occurrence once every 10 years. The initial soil sample analysis data (1987-88) indicate that the soil was moderately alkaline (pH 8.2), Electrical Conductivity (EC) 0.30 dS/m, Organic Carbon (OC) 4.6 g/kg, Available Nitrogen (AN) 214 kg/ha, Available Phosphorus (AP) 12.97 kg/ha, and Available Potassium (AK) 316 kg/ha (Anonymous, 1988).

Experimental design, treatments, and crop management

The experiment is a part of a long-term experiment that was taken on the same site since 1987-88 without changing randomization, under the rainfed condition on the farm of AICRPDA, Dr. PDKV, Akola, Maharashtra (India) in Randomized Block Design (RBD) with eight treatments replicated thrice. The eight treatments comprising organic and inorganic sources of fertilizer were : T_1- Control; T_2- 100 percent RDF; T_3- 50 percent RDF; T_4 -50 percent N/ha through gliricidia; T_5 -50 percent N/ha through FYM; T_6 -50 percent $N_{gliricidia}$ + 50 percent $N_{Fertilizers (F)}$ + 100 percent P_2O_5 $_{Fertilizers (F)}$ + 100 percent K_2O $_{Fertilizers (F)}$; T_7 -50 percent N_{FYM} + 50 percent $N_{Fertilizers (F)}$ + 100 percent P_2O_5 $_{Fertilizers (F)}$ + 100 percent K_2O $_{Fertilizers (F)}$; T_8 -100 percent $N_{gliricidia}$ + 100 percent P_2O_5 $_{Fertilizers (F)}$ + 100 percent K_2O $_{Fertilizers (F)}$. The Recommended Dose of Fertilizer (RDF) was 60:30:30 kg/ha N, P_2O_5, K_2O respectively. Treatment-wise basal dose of FYM and chemical fertilizers were applied at the time of sowing and the remaining half dose of N was applied through chemical fertilizers and gliricidia, 30 days after sowing (DAS) as per treatments. Every year, the same treatments were imposed on cotton (60 x 30 cm) + green gram (60 x 10 cm) intercrop. The gross plot size was 9.0 x 9.9 m^2 while the net plot size was 8.4 x 9.0 m^2. Both the crops (Cotton var. “AKH 9916”; Green gram var. “Greengold”) were sown in June or July depending upon the onset of the monsoon. All other agronomic practices were performed as per standard packages of practice recommended by the university.

Plant analysis and calculations of nutrient use efficiency

The plant samples were air-dried in shade and digested by using a di-acid and Tri-acid mixture. Total N was analysed by Micro-Kjeldahl method (Parkinson and Allen, 1975), total P by

Vanadomolybdate yellow colour method (Jackson, 1973), total K by Flame photometry (Chapman and Pratt, 1961). The uptake of major nutrients was worked out by multiplying total dry matter and nutrient concentration. Various use efficiency of nutrients N, P, and K was calculated as per the formulae given in Table 1.

Statistical Analysis

The data were statistically analysed by the technique of analysis of variance (ANOVA) as suggested by Gomez and Gomez, (1984) using the WASP statistical package (https://ccari.icar.gov.in/wasp/index.php). The least significant difference (*lsd*) at $p \leq 0.05$ was used for multiple comparisons of treatment means.

Table 1: Calculations of various indices of nutrient use efficiency

NUE indices	Formulae	Unit
Agronomic Efficiency (AE)	$AE = \frac{(EYf - EYc)}{F}$	kg grain yield increase per kg nutrient applied
Physiological Efficiency (PE)	$PE = \frac{(BYf - BYuf)}{(NUf - NUc)}$	Biological yield obtained per unit of applied nutrients.
Apparent Recovery Efficiency (ARE)	$ARE = (\frac{NUf - NUc}{F}) \times 100$	Quantity of nutrient uptake per unit of nutrient applied (%)
Internal Utilization Efficiency (IUE)	$IUE = \frac{EY}{NU}$	Kg grain per kg nutrient applied

Where, EYf- Economic Yield of crops in the fertilized plot; EYc- Economic Yield of crops in control plot; F- Amount of fertilizer input applied; BYf- Biological Yield of crops in the fertilised plot; BYuf- Biological Yield of crops in unfertilized plot; NUf-Nutrient Uptake in the fertilized plot; NUc-Nutrient Uptake in the control plot; EY-Economic Yield; NU: Nutrient Uptake.

Results and Discussion

Nutrient uptake by cotton and green gram

The uptake of Nitrogen (N), Phosphorus (P), and Potassium (K) by cotton and green gram were significantly affected by different nutrient management practices. The N uptake by cotton and green gram were significantly highest in Integrated Nutrient Management (INM) treatment T_6 (50% $N_{gliricidia}$ + 50% N_F + 100% P_F + 100% K_F) and T_7 (50% N_{FYM} + 50% N_F + 100% P_F + 100% K_F) followed by treatment T_8 (100% $N_{gliricidia}$ + 100% P_F + 100% K_F) and T_2 (100% RDF) (Figure 1). The uptake of N in cotton and green gram was higher by about 110 and 114 percent in treatment T_6 (50% $N_{gliricidia}$ + 50% N_F + 100% P_F + 100% K_F) or T_7 (50%N_{FYM} + 50% N_F + 100% P_F + 100% K_F) as compared to control (T_1). The P uptake by cotton and green gram was significantly higher in INM treatments, particularly T_6 (50% $N_{gliricidia}$ + 50% N_F + 100% P_F + 100% K_F) and T_7 (50%N_{FYM} + 50% N_F + 100% P_F + 100% K_F) (Figure 2). The P uptake by cotton and greengram were higher by about 195 and 131 percent in treatments T_6 (50%$N_{gliricidia}$ + 50% N_F + 100% P_F + 100% K_F) or T_7 (50%N_{FYM} + 50% N_F+100% P_F + 100% K_F) as compared to control (T_1). Similar result was also found for the K uptake by cotton and green gram, where K uptake in T_6 (50%$N_{gliricidia}$ + 50% N_F + 100% P_F + 100% K_F) or T_7 (50%N_{FYM} + 50% N_F + 100% P_F + 100% K_F) were higher by 154 and 200 percent as compared to control (T_1) (Figure 3). The higher nutrient uptake in INM treated plot is mainly because of improved soil properties resulting from the application of organics and inorganics, which helped in maintaining sufficient moisture in the soil for the better uptake of nutrients. These organics further help in reducing the P fixation in soil and thus increased the availability, mobility, and uptake of P in INM treated plots. The release of organic acids from the decomposition of gliricidia or FYM in INM treated plot may have resulted in the solubilisation of native potash-bearing minerals, as well as supplied a large amount of K. Further, the nutrient supply from both organic and chemical sources tended to increase nutrient content when compared to nutrient supply from only chemical fertilizers. This could be attributed to a balanced supply of plant nutrients from both organic and chemical sources (Panigrahi *et al.*, 2014). It could also be attributed to increased microbial activity as a result of the integrated use of organic manure, and chemical fertilizer which aided in improving nutrient supply and better nourishment of

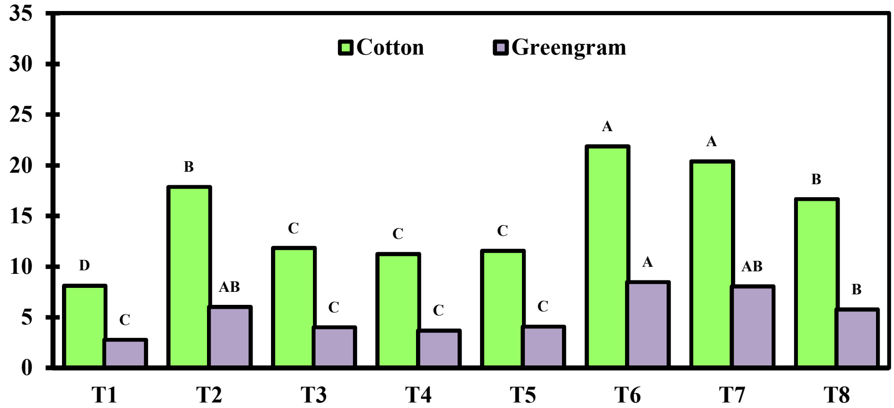

Figure 1: Nitrogen uptake (kg/ha) by cotton and green gram.

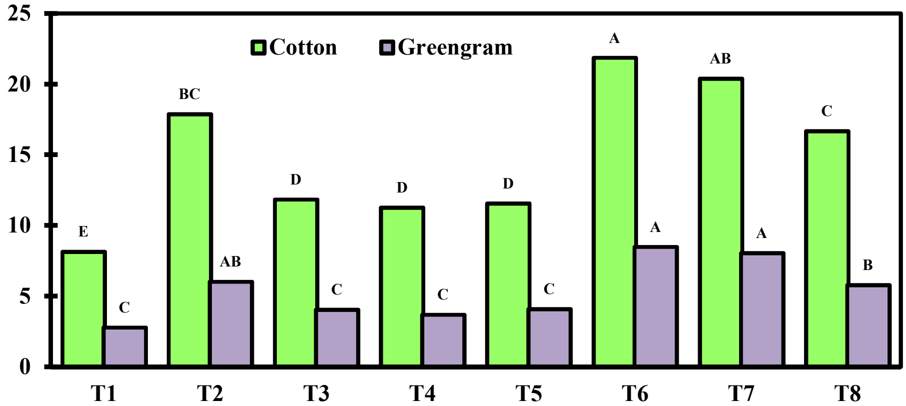

Figure 2: Phosphorus uptake (kg/ha) by cotton and green gram.

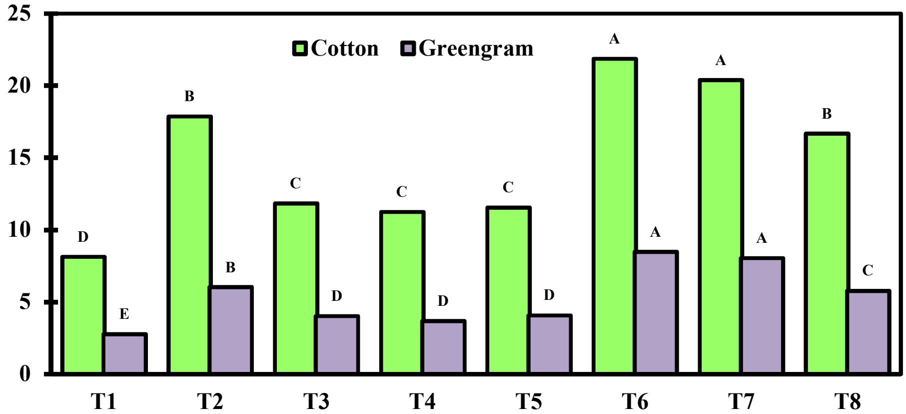

Figure 3: Potassium uptak (kg/ha) e by cotton and green gram.

Bars followed by a different letter are significantly different at $P < 0.05$ according to Tukey's HSD. T_1- Control; T_2- 100 percent RDF; T_3- 50 percent RDF; T_4 -50 percent N/ha through gliricidia; T_5 -50 percent N/ha through FYM; T_6 -50 percent $N_{gliricidia}$ + 50 percent N $_{Fertilizers (F)}$ + 100 percent P_2O_5 $_{Fertilizers (F)}$ + 100 percent K_2O $_{Fertilizers (F)}$; T_7 -50 percent N_{FYM} + 50 percent N $_{Fertilizers (F)}$ + 100 percent P_2O_5 $_{Fertilizers (F)}$ + 100 percent K_2O $_{Fertilizers (F)}$; T_8 -100 percent $N_{gliricidia}$ + 100 percent P_2O_5 $_{Fertilizers (F)}$ + 100 percent K_2O $_{Fertilizers (F)}$.

crops throughout their growing period, resulting in increased uptake of nutrients. All of these processes resulted in higher K uptake in INM treated plots. Similar results were also reported by Jadhao *et al.,* 2018; Ramakrishna *et al*., 2017; Khambalkar *et al.,* 2017.

Nitrogen use efficiency Indices

The various Nitrogen Use Efficiency (NiUE) indices in cotton were significantly affected by different nutrient management practices (Table 2). The Agronomic Efficiency (AE) in cotton ranged from 0.84 to 4.52 kg/kg. AE was significantly higher in the treatment T_6 (50% $N_{gliricidia}$ + 50% N_F + 100% P_F + 100% K_F), followed by treatment T_7 (50%N_{FYM} + 50% N_F + 100% P_F + 100% K_F). The treatments with 50 percent RDF (T_3) and sole organics (T_4 and T_5) treatments had lower AE. The Physiological Efficiency (PE) ranged between 37.86 to 77.78 kg/kg. It was highest in treatment T_4 (50% N through gliricidia) which was statistically at par with treatment T_5 (50% N through FYM). Similarly, treatment T_3 (50% RDF) also had higher PE. Further, it was observed that the INM treatments (T_6, T_7, and T_8) as well as 100 percent RDF treatment (T_2), had significantly lower PE over the rest of the treatments. Likewise, the Internal Utilization Efficiency (IUE) was highest in control (T_1) treatment followed by 50% RDF (T_3) and sole organics treatments (T_4 and T_5). Significantly lowest IUE was observed in the INM treatments (T_6, T_7, and T_8), however, INM treatments were not significantly different among themselves. The Apparent Recovery Efficiency (ARE) was significantly highest in treatment T_6 (50% $N_{gliricidia}$ + 50% N_F + 100% P_F + 100% K_F) while the lowest ARE was observed in sole organics treated plots (T_4 and T_5). Similar to cotton, in green gram too, AE and ARE were significantly highest in treatment T_6 (50% $N_{gliricidia}$ + 50% N_F + 100% P_F + 100% K_F) followed by treatment T_7 (50% N_{FYM} + 50% N_F + 100% P_F + 100% K_F), while the lowest AE and ARE were observed in 50 percent RDF (T_3) and sole organics treated plots (T_4 and T_5) (Table 3). The PE was lowest in treatment T_8 (100% $N_{gliricidia}$ + 100% P_F + 100% K_F), while IUE was significantly lowest in all the three INM treatments, as compared to other treatments.AE is used as a short-term indicator of the impact of applied nutrients on productivity. Significantly higher values of AE in INM treated plots were mainly due to the direct effect integration of organics and chemical fertilizers which suggests that the N mineralization from FYM/gliricidia was in synchronization with crop requirement during various growth stages. FYM/gliricidia used in the present investigation also contains a sufficient amount of NPK, thus enriching the nutrient pool of soil. Moreover, organics enhance the use efficiency of native as well as applied fertilizers. Combined use of organic manure and N fertilizer maintains a continuous N supply, checks losses and thus helps in more efficient utilization of the applied N. The higher values of PE in treatments except INM (T_6, T_7, and T_8) and T_2, suggest the deficiency of nutrients in those treatments. The lower PE in INM and T_2 indicates that the nutrient uptake was much better in these treatments due to improvement in soil properties. A higher value of IUE indicates the nutrient deficiency while a lower value suggests a poor internal nutrient conversion mechanism depending upon the stresses, management, and genotype environment (Dobermann, 2007; Fixen *et al.,* 2015). IUE was higher in control (T_1) and sole organics (T_4 and T_5) and inorganics treated plots (T_2 and T_3) indicating the deficiency of nutrients, while it was significantly lowered in INM treatments (T_6, T_7, and T_8). Better synchronization and slow-release nature of organics and immediate availability of fertilizers in INM treatments might have enhanced the IUE. ARE is a measure of the potential for nutrient loss from a cropping system and the effectiveness of management practices. Lower levels of ARE indicate that management changes could improve efficiency or that nutrients are accumulating in the soil (Dobermann, 2007; Fixen *et al.,* 2015). The ARE was higher under INM treatments because in these treatments N was supplied by both organic and inorganic sources thus help maintained the steady and continuous supply of N throughout the plant growth. Since only organics do not meet all the N requirements of a crop, ARE was found to be lowest under organic amended treatments. Several other long-term experiments also observed similar results (Swain *et al.,* 2006; Huang *et al.,* 2008; Singh, *et al.,* 2012; Mondal *et al.,* 2016).

Phosphorus use efficiency Indices

Similar to NiUE indices, the Phosphorus Use Efficiency (PUE) indices in cotton were also significantly affected by different nutrient management practices (Table 4). The AE and ARE in cotton ranged from 2.6 to 8.12 and 9.51 to 35.81% respectively. The significantly higher AE was observed in treatment T_6 (50% $N_{gliricidia}$ + 50% N_F + 100% P_F + 100% K_F) followed by T_2 (100% RDF) and treatment T_7 (50% N_{FYM} + 50% N_F + 100% P_F + 100% K_F) while ARE was highest in treatment T_4 (50% N through gliricidia). It was followed by treatment T_6 (50% $N_{gliricidia}$ + 50% N_F + 100% P_F + 100% K_F) and T_2 (100% RF). Furthermore, in case of PE and IUE, significantly higher PUE was

Table 2: Effect of nutrient management practices on nitrogen use efficiency indices in cotton

Treatments	AE (kg/kg)	PE (kg/kg)	IUE (kg/kg)	ARE (%)
T1	-	-	23.21^{a}	-
T2	3.51^{c}	37.86^{c}	19.91^{d}	20.30^{c}
T3	1.30^{e}	49.64^{bc}	20.62^{c}	12.32^{d}
T4	0.84^{f}	77.78^{a}	21.86^{b}	8.06^{e}
T5	1.12^{e}	63.35^{ab}	21.48^{b}	8.74^{e}
T6	4.52^{a}	35.33^{c}	19.32^{e}	30.98^{a}
T7	4.13^{b}	35.76^{c}	19.39^{e}	26.12^{b}
T8	2.34^{d}	37.57^{c}	19.66^{de}	18.71^{c}
lsd ($p \leq 0.05$)	0.18	18.7	0.45	2.5

Table 3: Effect of nutrient management practices on nitrogen use efficiency indices in greengram

Treatments	AE (kg/kg)	PE (kg/kg)	IUE (kg/kg)	ARE (%)
T1	-	-	34.39^{a}	-
T2	1.71^{b}	14.81^{b}	24.69^{d}	12.47^{c}
T3	0.56^{c}	20.42^{a}	29.73^{b}	6.51^{f}
T4	0.11^{d}	12.42^{d}	29.00^{b}	6.33^{f}
T5	0.53^{c}	12.88^{cd}	27.77^{c}	8.43^{e}
T6	2.23^{a}	13.85^{bcd}	22.67^{e}	18.36^{a}
T7	2.15^{a}	14.62^{bc}	23.80^{d}	15.24^{b}
T8	0.80^{c}	8.10^{e}	24.14^{d}	11.11^{d}
lsd ($p \leq 0.05$)	0.30	1.90	1.11	1.20

Means followed by the same letter in a column are not significantly different at $P < 0.05$ according to Tukey's HSD AE: Agronomic Efficiency, PE: Physiological Efficiency, IUE: Internal Use Efficiency, ARE: Apparent Recovery Efficiency. T_1- Control; T_2- 100 percent RDF; T_3- 50 percent RDF; T_4 -50 percent N/ha through gliricidia; T_5 -50 percent N/ha through FYM; T_6 -50 percent $N_{gliricidia}$ + 50 percent N $_{Fertilizers (F)}$ + 100 percent P_2O_5 $_{Fertilizers (F)}$ + 100 percent K_2O $_{Fertilizers (F)}$; T_7 -50 percent N_{FYM} + 50 percent N $_{Fertilizers (F)}$ + 100 percent P_2O_5 $_{Fertilizers (F)}$ + 100 percent K_2O $_{Fertilizers (F)}$; T_8 -100 percent $N_{gliricidia}$ + 100 percent P_2O_5 $_{Fertilizers (F)}$ + 100 percent K_2O $_{Fertilizers (F)}$.

Table 4: Effect of nutrient management practices on phosphorus use efficiency indices in cotton

Treatments	AE (kg/kg)	PE (kg/kg)	IUE (kg/kg)	ARE (%)
T1	-	-	115.09^{a}	-
T2	7.02^{ab}	103.01^{b}	70.97^{d}	15.03^{c}
T3	2.60^{c}	125.13^{a}	85.35^{c}	9.51^{e}
T4	7.34^{ab}	142.25^{a}	89.37^{b}	35.81^{a}
T5	3.19^{c}	138.45^{a}	88.58^{b}	11.93^{d}
T6	8.12^{a}	100.96^{b}	68.49^{e}	17.91^{b}
T7	6.11^{b}	99.50^{b}	68.29^{e}	13.61^{cd}
T8	3.82^{c}	90.27^{b}	68.12^{e}	11.57^{de}
lsd ($p \leq 0.05$)	1.39	22.5	2.4	2.15

observed under INM treated plots (T_6, T_7, and T_8).
However, the INM treatments were statistically at par with each other. Similar results were also observed for the various PUE indices in green gram too (Table 5). It was observed that the range of the AE and ARE was highest in cotton while IUE was dramatically higher in green gram crop. AE and ARE in green gram were highest in treatment T_6 (50% $N_{gliricidia}$ + 50% N_F + 100% P_F + 100% K_F), whereas, the same treatment also had significantly lower PE and IUE. Higher AE in INM treated plots (T_6, T_7, and T_8) reflects the use of P at lower rates and because, while yield was increased, P was less efficiently utilized, whereas lower AE of P indicates less P being mobilized during the crop growth period, resulting in an increased availability as well as higher yield. This was also supported by the findings of Mitran and Mani, (2017). The higher value of PE in the sole organic treated plos (T_4 and T_5) and also in 50 percent RDF (T_3) suggest the deficiency of nutrients in these plots. The INM treated plots (T_6, T_7, and T_8) have significantly improved the soil conditions resulting in better uptake of nutrients. Further, lower PE in organics treated plot may also be ascribed to the fact that P released from FYM/gliricidia during crop growth season is less mobile in nature. Under INM, recovery of P was invariably greater compared with sole organics and sole inorganics treatments. The treatments that received organics in combination with mineral fertilizers (INM treatments) had lower IUE than the treatments that received only mineral fertilizers (T_2 and T_3) or sole organics (T_4 and T_5). High IUE in the sole inorganic treated plot (T_2 and T_3) indicated nutrient deficiency and suboptimal utilization of P, resulting in higher values although the nutrients were used at reasonably higher rates. ARE of P was higher in treatment T_4 (50% N through gliricidia) and in INM treatment T6 (50% $N_{gliricidia}$ + 50% N_F + 100% P_F + 100% K_F).
This is because in this treatment lower rate of P was applied resulting in a more recovery at a lower rate of application. This could be also because long-term application of gliricidia altered surface soil properties, optimized soil P status, and maximized P recycling. These results are in conformity with the findings of (Singh *et al.,* 2012.) ARE was higher in the treatment T_4 (50% N through gliricidia) may be due to the mobilization of P from the organic pool to the inorganic pool from gliricidia and also that the release was not in congruent between nutrient supply and crop demand. Similar results were also reported by Das *et al.,* (2015). Similar to our findings, Vats *et al.*, (2001) found that using organic materials in conjunction with fertilizer was very beneficial for improving the efficiency of fertilizer P. This could be because long-term application of organic materials modified surface soil properties, optimised soil P status, and maximized P recycling from organic and mineral fertilizers. Further, Das *et al.,* (2015) and Dwivedi *et al.,* (2017) also reported similar results.

Potassium Use Efficiency

In case of Potassium (K), all the Potassium Use Efficiency (KUE) indices were significantly affected by different nutrient management practices except for the PE of cotton (Table 6). The AE in cotton ranged from 1.17 to 7.02 kg/kg and was maximum in treatment T_2 (100% RDF) followed by treatment T_6 (50% $N_{gliricidia}$ + 50% N_F + 100% P_F + 100% K_F) and T_7 (50%N_{FYM} + 50% N_F + 100% P_F + 100% K_F). The IUE was significantly lowest in INM treatments (T_6, T_7, and T_8), while highest IUE was observed in control (T_1) treatment. AE was highest for the treatment T_2 (100% RF), followed by treatment T_6 (50% $N_{gliricidia}$ + 50% N_F + 100% P_F + 100% K_F) and T_7 (50% N_{FYM} + 50% N_F + 100% P_F + 100% K_F). Significantly lowest ARE was observed in treatment T_5 (50% N through FYM). In green gram, KUE indices were smaller as compared cotton, except for the IUE which was more in green gram. AE in green gram ranged from 0.16 to 3.42 kg/kg and was significantly highest in T_2 (100% RDF), followed by INM treatments T_6 (50% $N_{gliricidia}$ + 50% N_F + 100% P_F + 100% K_F) and T_7 (50%N_{FYM} + 50% N_F + 100% P_F + 100% K_F) (Table 7). The PE was lower in INM treatments (T_6 and T_7) and sole organics treatments (T_4 and T_5) as compared to sole inorganics treatments (T_2 and T_3) indicating that during the crop growth period, K was not properly mobilized from organics. This might also be the probable reason for higher PE in the sole inorganic fertilized plots. The IUE was highest in control (T_1) and reduced significantly in all other treatments, with the lowest IUE was observed under INM treatments (T_6 and T_7). Higher IUE in control (T_1) plots also showed nutrient mining over the years resulting in a deficiency of nutrient to plants and thus lower yield and uptake. This may also be attributed to farmers' indifferent and non-judicious use of fertilizers and manures, which results in reduced available nutrients in the soil and lower uptake. The ARE ranged from 4.50 to 11.68 percent. The significantly lowest ARE was observed in treatment T_6 (50% $N_{gliricidia}$ + 50% N_F + 100% P_F + 100% K_F) might be due to the fact that gliricidia has more K content and continuous mineralization of K over the years has led to increased K in soil and ultimately resulting in higher uptake by the crop and thus ARE. The soils of the present investigation are inherently higher in available K content, therefore previously K

Table 5: Effect of nutrient management practices on phosphorus use efficiency indices in green gram

Treatments	AE (kg/kg)	PE (kg/kg)	IUE (kg/kg)	ARE (%)
T1	-	-	270.68^{a}	-
T2	3.42^{ab}	115.72^{b}	193.66^{e}	3.28^{c}
T3	1.12^{c}	107.77^{bc}	214.70^{d}	2.52^{d}
T4	1.00^{c}	140.78^{a}	240.46^{b}	5.01^{a}
T5	1.51^{c}	119.56^{b}	226.62^{c}	2.77^{d}
T6	4.00^{a}	98.37^{c}	168.45^{f}	4.35^{b}
T7	3.18^{b}	96.05^{c}	169.87^{f}	3.55^{c}
T8	1.30^{c}	72.02^{d}	199.03^{e}	1.83^{e}
lsd ($p \leq 0.05$)	0.73	17.12	8.96	0.37

Table 6: Effect of nutrient management practices on potassium use efficiency indices in cotton

Treatments	AE (kg/kg)	PE (kg/kg)	IUE (kg/kg)	ARE (%)
T1	-	-	40.82^{a}	-
T2	7.02^{a}	50.29	30.34^{c}	32.82^{a}
T3	2.60^{d}	49.24	31.31^{b}	24.77^{c}
T4	1.17^{f}	50.45	31.70^{b}	16.58^{e}
T5	1.22^{f}	50.05	31.60^{b}	11.98^{f}
T6	5.28^{b}	43.50	27.57^{e}	27.74^{b}
T7	4.31^{c}	45.41	28.40^{d}	21.13^{d}
T8	1.93^{e}	42.76	28.32^{de}	12.21^{f}
lsd ($p \leq 0.05$)	0.27	NS	0.81	1.31

Table 7: Effect of nutrient management practices on potassium use efficiency indices in green gram

Treatments	AE (kg/kg)	PE (kg/kg)	IUE (kg/kg)	ARE (%)
T1	-	-	105.54^{a}	-
T2	3.42^{a}	34.18^{a}	65.63^{d}	11.04^{b}
T3	1.12^{c}	31.04^{a}	76.91^{c}	8.56^{c}
T4	0.16^{d}	23.21^{b}	80.37^{b}	4.86^{d}
T5	0.58^{cd}	25.75^{b}	75.72^{c}	4.50^{d}
T6	2.60^{b}	24.98^{b}	50.26^{f}	11.68^{a}
T7	2.24^{b}	25.47^{b}	52.33^{f}	9.03^{c}
T8	0.66^{cd}	15.07^{c}	58.88^{e}	4.39^{d}
lsd ($p \leq 0.05$)	0.55	3.32	3.40	0.54

Means followed by the same letter in a column are not significantly different at $P < 0.05$ according to Tukey's HSD
AE: Agronomic Efficiency, PE: Physiological Efficiency, IUE: Internal Use Efficiency, ARE: Apparent Recovery Efficiency. T_1- Control; T_2- 100 percent RDF; T_3- 50 percent RDF; T_4 -50 percent N/ha through gliricidia; T_5 -50 percent N/ha through FYM; T_6 - 50 percent $N_{gliricidia}$ + 50 percent $N_{Fertilizers (F)}$ + 100 percent P_2O_5 $_{Fertilizers (F)}$ + 100 percent K_2O $_{Fertilizers (F)}$; T_7 -50 percent N_{FYM} + 50 percent $N_{Fertilizers (F)}$ + 100 percent P_2O_5 $_{Fertilizers (F)}$ + 100 percent K_2O $_{Fertilizers (F)}$; T_8 -100 percent $N_{gliricidia}$ + 100 percent P_2O_5 $_{Fertilizers (F)}$ + 100 percent K_2O $_{Fertilizers (F)}$.

supplementation through fertilizer was not recommended. Further, the organic sources such as gliricidia and FYM used in this experiments are also rich sources of K. All these resulted in better KUE indices in INM treated plots as compared to others. Furthermore, several researchers (Singh *et al*., 2010; Singh *et al*., 2018; Dhillon *et al*., 2019) also reported that crop K requirements could be improved by use of different organics further improving KUE. Such improvements in KUE were also supported by the findings of Singh *et al*., (2004); Oborn *et al*., (2005); Yadav and Sidhu, (2016).

Conclusion

Apart from the loss of productive potential of soils as a result of unscientific land management practices, the NUE is one of the most important yield constraints in crop production in almost all the agro-ecological regions of the world. The present investigation revealed that under the cotton + green gram intercropping system in Vertisols, INM that involves conjoint use of different nutrient sources appears to be a promising strategy for improvement in fertilizer use efficiency as a whole including NUE. Further, it was observed that the overall NUE of N, P, and K was better under different INM treatments. All the NUE indices of N, P, and K were higher during cotton except for IUE which was higher during green gram. Further, in the sole organic and inorganic plots, the nutrients either do not synchronize the crop requirement or are lost in the soil-plant system resulting in comparatively lower NUE indices.

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Conflict of interest

The authors declare that they have no conflict of interest.

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