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System-Based Integrated Nutrient Management Improves Productivity, Profitability, Energy Use Efficiency and Soil Quality in Peanut-Wheat Cropping Sequence in Light Black Soils

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Abstract: Peanut (*Arachis hypogaea* L.), being an energy-rich crop, is sensitive to nutrient deficiencies and a scavenger of nutrients from the soil. Optimum and integrated nutrient management (INM) improves productivity and the quality of seeds. The objective of this study was to identify suitable system-based INM (S-INM) options for peanut–wheat cropping sequence in the Saurashtra region of India. Results showed that peanut growth, yield attributing parameters, pod, and haulm yield, and NPK uptake were higher when 100% recommended fertilizer doses (RDFs) + farmyard manure (FYM) @5 t/ha + plant growth-promoting rhizobacteria (PGPR) were applied. However, application of 75% RDFs + FYM @5 t/ha + PGPR in peanut and 100% RDF in wheat was most effective to improve growth and yield attributes, yields and nutrient uptake by wheat. Further, this FYM- and PGPR-amended treatment was found to increase system productivity by 15.3 and 17.1%, system profitability by 17.0 and 22.6%, and net energy gain by 10.0 and 17.9% over the reference treatment and over farmers' practice (FF), respectively. This sustainable system approach will be helpful for agronomists and farmers in identifying and practicing suitable field practices with further study on the residual effect of organic manures on the peanut–wheat based cropping system in the western region of India with light black soils.

Keywords: ex-situ green manure; peanut; PGPR-plant growth promoting rhizobacteria; system-based INM; wheat; FYM-farm-yard manure

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1. Introduction

Peanut (*Arachis hypogaea* L.) is one of the most important oilseed crops in India with a total annual production of 9.9 million tonnes from 4.8 M ha area [1]. It is a major oilseed crop accounting for ~18% of the area and ~30% of the production of oilseeds in India. However, the current average yield level of peanut in the country is very low (2063 kg ha^{-1}) as compared to 4335 kg ha^{-1} in USA and 3671 kg ha^{-1} in China [2]. Poor crop nutrition is among the major factors responsible for the low yield of peanut in India. Peanut is an oil- and protein-rich energy crop, but is cultivated on marginal soils with low fertility status and predominantly under rainfed conditions (~80% area). Being an energy-rich crop, it is sensitive to nutrient deficiencies, especially nitrogen, sulphur, and micronutrients such as iron and manganese [3]. Peanut performs better in terms of yield and quality when grown under optimum nutrient management conditions [4]. It has huge nutrient requirements, thus removing a fairly large amount of nutrients from the soil and it therefore depletes the fertility of the soil unless it is replenished adequately [5].

Indiscriminate use and sole dependence on chemical fertilizers in intensive agriculture leads to instability in crop yields and deteriorates soil health, thus causing threats to the environment [6,7]. Although chemical fertilizers have played important roles in achieving food security in the country, their overuse is causing numerous serious challenges such as soil health degradation, pollution of water bodies and emissions of greenhouse gases, etc. Synthetic fertilizers are becoming hazardous not only to the environment but also to humans, animals, and soil microbial life [8,9]. Hence, for the long-term sustainability of production systems, optimization of crop nutrition through integrated use of all available nutrient sources is essential [10,11]. Integrated nutrient management (INM) involves the conjunctive use of chemical fertilizers, organic manures, and biofertilizers, and has assumed greater importance due to decreasing soil health and reduced factor productivity across the production systems [12]. Hence, INM practice is perceived as a feasible option to restore soil health and obtain sustained higher crop yields in these systems. INM is the approach of using sufficient quantities of organic and inorganic fertilizers in combination with specific microorganisms to make a balanced supply of nutrients and is most effective for sustaining higher yields with the least depletion of native soil fertility and causing minimum environmental pollution [13]. Organic manures such as farmyard manure (FYM), besides supplying plant nutrients, have positive effects in maintaining the soil properties such as moderating soil pH, increasing the water-holding capacity and infiltration rate, and improving soil flora and fauna [14]. Organic manures not only benefit the target crop but also have a pronounced residual effect on the subsequent crops [15]. However, availability of commonly used organic manure in the country, i.e., FYM, has been declining because of the higher demand in intensified cropping systems and a decreasing cattle population [10]. Hence, the option of ex-situ green manuring (GM), by growing crops such as *Sesbania aculeata* in less fertile soils [16], may be explored. This will not only improve the nutrient status of such low-fertility soils but will also provide biomass for the ex-situ GM of soils under intensive cultivation. Plant-growth promoting rhizobacteria (PGPRs) are consortia of microorganisms that have multiple plant-growth promoting attributes such as ACC deaminase, phosphate solubilization, production of siderophore, antifungal metabolites, hormones, and ammonification traits [17]. Besides, these PGPR isolates also exhibit the solubilization of Zn and potassium (K), and have antifungal activities against major soil-borne fungal pathogens such as *Sclerotium rolfsii* and *Aspergillus niger* [18].

Peanut–wheat is an important cropping system followed in many parts of India [19]. Both peanut and wheat being high nutrient-requirement crops, adequate nutrition is important to obtain high yields and returns from the system on a sustainable basis. The type of preceding crop and its nutrient management have significant influence on growth and development, and the yield of succeeding peanut [3]. It is being increasingly realized that when crops are grown in the system, the nutrient requirement of the cropping system is more important than that of the individual crop [20]. This highlights the importance of developing system-based integrated nutrient management (S-INM) rather than focusing on single-crop nutrition in the system to obtain sustained higher yield, returns and nutrient-use efficiency in the peanut-based sequential systems. Analysis of energy input–output is an important indicator of the efficiency and environmental footprints of different nutrient combinations, management practices, tillage systems, etc., used for different crop production systems [21,22]. Cultivation of a peanut–wheat cropping system is energy-intensive due to the usage of fertilizers and pesticides, a high seed rate, a higher number of irrigations in the wheat crop, excessive tillage and interculture operations, a higher labor need for harvesting and threshing especially in peanut, etc. Therefore, energy use efficiency and agricultural practices affecting the surrounding environment need to be carefully considered [23].

Thus, S-INM appears to be an appropriate approach to achieve higher productivity, profitability and nutrient use efficiency on a long-term basis. S-INM ensures the plant nutrient supply through the optimization of a nutrient supply from all possible sources of plant nutrients in an integrated manner to achieve as well as sustain the desired crop productivity while maintaining soil fertility [24]. However, little information is available especially on an S-INM strategy in a peanut–wheat cropping sequence. Hence, the present study was carried out to identify suitable S-INM options for a peanut–wheat cropping sequence in the Saurashtra region of India. We hypothesized that S-INM would improve productivity, profitability, and resource use efficiency in the peanut–wheat system through a higher and sustained nutrient supply and improved soil health and fertility. Hence, the treatments were designed to study the effect of FYM, GM and PGPR, in conjunction with chemical fertilizers in a peanut–wheat system and identify the suitable S-INM options.

2. Materials and Methods

2.1. Site Description

A field experiment was carried out at the Research Farm of the ICAR-Directorate of Groundnut Research, Junagadh, Gujarat, India, during 2014–15 to 2016–17. The site is located at 60 m above the mean sea level with 70°28′ E longitude and 21°28′ N latitude. During the study period, the mean maximum and minimum temperature were 37.1, 37.3 and 36.6 °C, and 20.5, 22.8 and 21.4 °C during the peanut-growing season in 2014, 2015, and 2016, respectively, and 34.3, 35.0 and 34.3 °C and 10.2, 12.5 and 11.9 °C during the wheat-growing season in 2014–15, 2015–16, and 2016–17, respectively. The detailed information on the meteorological parameters of growing periods during the study seasons is given in Figure 1a–c.

The soil of the experimental site was Typic Haplustepts with 35%, 14% and 51% sand, silt, and clay, respectively. The soil was highly calcareous (24.5% $CaCO_3$) in nature with pH of 7.8 and EC of 0.20 dS/m. The soil was low in organic carbon (5.7 g kg^{-1}) and medium in available N (252 kg ha^{-1}), P_2O_5 (12.2 kg ha^{-1}) and K_2O (305 kg ha^{-1}).

(**a**)

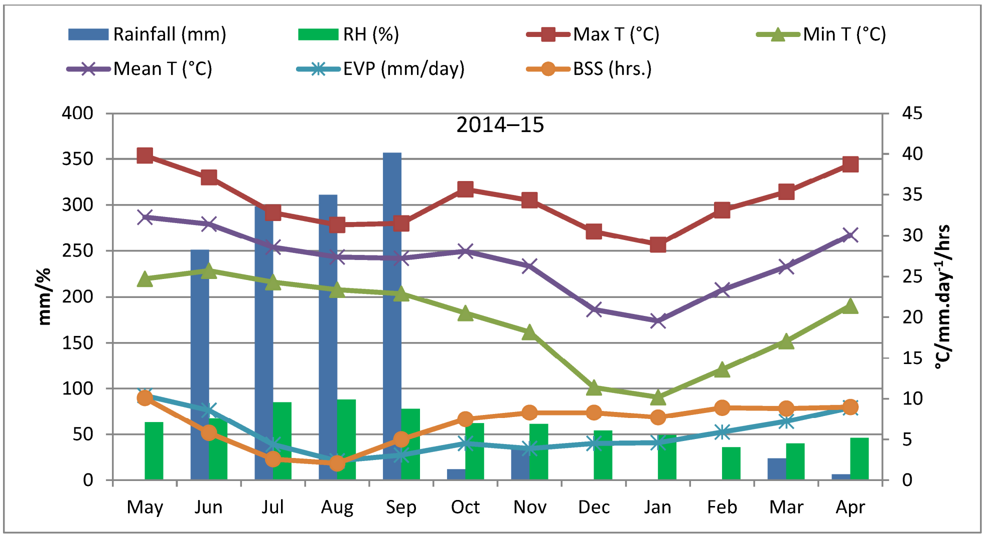
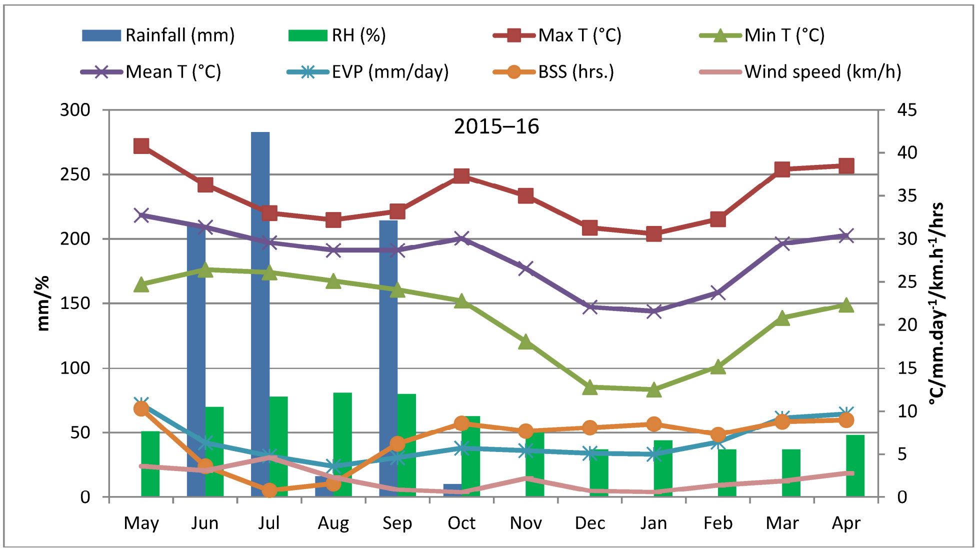


Figure 1. *Cont.*

(**b**)



(**c**)

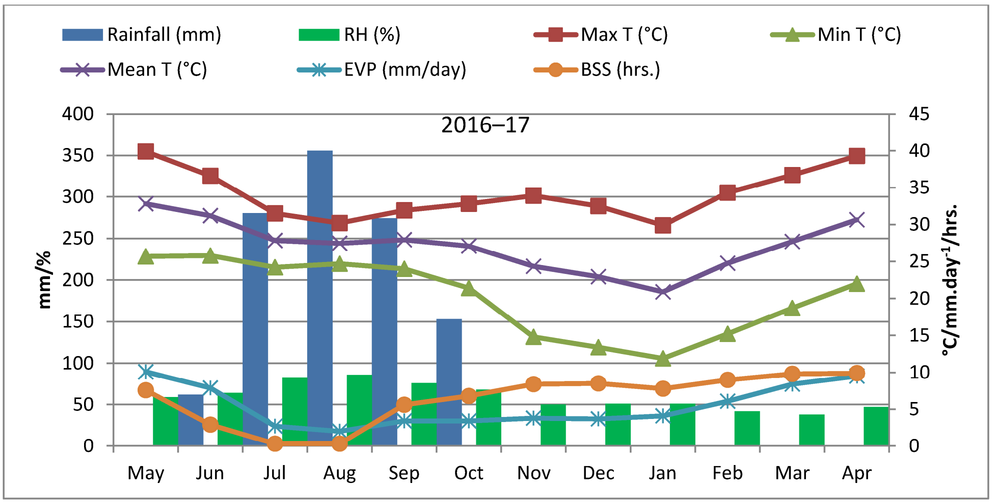


Figure 1. (**a**–**c**) Weather information during 2014–15, 2015–16, and 2016–17. RH = relative humidity, Max T = maximum temperature, Min T = minimum temperature, Mean T = mean temperature, EVP = evaporation, BSS = bright sunshine.

2.2. Experimental Design and Crop Management

A total of 12 treatments were tested in randomized block design and replicated thrice. The treatment details are given in Table 1. The 100% recommended dose of fertilizers (RDF) in peanut and wheat was 25-50-30 and 120-60-60 kg ha^{-1} of N, P_2O_5 and K_2O, respectively. No nutrients were applied in the treatment "control". In the treatment, "farmers' practice" 100 kg ha^{-1} of DAP (diammonium phosphate) was applied in the soil at the time of sowing in both the crops. The gross plot size was 5.0 × 4.2 m^2 and plots were separated by a 1.0 m wide space with bunds on four sides of the plots. The field was made suitable for the sowing of peanut by running a cultivator twice followed by blade harrowing once and the opening of furrows with a tractor at 30 cm spacing. A seed rate of about 140 kg ha^{-1} was used for sowing at 30 × 10 cm spacing. FYM (25% moisture) having 0.5, 0.3 and 0.6% N, P_2O_5, K_2O, respectively, was spread uniformly and incorporated in the soil before sowing as per the treatments. A whole quantity of nutrients (N, P_2O_5, and K_2O), as per the treatments, was applied just before the sowing of peanut. In treatments involving biofertilizers, PGPR containing *Pseudomonas gessardii* (BHU1 strain) @5 kg ha^{-1} was applied in the soil in furrows at the time of sowing, while *Rhizobium* @5 g kg^{-1} seed was applied through seed treatment in all the treatments. All the cultures were obtained from the Division of Microbiology, ICAR-DGR, Junagadh. Cultures were maintained at 4 °C in a charcoal carrier until the time of seed treatment. *Sesbania aculeata*, grown for 45 days during the summer season on wasteland, was harvested, and applied in relevant plots as per the treatments. Peanut was sown manually in furrows opened at 30 cm spacing with tractor on the 30, 22, and 20 June and the crop was harvested on the 27, 5, 20 October in 2014, 2015, and 2016, respectively. One or two protective irrigations (check-basin method) were applied, when needed, during deficit rains. Weeds were controlled by the pre-emergence spray of pendimethalin (1.0 kg a.i. ha^{-1}) in conjunction with manual weeding at 25 and 45 days after sowing (DAS).

Table 1. Description of treatment number with abbreviations and their details used in peanut and wheat crops.

Treatment Numbers with Abbreviations	Nutrients Used in Peanut	Nutrients Used in Wheat
T1; Cont.	No fertilizer	No Fertilizer
T2; P_{50RDF} + W_{100RDF}	50% RDF	100% RDF
T3; P_{75RDF} + W_{75RDF}	75% RDF	75% RDF
T4; P_{100RDF} + W_{100RDF}	100% RDF	100% RDF
T5; $P_{75RDF+5tFYM}$ + W_{75RDF}	75% RDF + 5 t/ha FYM	75% RDF
T6; $P_{75RDF+2.5tFYM}$ + W_{100RDF}	75% RDF + 2.5 t/ha FYM	100% RDF
T7; $P_{75RDF+2.5t\ ex\ situ\ GM}$ + W_{75RDF}	75% RDF + 2.5 t/ha GM	75% RDF
T8; $P_{50RDF+5t\ ex\ situ\ GM}$ + W_{100RDF}	50% RDF + 5 t/ha GM	100% RDF
T9; $P_{100RDF+PGPR}$ + $W_{100RDF+Azot.}$	100% RDF + PGPR	100% RDF + Azotobacter
T10; $P_{100RDF+5tFYM+PGPR}$ + W_{75RDF}	100% RDF + 5 t/ha FYM + PGPR	75% RDF
T11; $P_{75RDF+5tFYM+PGPR}$ + W_{100RDF}	75% RDF + 5 t/ha FYM + PGPR	100% RDF
T12; FF	100 kg ha^{-1} DAP	100 kg ha^{-1} DAP

RDF = Recommended dose of fertilizer; FYM = Farmyard manure; GM = Green manure; PGPR = Plant growth promoting rhizobacteria; DAP = Di-ammonium phosphate.

Wheat was sown in the post-rainy season succeeding the peanut crop. After the harvest of peanut, the field was prepared for the sowing of wheat by running a cultivator twice followed by blade harrowing and levelling. Furrows were opened at 22.5 cm spacing with a tractor and a seed rate of 100 kg ha^{-1} was used for wheat sowing. As per the treatments, half of the N and a full dose of P_2O_5 and K_2O were applied manually in the furrows at the time of sowing, while the remaining half of N was top dressed in two equal splits at 25 and 45 DAS. Sowing was done manually on the 12, 26 and 22 November, and the crop was harvested on the 24 February, 2 March and 29 February in 2014–15, 2015–16 and 2016–17, respectively. In treatments having biofertilizers, wheat seeds were treated with *Azotobacter* @ 6 g kg^{-1} of seed and dried in the shade. A total of 10–11 irrigations, applied with the check-basin method, were required for raising the wheat crop as the water-holding capacity of the soil in the region is low. Pre-emergence application of pendimethalin (1.0 kg a.i. ha^{-1}) and hand weeding at 25 and 45 DAS were used for effectively controlling the weeds.

2.3. Measurements of Yield and Growth and Yield Parameters

Peanut was harvested from a net plot area of 3.0×4.0 m^2 at maturity and sun-dried for 4–5 days. Pods were weighed after drying to 10% moisture. Five plants were randomly selected in each plot before harvesting and values were averaged to obtain plant height (cm). The leaf area of five plants in each plot was measured at 45 DAS using a portable leaf area meter (Model CI-202, CID Bio Science, Inc., Camas, WA, USA). The leaf area (cm^2) was divided by the ground area (cm^2) of five plants to obtain a leaf area index (LAI). Mature pods from five random plants $plot^{-1}$ were taken at maturity and averaged to obtain mature pods $plant^{-1}$. Oven drying of mature pods w at 60 °C for 72 h was done to obtain a 10% moisture level and weighed and averaged to obtain the dry weight of mature pods $plant^{-1}$.

A total of 100 random kernels were selected and weighed to obtain the 100 kernel weight (g). Shelling percentage was calculated using the following formula [25]:

$$\text{Shelling } (\%) = \frac{\text{Seed weight per plot}}{\text{Pod weight per plot}} \times 100$$

In wheat, produce from a 5 × 3.3 m^{-2} net plot area was harvested and dried in the sun for 4–5 days. Grains were threshed manually and weighed with moisture adjusted to 12% [26]. The plant height was measured of five random plants. Five random plants were cut just above the ground level at 60 DAS and oven-dried at 60 °C for 72 h, weighed and then averaged to obtain dry matter $plant^{-1}$ (g). All the plants of the wheat from a one-meter row-length were counted for total and effective tillers at harvest. The soil plant analysis development (SPAD) value, indicative of plant nitrogen status, was measured from the middle of the second top leaf at 45 DAS using a SPAD chlorophyll meter (Minolta Corp., Osaka, Japan). The ear length (cm) and spikelet $plant^{-1}$ were measured on five random plants. The test weight (g) was measured by weighing 1000 random seeds. The haulm yield of peanut and straw yield of wheat were weighed after adjusting to 14% moisture on an oven-dry weight basis; a representative sample of 1.0 kg from each plot was oven-dried at 60 °C for 72 h.

Peanut pod equivalent yield (PPEY) was calculated using the following formula [27]:

$$\text{PPEY}\left(\text{kg ha}^{-1}\right) = \left\{\text{Pod yield of peanut } \left(\text{kg ha}^{-1}\right)\right\} + \left[\left\{\text{wheat grain yield } \left(\text{kg ha}^{-1}\right)\right\} \times \frac{\left\{\text{Price of wheat grain } \left(\text{INR kg}^{-1}\right)\right\}}{\left\{\text{Price of peanut pod } \left(\text{INR kg}^{-1}\right)\right\}}\right]$$

2.4. Economic Analysis

To work out the economics of production, different variable costs were considered. The variable costs included expenditure incurred on inputs such as seed, fertilizers, FYM, ex-situ GM, pesticides, etc., and field operations such as field preparation, application of FYM and ex-situ GM, sowing, irrigation, weeding and interculturing, application of fertilizer and pesticides, harvesting, stripping/threshing and other miscellaneous expenses incurred on the production of peanut and wheat calculated on the 2016–17 basis. The gross returns included price of pods and haulm in case of peanut and grain and straw in case of wheat at the minimum support price of 2016–17. All the parameters such as cost of cultivation, net returns, gross returns, etc., were calculated on a pooled basis.

The net returns from individual crops were calculated by subtracting the cost of cultivation from gross returns on a per hectare basis.

$$\text{Net returns } \left(\text{INR ha}^{-1}\right) = \text{Gross returns } \left(\text{INR ha}^{-1}\right) - \text{ Cost of cultivation } \left(\text{INR ha}^{-1}\right)$$

System net returns were arrived at by adding net returns from both peanut and wheat, while the benefit: cost ratio (BCR) was calculated by dividing gross returns by the cost of cultivation.

2.5. Net Energy and Energy Use Efficiency

In the peanut–wheat cropping system, energy balances were assessed by estimating energy inputs and energy outputs. The energy inputs included manual work, fuel, machinery, electricity, irrigation, seed, chemical fertilizers, FYM, ex-situ GM, biofertilizers and herbicides. Energy output is in terms of the harvested product (pods, grain, haulm and straw). Energy for all treatment combinations was calculated by multiplying the amount of input by the corresponding energy equivalents, which were taken from literature and are given in Table 2. Similarly, to obtain energy output from the product (pods, grain, haulm and straw), the quantity of produce was multiplied by its energy equivalent. The energy use indices were calculated as per the procedures given by Devasenapathy et al. (2009) and Mittal and Dhawan (1988) [28,29].

$$\text{Net energy} = \text{Energy output}\left(\text{MJ ha}^{-1}\right) - \text{Energy input}\left(\text{MJ ha}^{-1}\right)$$

$$\text{Energy use efficiency} = \frac{\text{Energy output}\left(\text{MJ ha}^{-1}\right)}{\text{Energy input}\left(\text{MJ ha}^{-1}\right)}$$

Table 2. Energy equivalents of inputs and outputs used in agricultural operations and production in the study.

S. No.	Particulars	Units	Equivalent Energy (MJ)
Inputs			
1.	Human labour		
	Man	Man-hour	1.96
	Woman	Woman-hour	1.57
2.	Electric motor	kg	64.8
3.	Electricity	KWh	11.93
4.	Farm machinery	kg	62.7
4.	Diesel fuel	L	56.30
5.	Irrigation water	m^3	1.02
6.		Chemical fertilizers	
a.	N	kg	60.60
b.	P_2O_5	kg	11.10
c.	K_2O	kg	6.70
7.	Superior chemical	kg	120
8.	FYM	kg (dry mass)	0.3
9.	Biofertilizers	kg	10.0
10.	Green manuring	kg (dry mass)	18.0
11.		Seed of crops	
	Peanut	kg	25
	Wheat	kg	14.7
Outputs			
	Grain (wheat)	kg	14.7
	Pod (peanut)	kg	25
	Straw (wheat)	kg	12.5
	Haulm (peanut)	kg	10

References: [28,29].

2.6. Plant Nutrient Uptake

The N, P and K uptake by peanut and wheat were estimated by multiplying the nutrient content in the economic produce (pod/grain) and fodder (haulm/straw) by the yield (kg ha^{-1}) of the respective economic produce (pod/grain) and fodder (haulm/straw). Nutrient uptake by individual crop included uptake by economic produce and fodder. System uptake for a particular nutrient was calculated by adding the uptake by peanut and wheat. Estimation of nitrogen was carried out by the procedure given by Subbiah and Asija (1956) [30], phosphorus by Koening and Johnson (1942) [31], and potassium by Kalra (1997) [32].

$$\text{N/P/K uptake (kg ha}^{-1}) = \text{N/P/K (\%)} \times \text{yield (kg ha}^{-1})/100$$

2.7. Soil Available N, P_2O_5 and K_2O and Soil Organic Carbon (SOC)

For the estimation of available N, P_2O_5 and K_2O and soil organic carbon percentage (SOC), soil samples were collected from a 0–15 cm depth after harvest of the wheat in the third year of the experimentation. The soil samples were sun-dried, ground and passed through a 0.2 mm sieve. Available N was estimated following Subbiah and Asija (1956) [30], available P_2O_5 as per Olsen et al. (1954) [33] and available K_2O as per Hanway and Heidal (1952) [34].

A modified Walkley and Black (1934) [35] method was used for the determination of SOC. One gram of soil sample was taken, to which 10 mL of 1N $K_2Cr_2O_7$ and 20 mL of conc. H_2SO_4 was added. After 30 min, 10 mL of 70% H_3PO_4 together with 10 mL of 2% NaF and 2 mL of diphenylamine was added. An amount of 0.5 N Ferrous ammonium sulphate was used for titration of the samples. A blank sample without soil was run concurrently.

$$\text{Soil organic carbon\%} = (10/\text{blank}) \times (\text{blank reading}) \times (0.003 \times 100/(\text{weight of soil}))$$

2.8. Soil Enzymatic Activities

Moist soil samples were taken from a 0–15 cm depth at 30 DAS of peanut during the third year of the experimentation to estimate the enzymatic activities in the soil. Samples were passed through a 2-mm sieve for assaying enzymatic activities. Protocol developed by Tabatabai (1994) [36] was used for the estimation of dehydrogenase activity. One gram of a moist soil sample with 0.2 mL of 3% TTC and 0.5 mL of 1.0% glucose was used. After 24 h incubation at 35 °C, 10 mL of methanol were added and centrifuged to take the supernatant. The red color of the TPF was determined at 485 nm and expressed as μg Triphenylformazon g^{-1} soil 24 h^{-1}. Acid and alkaline phosphatase activity was measured using the modified protocol suggested by Schinner et al. (1996) [37]. To one gram of soil, 4 mL of 0.25% p-nitrophenyl phosphate in acetate buffer for acid phosphatase (pH 5.4) or borax-NaOH buffer for alkaline phosphatase (pH 9.4) was added. After incubation at 37 °C for 1 h, the suspension was filtered through Whatman No. 42; thereafter, 1 mL of $CaCl_2$ followed by 4 mL of NaOH was added. A reading was taken on an UV/Visible spectrophotometer at 420 nm. For determining the non-enzymatic yellowing of the solution, controls were additionally conducted on the soil samples. Results were expressed as μg p-nitrophenol g^{-1} soil h^{-1}.

2.9. Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using the general linear model procedure of SAS 9.4 (SAS Institute Inc., Cary, NC, USA). The year component in the model has variance homogeneity; hence, a pooled analysis was carried out over years for growth and yield parameters, yield of peanut and wheat, economics and energy parameters, and nutrient uptake data for three seasons. However, shoot dry matter data were subjected to repeated measures. Hence, the repeated statement in the GLM, which provides automatic computation and analyzes several common choices of contrast variables, of SAS 9.4 (SAS Institute Inc., Cary, NC, USA), was used. The main effect of the year on response variable was not significant; interaction between year and treatment was also not significant. Treatment means were separated using the least significant difference $p \leq 0.05$ as given by Gomez and Gomez (1984) [38].

3. Results

3.1. Peanut

The data pooled over three years indicated that S-INM practices significantly affected growth parameters viz., plant height, LAI, shoot dry matter; yield-attributing parameters viz., mature pods plant^{-1} and their dry weight, 100 kernel weight, shelling percentage; and yield of peanut. The highest plant height (32.5 cm) was observed with T10 treatment i.e., application of 100% RDF + 5 t/ha FYM + PGPR in peanut and 75% RDF in wheat, which was found to be significantly higher than the rest of the treatments except for T5, T8 and T11 (Table 3). The shoot dry weight of peanut at all the growth stages (i.e., at 30, 60 and 90 DAS, and harvesting) was also highest with T10 treatment (4.2, 8.7, 10.1 and 12.4 g plant^{-1}, respectively), which was found to be significantly higher than the rest of the treatments except for T5, T9 and T11 at 30 and 90 DAS, and T11 at harvest of the crop

(Figure 2). LAI at 45 DAS was highest with T 10 (3.4) and was found to be statistically equivalent to T11.

Table 3. Effect of nutrient management practices on growth and yield attributes of peanut (pooled value of three years).

Treatments	Plant Height at Harvest (cm)	LAI at 45 DAS	Mature Pods Plant^{-1} at Harvest	Dry Weight of Mature Pods Plant^{-1} (g)	100 Kernel Weight (g)	Shelling Percentage
T1	28.0 ^{E}	1.6 ^{E}	11.7 ^{D}	10.9 ^{E}	35.0 ^{E}	62.3 ^{C}
T2	29.0 ^{DE}	1.8 ^{E}	14.2 ^{C}	11.7 ^{D}	37.5 ^{ABCD}	63.1 ^{BC}
T3	29.6 ^{DE}	2.5 ^{D}	14.2 ^{C}	12.4 ^{C}	37.5 ^{ABCD}	62.6 ^{C}
T4	30.5 ^{CD}	2.6 ^{CD}	15.2 ^{C}	12.9 ^{B}	36.1 ^{CDE}	62.1 ^{C}
T5	31.4 ^{ABC}	2.7 ^{CD}	17.3 ^{B}	14.0 ^{A}	38.3 ^{A}	66.1 ^{A}
T6	30.6 ^{BCD}	2.6 ^{CD}	17.2 ^{B}	13.9 ^{A}	37.7 ^{ABC}	65.7 ^{A}
T7	30.1 ^{CD}	2.5 ^{D}	14.5 ^{C}	12.8 ^{BC}	36.9 ^{ABCD}	64.7 ^{AB}
T8	31.7 ^{ABC}	2.5 ^{D}	14.5 ^{C}	14.2 ^{A}	38.1 ^{AB}	64.6 ^{AB}
T9	30.6 ^{BCD}	2.9 ^{BC}	17.3 ^{B}	13.1 ^{BC}	36.5 ^{BCDE}	63.6 ^{B}
T10	32.5 ^{A}	3.1 ^{AB}	18.8 ^{A}	14.5 ^{A}	38.4 ^{A}	65.4 ^{A}
T11	32.2 ^{AB}	3.4 ^{A}	18.4 ^{AB}	14.4 ^{A}	38.2 ^{A}	65.5 ^{A}
T12	29.8 ^{D}	1.7 ^{E}	14.0 ^{C}	11.4 ^{DE}	35.9 ^{DE}	63.5 ^{BC}

Treatment means followed by superscripted different letters are significantly different at $p \leq 0.05$.

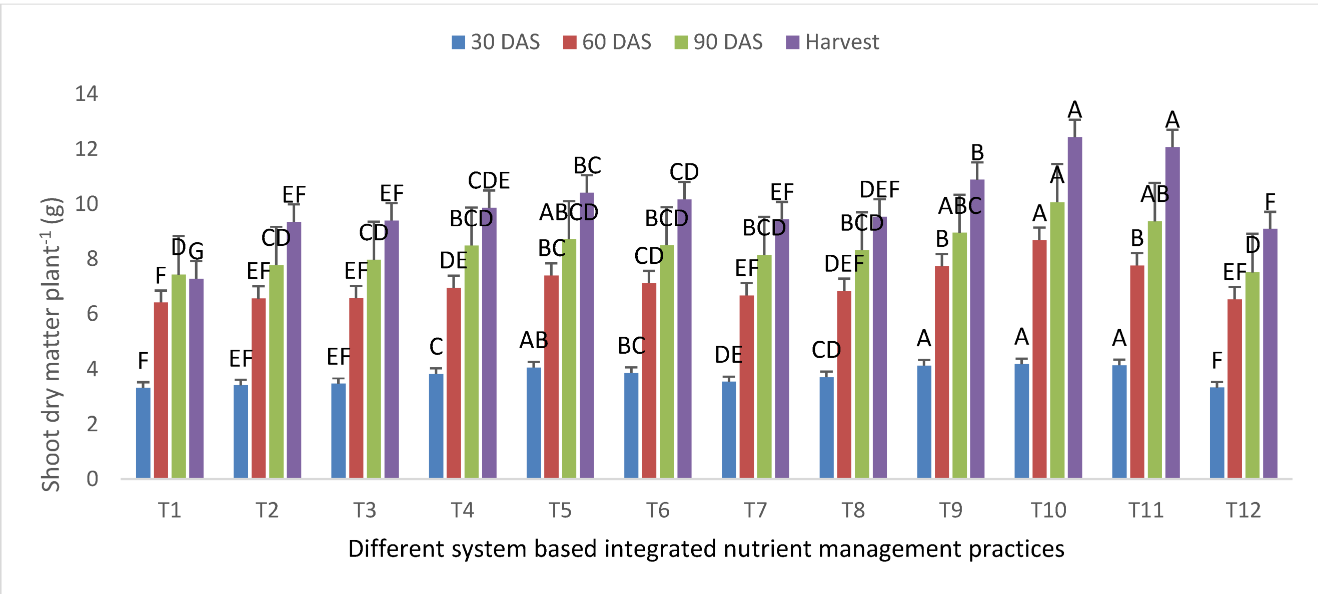


Figure 2. Effect of nutrient management practices on shoot dry matter plant^{-1} of peanut. Vertical lines above bars represent $p \leq 0.05$ values, while bars marked with different letters at particular growth stages indicate significant differences between treatment means.

Similarly, the addition of 100% RDF + 5 t/ha FYM + PGPR in peanut and 75% RDF in wheat (T10) resulted in ($p < 0.05$) highest mature pods plant^{-1} (18.8), and their dry weight (14.5 g), and 100 kernel weight (38.4 g); however, the shelling percentage (65.5) was observed to be highest with T6 treatment (75% RDF + 2.5 t/ha FYM in peanut and 100% RDF in wheat) among all the S-INM practices (Table 3). The treatments T10 and T11 were found at par for mature pods; treatments T5, T6, T8 and T11 for the dry weight of mature pods; treatments T2, T3, T5, T6, T7, T8 and T11 for a 100 kernel weight; and treatment T5, T6, T7, T8, T10 and T11 for shelling percentage. The pod (3706 kg ha^{-1}) and haulm yield (3813 kg ha^{-1}) of peanut obtained by application of treatment T10 was found ($p < 0.05$) highest over all the treatments except for treatment T5, T6, T8 and T11 for pod yield and treatment T11 for haulm yield (Figure 3). In general, T10 improved the pod yield by 13.3 and 48.2% and haulm yield by 12.4 and 41.2%, over 100% RDF in peanut and 100% RDF in wheat (T4) and farmers' practice (T12), respectively.

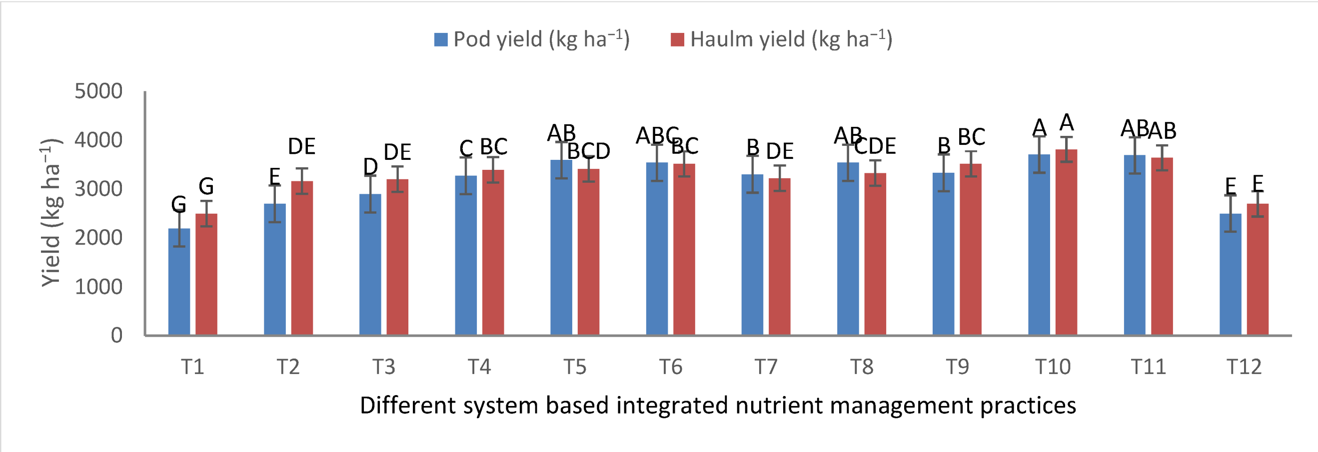


Figure 3. Effect of system-based integrated nutrient management practices on pod and haulm yield of peanut. Vertical lines above bars represent $p \leq 0.05$ values, while bars marked with different letters at a particular growth stage indicate significant differences between treatment means (pooled value of three years).

Treatment 75% RDF + 5 t/ha FYM in peanut and 75% RDF in wheat (T5) resulted in significantly higher plant height, mature pods plant^{-1}, a dry weight of mature pods, shelling percentage, pod yield (10.8%) and haulm yield (6.5%) in peanut compared to application of only 75% RDF in peanut + 75% RDF in wheat (T3), indicating a significant effect of FYM on growth and yield of peanut. Further, treatment T5 was also found to significantly increase peanut plant height, mature pods plant^{-1} and their dry weight, compared to application of 75% RDF + 2.5 t/ha ex-situ GM in peanut and 75% RDF in wheat (T7). This implies that application of FYM (5 t/ha) was more effective in improving growth and yield attributes of peanut as compared to ex-situ GM (2.5 t/ha). Similarly, the effectiveness of biofertilizer application was reflected through a significant increase in mature pods plant^{-1} and shelling percentage with treatment 100% RDF + PGPR in peanut and 100% RDF + Azotobacter in wheat (T9) as compared to 100% RDF in peanut and 100% RDF in wheat (T4).

3.2. Wheat

Wheat, as the subsequent crop following peanut, significantly ($p < 0.05$) responded to different S-INM practices. Application of treatment T11 (i.e., 75% RDF + 5 t/ha FYM + PGPR in peanut and 100% RDF in wheat) produced the highest plant height (74.3 cm), dry matter accumulation at 60 DAS (3.5 g plant^{-1}), SPAD value at 60 DAS (48.10), total (103.7) and effective (95.5) tillers metre^{-1} row length at harvest, ear length (8.3 cm), spikelet per plant (20.4) and test weight (41.5 g) in wheat over 100% RDF in peanut + 100% RDF in wheat (T4) as well as farmers' practice (T12) (Table 4). Treatment T11 was found to be at par with treatment T8 (50% RDF + 5 t/ha ex situ GM in peanut and 100% RDF in wheat) and treatment T10 (100% RDF + 5 t/ha FYM + PGPR in peanut and 75% RDF in wheat) for plant height at harvest, and with treatment T10 for dry matter at 60 DAS. Similarly, treatments T5, T6, T8 and T10 had an at par effect with the best treatment T11 for SPAD value at 60 DAS and test weight, while treatments T5, T6, T7, T8 and T10 were found to be at par for ear length and spikelet per plant. The highest value of total as well as effective tillers was found with treatment T11 ($p < 0.05$) over the rest of the treatments applied (Table 4).

Table 4. Effect of nutrient management practices on growth and yield attributes of wheat (pooled value of three years).

Treat-ments	Plant Height at Harvest (cm)	Dry Matter Plant^{-1} at 60 DAS (g)	SPAD at 60 DAS	Total Tillers per Metre Row at Harvest	Effective Tillers per Metre Row at Harvest	Ear Length (cm)	Spikelet Plant^{-1}	1000 Seed Weight (g)
T1	62.3 ^{G}	2.2 ^{G}	41.73 ^{F}	67.4 ^{H}	59.2 ^{E}	6.6 ^{D}	14.5 ^{D}	29.7 ^{D}
T2	69.0 ^{E}	2.5 ^{EFG}	43.67 ^{DE}	76.0 ^{G}	70.1 ^{D}	7.5 ^{C}	18.1 ^{C}	35.1 ^{C}
T3	70.2 ^{DE}	2.5 ^{DEF}	44.76 ^{CD}	78.6 ^{FG}	76.2 ^{C}	7.6 ^{BC}	18.5 ^{C}	36.1 ^{BC}
T4	70.9 ^{D}	2.6 ^{CDE}	46.10 ^{BC}	84.7 ^{DE}	77.3 ^{C}	7.6 ^{BC}	18.5 ^{C}	37.4 ^{B}
T5	72.4 ^{BC}	2.7 ^{CD}	46.70 ^{AB}	86.7 ^{CD}	78.1 ^{C}	7.8 ^{ABC}	19.3 ^{ABC}	40.4 ^{A}
T6	71.4 ^{CD}	3.1 ^{B}	46.58 ^{AB}	86.1 ^{DE}	78.0 ^{C}	7.8 ^{ABC}	19.0 ^{ABC}	39.6 ^{A}
T7	70.5 ^{D}	2.5 ^{DEF}	44.90 ^{CD}	80.1 ^{F}	76.9 ^{C}	7.8 ^{ABC}	19.4 ^{ABC}	37.1 ^{BC}
T8	72.9 ^{AB}	3.1 ^{B}	46.78 ^{AB}	83.7 ^{E}	77.3 ^{C}	7.7 ^{ABC}	18.9 ^{ABC}	40.4 ^{A}
T9	71.1 ^{CD}	2.6 ^{CDE}	45.68 ^{BC}	87.0 ^{CD}	79.1 ^{C}	7.7 ^{BC}	18.8 ^{BC}	37.3 ^{B}
T10	73.5 ^{AB}	3.3 ^{AB}	46.97 ^{AB}	95.6 ^{B}	87.2 ^{B}	8.2 ^{AB}	20.0 ^{AB}	41.5 ^{A}
T11	74.3 ^{A}	3.5 ^{A}	48.10 ^{A}	103.7 ^{A}	95.5 ^{A}	8.3 ^{A}	20.4 ^{A}	41.5 ^{A}
T12	67.6 ^{F}	2.3 ^{FG}	42.98 ^{EF}	89.5 ^{C}	68.1 ^{D}	7.3 ^{C}	15.6 ^{D}	31.3 ^{D}

Treatment means followed by superscripted different letters are significantly different at $p \leq 0.05$.

The grain and straw yield of wheat was observed highest (3706 and 5772 kg ha^{-1}, respectively) with the application of treatment T11 (Figure 4). The grain yield obtained with treatment T11 was found to be statistically equivalent to treatments T5, T6, T8, T9 and T10, while the straw yield was equivalent to T10. In general, about a 7.8 to 83.6% higher grain yield and 8.5 to 78.3% higher straw yield was observed with application of the best treatment (i.e., T11) than the remaining treatments. Addition of FYM in peanut was found to have a significant residual effect on growth and yield attributes of wheat grown in sequence. With the application of 75% RDF + 5 t/ha FYM in peanut and 75% RDF in wheat (T5), a significant improvement in wheat plant height, SPAD value, total tillers metre^{-1} row length and test weight was observed as compared to the application of only 75% RDF in both peanut and wheat (T3). Moreover, T5 significantly increased wheat plant height, total tillers metre^{-1} row length and test weight, compared to the application of 75% RDF + 2.5 t/ha ex situ GM in peanut and 75% RDF in wheat (T7), indicating the effectiveness of FYM over ex situ GM in improving growth and development of succeeding wheat. With the application of 100% RDF + PGPR in peanut and 100% RDF + Azotobacter in wheat (T9), there was a significant increase in the numbers of effective tillers metre^{-1} row length over application of only 100% RDF in both peanut and wheat (T4).

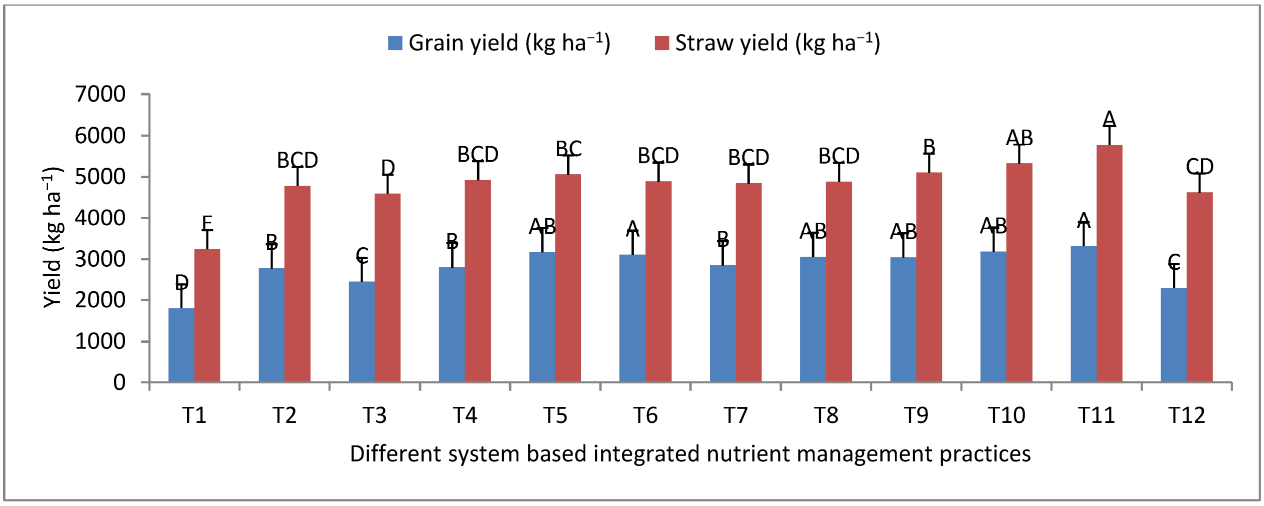


Figure 4. Effect of system-based integrated nutrient management practices on grain and straw yield of wheat. Vertical lines above bars represent $p \leq 0.05$ values, while bars marked with different letters

at a particular growth stage indicate significant differences between treatment means (pooled value of three years).

3.3. System Productivity, Economics and Energy Use Efficiency

The system productivity, expressed as peanut pod equivalent yield, was recorded highest (4795 kg ha^{-1}) with the application of treatment T11 (75% RDF + 5 t/ha FYM + PGPR in peanut and 100% RDF in wheat), which was at par with treatments T5, T6, T7, T8, and T10 (Table 5). Treatment T11 increased the system productivity by 14.0 and 17.1%, over treatment T4 (100% RDF in peanut and wheat) and T12 (farmers' practice), respectively. The highest net returns were obtained with treatment T10 (100% RDF + 5t FYM + PGPR in peanut and 75% RDF in wheat) in peanut (INR ha^{-1} 151,623) and with treatment T11 (75% RDF + 5tFYM + PGPR in peanut and 100% RDF in wheat) in wheat (INR ha^{-1} 26,274) as well as in the system (INR ha^{-1} 176,246). The net returns in the system remained at par in treatments T5, T6, T10 and T11. The application of treatment T11 increased system net returns by 17.0 and 22.6%, respectively, over T4 (100% RDF in both peanut and wheat) and T12 (farmers' practice). Similarly, the highest BCR was obtained with the application of T10 in peanut (6.0) and with treatment T4 and T11 in the wheat (1.9) crop, and with treatments T10 and T11 (3.9) in the system (Table 5).

Table 5. Effect of nutrient management practices on economics, net energy and energy use efficiency of peanut–wheat cropping system (pooled value of three years).

Treatments	Peanut Equivalent Yield (kg ha^{-1})	Net Returns (INR ha^{-1})			B:C Ratio			Net Energy (MJ ha^{-1})	Energy Use Efficiency
		Peanut	Wheat	System	Peanut	Wheat	System		
T1	2802 ^{G}	118,638 ^{C}	3639 ^{C}	122,277 ^{D}	5.1 ^{C}	1.1 ^{C}	3.2 ^{C}	152,247 ^{C}	8.4 ^{A}
T2	3583 ^{EF}	133,268 ^{B}	17,889 ^{B}	151,157 ^{B}	5.4 ^{B}	1.6 ^{B}	3.6 ^{AB}	188,462 ^{B}	7.6 ^{B}
T3	3825 ^{DE}	124,541 ^{C}	18,189 ^{B}	142,730 ^{C}	5.1 ^{C}	1.6 ^{B}	3.5 ^{C}	181,448 ^{B}	7.6 ^{B}
T4	4204 ^{C}	126,480 ^{C}	24,189 ^{A}	150,669 ^{B}	5.1 ^{C}	1.9 ^{A}	3.6 ^{AB}	199,179 ^{B}	7.7 ^{B}
T5	4649 ^{AB}	140,377 ^{A}	24,039 ^{A}	164,416 ^{A}	5.6 ^{AB}	1.8 ^{A}	3.8 ^{A}	202,421 ^{A}	8.1 ^{A}
T6	4575 ^{ABC}	142,924 ^{A}	23,124 ^{A}	166,048 ^{A}	5.7 ^{A}	1.8 ^{A}	3.8 ^{A}	200,460 ^{A}	7.7 ^{B}
T7	4250 ^{C}	139,152 ^{B}	20,214 ^{B}	159,366 ^{B}	5.6 ^{AB}	1.7 ^{AB}	3.7 ^{A}	186,755 ^{B}	7.6 ^{B}
T8	4557 ^{ABC}	142,429 ^{A}	19,329 ^{B}	161,758 ^{B}	5.7 ^{A}	1.7 ^{AB}	3.8 ^{A}	187,568 ^{B}	7.2 ^{B}
T9	4323 ^{BC}	138,872 ^{B}	22,389 ^{A}	161,261 ^{B}	5.3 ^{B}	1.8 ^{A}	3.6 ^{AB}	202,363 ^{A}	7.8 ^{B}
T10	4764 ^{A}	151,623 ^{A}	22,689 ^{A}	174,312 ^{A}	6.0 ^{A}	1.8 ^{A}	3.9 ^{A}	213,136 ^{A}	8.3 ^{A}
T11	4795 ^{A}	149,972 ^{A}	26,274 ^{A}	176,246 ^{A}	5.9 ^{A}	1.9 ^{A}	3.9 ^{A}	219,032 ^{A}	8.2 ^{A}
T12	3267 ^{F}	126,176 ^{C}	17,514 ^{B}	143,690 ^{C}	5.2 ^{BC}	1.6 ^{B}	3.5 ^{C}	185,750 ^{B}	8.8 ^{A}

Treatment means followed by superscripted different letters are significantly different at $p \leq 0.05$. Input prices: Urea@ INR 6.3 kg^{-1}; Single super phosphate@ INR 20.0 kg^{-1}; Muriate of potash@ INR 17.5 kg^{-1}; Di-Ammonium Phosphate @ INR 26.0 kg^{-1}; Biofertilizers@ INR 250 ha^{-1}; FYM@ INR 1000 t^{-1}; Green manure@ INR 800 t$^{-1.}$ Output prices: Peanut pod@ INR 45 kg^{-1}; Peanut haulm@ INR 4.0 kg^{-1}; Wheat grain@ INR 15.0 kg^{-1}; Wheat straw@ INR 1.0 kg$^{-1.}$

The net energy gain was highest (219,032 MJ ha^{-1}) with treatment T11 (75% RDF + 5 t/ha FYM + PGPR in peanut and 100% RDF in wheat), which was at par with treatments T5, T6, T9 and T10 (Table 5). The application of treatment T11 increased the net energy gain by 10.0 and 17.9%, respectively, over treatment T4 (100% RDF in both peanut and wheat) and T12 (farmers' practice). Although the energy use efficiency was highest (8.8) in farmers' practice (T12), it remained statistically equivalent to T1, T5, T10, and T11. The application of 75% RDF + 5 t/ha FYM in peanut and 75% RDF in wheat (T5) significantly increased the system productivity by 412 kg ha^{-1}, system net returns by 21,686 INR ha^{-1}, and system net energy by 20,973 MJ ha^{-1} compared to the application of 75% RDF alone in both peanut and wheat (T3), underlining the importance of the conjoint application of FYM and chemical fertilizers for obtaining higher productivity, returns, and energy use efficiency. The application of 75% RDF + 5 t/ha FYM in peanut and 75% RDF in wheat (T5) also led to a significant increase in system net returns by 5050 INR ha^{-1}, system net energy by 15,666 MJ ha^{-1} compared to application of 75% RDF + 2.5 t/ha ex situ

GM in peanut and 75% RDF in wheat (T7). Treatment 100% RDF + PGPR in peanut and 100% RDF + Azotobacter in wheat (T9) led to a significant increase in the system yield by 265 kg ha^{-1} and a system net energy by 3184 MJ ha^{-1} over 100% RDF alone in both peanut and wheat (T4).

3.4. Nutrient Uptake, Enzymatic Activities and Residual Soil Fertility

The uptake of NPK by peanut, wheat, and the system was significantly ($p < 0.05$) influenced by the S-INM practices (Table 6). The highest N (222.9 kg ha^{-1}), P (24.8 kg ha^{-1}), and K (37.3 kg ha^{-1}) uptake by peanut was registered with treatment T10, i.e., 100% RDF + 5 t/ha FYM + PGPR in peanut and 75% RDF in wheat. However, the highest N (94.3 kg ha^{-1}), P (17.7 kg ha^{-1}) and K (72.8 kg ha^{-1}) uptake by wheat, and P (40.9 kg ha^{-1}) and K (109.5 kg ha^{-1}) uptake by the system was obtained in treatment T11 (75% RDF + 5 t/ha FYM + PGPR in peanut and 100% RDF in wheat). N uptake in the system was found to be highest (310.4 kg ha^{-1}) in treatment T10 ($p < 0.05$). An equivalent influence on P uptake by peanut and the system was observed among treatments T9, T10, T11 and among treatments T10 and T11, respectively. Similarly, the K uptake was found at par among treatments T5, T6, T8, T9 T10 and T11 for peanut and among treatments T9, T10 and T11 for wheat and the system as a whole.

Table 6. Effect of nutrient management practices on NPK uptake by peanut, wheat and system (pooled value of three years).

Treatments	N Uptake by Peanut (kg ha^{-1})	N Uptake by Wheat (kg ha^{-1})	N Uptake of System (kg ha^{-1})	P Uptake by Peanut ((kg ha^{-1})	P Uptake by Wheat (kg ha^{-1})	P Uptake of System (kg ha^{-1})	K Uptake by Peanut (kg ha^{-1})	K Uptake by Wheat (kg ha^{-1})	K Uptake of System (kg ha^{-1})
T1	142.8 ^{H}	65.6 ^{F}	208.4 ^{I}	18.1 ^{G}	12.6 ^{G}	30.7 ^{H}	30.1 ^{D}	48.9 ^{E}	79.0 ^{H}
T2	151 ^{FG}	74.3 ^{E}	225.3 ^{GH}	19.8 ^{FG}	13.5 ^{F}	33.3 ^{G}	32.8.0 ^{BCD}	53.3 ^{D}	86.1 ^{FG}
T3	157.7 ^{EF}	76.1 ^{E}	233.8 ^{FG}	20.0 ^{EF}	13.9 ^{EF}	33.9 ^{FG}	33.0 ^{BCD}	57.7 ^{C}	90.7 ^{EF}
T4	164.6 ^{D}	81.9 ^{D}	246.5 ^{DE}	21.6 ^{CDE}	14.6 ^{CDE}	36.2 ^{CDE}	34.8 ^{B}	65.9 ^{B}	101.7 ^{CD}
T5	165.1 ^{D}	85.1 ^{BC}	250.2 ^{D}	22.6 ^{BC}	15.3 ^{BC}	37.9 ^{BC}	36.6 ^{AB}	67.1 ^{B}	103.7 ^{BCD}
T6	164.7 ^{D}	84.5 ^{BC}	249.2 ^{D}	21.8 ^{CD}	14.7 ^{CD}	36.5 ^{CD}	36.5 ^{AB}	66.1 ^{B}	102.6 ^{CD}
T7	158.5 ^{DE}	80.9 ^{D}	239.4 ^{EF}	20.3 ^{DEF}	14.0 ^{DEF}	34.3 ^{EFG}	33.1 ^{BCD}	58.6 ^{C}	92.2 ^{E}
T8	160.5 ^{DE}	84.6 ^{BC}	245.1 ^{DE}	21.2 ^{CDEF}	14.4 ^{DE}	35.6 ^{DEF}	34.8 ^{ABC}	65.5 ^{B}	100.3 ^{D}
T9	178.2 ^{C}	85.1 ^{BC}	263.3 ^{C}	24.2 ^{AB}	15.6 ^{B}	39.8 ^{B}	36.7 ^{AB}	70.2 ^{A}	106.9 ^{ABC}
T10	222.9 ^{A}	87.5 ^{B}	310.4 ^{A}	24.8 ^{A}	16.0 ^{B}	40.8 ^{A}	37.3 ^{A}	70.8 ^{A}	108.1 ^{AB}
T11	193.8 ^{B}	94.3 ^{A}	288.1 ^{B}	23.2 ^{AB}	17.7 ^{A}	40.9 ^{A}	36.7 ^{AB}	72.8 ^{A}	109.5 ^{A}
T12	145.4 ^{GH}	74.0 ^{E}	219.4 ^{H}	19.6 ^{FG}	13.3 ^{FG}	32.9 ^{G}	31.2 ^{CD}	49.6 ^{E}	80.8 ^{G}

Treatment means followed by superscripted different letters are significantly different at $p \leq 0.05$.

An appreciable increase in N uptake by the system was found with treatment T10 (25.9 and 41.5%, respectively) over treatments T4 (100% RDF alone in both peanut and wheat) and T12 (farmers' practice). Similarly, treatment T11 led to a significant increase in system P (13.0 and 24.3%) and K (7.7 and 35.5 %) uptake over treatments T4 and T12, respectively. Nutrient management practices significantly ($p < 0.05$) influenced soil available N, P_2O_5 and K_2O, and SOC after three years of the experimentation (Table 7). Application of treatment T11, i.e., 75% RDF + 5tFYM + PGPR in peanut and 100% RDF in wheat improved the availability of N (485.8 kg ha^{-1}), P (19.2 kg ha^{-1}) K (477.4 kg ha^{-1}), and SOC (8.5 g kg^{-1}) over all other treatments after three years of the experimentation. Furthermore, except for treatment T7, all other S-INM-based options (T5, T6, T8, T9 and T10) also performed better in terms of soil available N over traditional practice (T12) and other chemical fertilizer-based nutrient management options, i.e., treatments T2, T3 and T4. Treatment T11 was found at par with treatments T5, T8, and T10 regarding available phosphorus in soil. Similarly, the activities of soil enzymes such as dehydrogenase (108.9 μg TPF g^{-1} 24 h^{-1}), acid phosphatase (36.1 μgp NP g^{-1} h^{-1}) and alkaline phosphatase (548.8 μgp NP g^{-1} h^{-1}) were recorded highest with treatment T11 (75% RDF + 5 t/ha FYM + PGPR in peanut and 100% RDF in wheat) over all the remaining treatments. Furthermore, activities of dehydrogenase and alkaline phosphatase were statistically at par in T10 and T11.

Table 7. Effect of nutrient management practices on available NPK, soil organic carbon and on activities of soil enzymes dehydrogenase, acid phosphatase and alkaline phosphatase in peanut–wheat cropping system after three years of experimentation.

Treatments	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Soil Organic Carbon (g kg^{-1})	Dehydrogenase (µg TPF g^{-1} 24 h^{-1})	Acid Phosphatase (µg pNP g^{-1} h^{-1})	Alkaline Phosphatase (µg p-NP g^{-1} h^{-1})
T1	231.6 ^{G}	11.7 ^{F}	337.9 ^{H}	5.3 ^{I}	79.2 ^{F}	26.6 ^{F}	127.1 ^{F}
T2	373.8 ^{EF}	14.6 ^{DE}	353.1 ^{FGH}	6.0 ^{GH}	84.7 ^{EF}	29.3 ^{E}	152.7 ^{EF}
T3	377.9 ^{EF}	14.9 ^{DE}	355.3 ^{EFG}	6.1 ^{G}	85.8 ^{EF}	31.1 ^{D}	189 ^{DE}
T4	380.4 ^{EF}	15.3 ^{CD}	363.8 ^{DEF}	6.6 ^{F}	90.2 ^{DE}	33.4 ^{BC}	422 ^{C}
T5	391.3 ^{D}	17.8 ^{AB}	379.9 ^{D}	6.8 ^{EF}	94.8 ^{CD}	33.7 ^{BC}	428.2 ^{C}
T6	412.3 ^{CD}	17.2 ^{BC}	379.2 ^{D}	7.1 ^{D}	91.5 ^{CDE}	33.5 ^{BC}	422.2 ^{C}
T7	377.9 ^{EF}	15.8 ^{CD}	358.8 ^{EFG}	7.3 ^{CD}	89.7 ^{DE}	31.2 ^{D}	212.8 ^{D}
T8	413.6 ^{CD}	17.8 ^{AB}	370.6 ^{DE}	7.5 ^{C}	99.1 ^{BC}	33.7 ^{BC}	465.7 ^{B}
T9	421.2 ^{C}	16.2 ^{BCD}	413.6 ^{C}	7.0 ^{DE}	90.1 ^{DE}	32.6 ^{C}	410.5 ^{C}
T10	454.3 ^{B}	19.1 ^{A}	438.5 ^{B}	8.0 ^{B}	105.9 ^{AB}	35.6 ^{A}	524.4 ^{A}
T11	485.8 ^{A}	19.2 ^{A}	477.4 ^{A}	8.5 ^{A}	108.9 ^{A}	36.1 ^{A}	548.8 ^{A}
T12	356.7 ^{F}	13.3 ^{EF}	344.8 ^{GH}	5.8 ^{H}	84.7 ^{EF}	27.7 ^{F}	133.2 ^{F}

Treatment means followed by superscripted different letters are significantly different at $p \leq 0.05$. TPF, Triphenylformazon; p-NP, Para Nitro-phenol.

Thus, an appreciable increase in residual soil fertility was observed by the application of treatment T11, which ranged from 36.2 to 109.8% for available N, 44.4 to 64.1% for available P_2O_5, 38.5 to 41.3% for available K_2O, 46.6 to 60.4% for SOC, 28.6 to 37.5% for dehydrogenase activities, 30.31 to 35.7% for acid phosphatase activities and 312.0 to 331.8% for alkaline phosphatase activities over T12 and T1, respectively. With the application of 75% RDF + 5 t/ha FYM in peanut and 75% RDF in wheat (T5), there was a significant increase in system N uptake by 16.4 kg ha^{-1}, system P uptake by 4.0 kg ha^{-1}, system K uptake by 12.9 kg ha^{-1}, soil available N by 13.4 kg ha^{-1}, available P_2O_5 by 2.9 kg ha^{-1}, available K_2O by 24.6 kg ha^{-1}, SOC by 0.7 g kg^{-1}, dehydrogenase activity by 9 µg TPF/g soil/day, acid phosphate activity by 2.6 µg PNP/g/h, alkaline phosphatase activity by 239.2 µg PNP/g/h compared to the application of 75% RDF alone in peanut and wheat (T3). Treatment T5 also caused a significant increase in system N uptake by 10.8 kg ha^{-1}, system P uptake by 3.6 kg ha^{-1}, system K uptake by 11.5 kg ha^{-1}, soil available N by 13.4 kg ha^{-1}, available P_2O_5 by 2.0 kg ha^{-1}, available K_2O by 21.1 kg ha^{-1}, SOC by 0.5 g kg^{-1}, dehydrogenase activity by 5.1 µg TPF g^{-1} soil 24 h^{-1}, acid phosphatase by 2.5 µg PNP g^{-1} h^{-1} and alkaline phosphatase by 215.4 µg PNP g^{-1} h^{-1} compared to treatment 75% RDF + 2.5 t/ha ex situ GM in peanut and 75% RDF in wheat (T7). Application of 100% RDF + PGPR in peanut and 100% RDF + Azotobacter in wheat (T9) increased N uptake by peanut by 13.5 kha^{-1}, P uptake by peanut, wheat and system by 2.6, 1.0 and 3.6 kg ha^{-1}, respectively, K uptake by wheat by 4.3 kg ha^{-1}, soil available N by 40.8 kg ha^{-1}, available P_2O_5 by 0.9 kg ha^{-1}, available K_2O by 49.8 kg ha^{-1}, SOC by 0.4 g kg^{-1} over sole application of 100% RDF in both peanut and wheat (T4).

4. Discussion

4.1. Performance of Peanut

S-INM practices showed a significant effect on the growth and yield of peanut. The significantly increased growth parameters viz., plant height, LAI, and above ground biomass over T4 and FF were recorded with treatment T10 (100% RDF + 5 t/ha FYM + PGPR in peanut and 75% RDF in wheat), which was statistically equivalent to the other S-INM based practices of T5, T6, T7, T8 and T11 (Table 3 and Figure 2). This is attributed to a higher and sustained nutrient supply with conjunctive use of chemical fertilizers, organic manures, and PGPR [24]. The application of FYM and ex situ GM enhanced microbial activities in the soil, as indicated by higher enzymatic activities under S-INM practices, thus releasing more nutrients for plant uptake. This is also supported by the overall higher nutrient uptake with S-INM practices (T5, T6, T8, T10 and T11) over treatments having chemical fertilizers alone (T2, T3, T4) and farmers' practice (T12) (Table 6). Furthermore, organic manures adsorb plant nutrients on organic micelles and subsequently release them at a slow pace for plant uptake over a relatively longer period of time [39,40]. In addition, organic manures are known to improve soil physical parameters, ensuring better water and air dynamics in the soil and improved plant root development [41,42]. The higher vegetative growth under T10 led to a higher pod yield with this treatment over all the remaining treatments except for T5, T6, T8 and T11. Treatment T10 increased thepod yield by 13.3 and 48.2% and haulm yield by 12.4 and 41.2% over treatment T4 (100% RDF in peanut and wheat) and T12 (farmers' practice), respectively. In peanut, contrary to crops such as wheat, maize and soybean, yield is typically limited by the source strength rather than sink capacity [43]; therefore, increased vegetative growth with S-INM practices caused the higher pod yield of peanut. The S-INM practices also improved the root system (data not given) of peanut, which supported higher yields through a higher nutrient uptake (Table 6). Moreover, FYM acts as a conditioner in these light black soils and helps in better peg-setting and pod development by reducing the compactness of the soil [42]. FYM is also known to improve water-holding capacity, thus delaying the water stress effect on vegetative growth and productivity of rainfed crops in shallow black soils in the region [44].

The significant improvement in growth- and yield-contributing characters, and haulm yield of peanut with treatment 75% RDF + 5 t/ha FYM in peanut and 75% RDF in wheat (T5) as compared to the application of only 75% RDF in peanut + 75% DRF in wheat (T3) reaffirms the role of FYM in improving the growth and yield of peanut. The significant increase in mature pods plant^{-1} and shelling percentage with 100% RDF + PGPR in peanut and 100% RDF + Azotobacter in wheat (T9) over the sole application of 100% RDF in both peanut and wheat (T4) is attributed to improved plant growth as PGPR enhances the production of plant hormones and causes solubilization of soil nutrients (especially P and K) through the production of organic acids, hydrolases and phosphatases [17,45]. Among the chemical fertilizer-based nutrient management practices, treatment 100% RDF in peanut and 100% RDF in wheat (T4) gave higher pod and haulm yields over T2 (50% RDF in peanut and 100% RDF in wheat) and T3 (75% RDF in peanut and 75% RDF in wheat), indicating that a reduction in fertilizer doses in the system reduces yield levels of peanut.

4.2. Performance of Wheat

Treatment T11, i.e., 75% RDF + 5tFYM + PGPR in peanut and 100% RDF in wheat, besides significantly increasing growth and yield attributes, improved grain (18.4 and 44.1%) and straw yield (17.4 and 25.0%) over 100% RDF in peanut and 100% RDF in wheat (T4) and farmers' practice (T12), respectively (Table 4). The economic yield recorded in T11 was statistically equivalent to T5, T6, T8 and T10, corroborating the positive impact of S-INM on wheat yield. The residual nutrient supply from FYM and ex situ GM, applied in peanut, supplemented the chemical fertilizer source of nutrition, thus improving nutrient availability in the soil (Table 6). Because the organic manures release nutrients slowly, they have considerable influence on the nutrition of second-season crops as well [12,46]. Higher nutrient availability, better soil conditions, and improved root parameters (data not given here) facilitated a higher nutrient uptake (Table 7) and ultimately favored better growth and development and higher yield of wheat. Our results agree with the findings of Sharma et al. (2008) [47] and Kumar et al. (2009) [48].

4.3. System Productivity, Economics, and Energy Use Efficiency

The system productivity, expressed as peanut equivalent yield, was highest with treatment 75% RDF + 5 t/ha FYM + PGPR in peanut and 100% RDF in wheat (T11), and was found statistically at par with other S-INM options of 75% RDF + 5 t/ha FYM in peanut and 75% RDF in wheat (T5), 75% RDF + 2.5 t/ha FYM in peanut and 100% RDF in wheat (T6), 50% RDF + 5 t/ha ex situ GM in peanut and 100% RDF in wheat (T8), and 100% RDF + 5 t/ha FYM + PGPR in peanut and 75% RDF in wheat (T10). Higher system productivity in S-INM practices was due to a sufficient and balanced supply of nutrients to the crops throughout the growth period of crops resulting in better nutrient uptake (Table 6). S-INM practices resulted in higher soil fertility status in terms of available N, P_2O_5 and K_2O and SOC (Table 7), which enhanced the availability of nutrients for the crop plants leading to higher system productivity. The better performance of both peanut and wheat in terms of yield under T11 caused a realization of higher system net returns with this treatment over the conventional practice of 100% RDF to both peanut and wheat (T4) and farmers' practice (T12). Singh et al. (2017) [49] have also reported higher net returns with INM practices. The higher net energy gain with T11 is attributed to higher crop yields under this treatment. Higher energy use efficiency in farmers' practice (T12) was due to low energy input compared to other treatments. Rational and effective use of input energy resources in cropping systems is primal for the system sustainability because it will minimize environmental harm and conserve natural resources [50].

4.4. Nutrient Uptake, Enzyme Activities and Residual Soil Fertility

The highest uptake of nutrients by peanut and wheat was found with treatment 100% RDF + 5 t/ha FYM + PGPR in peanut and 75% RDF in wheat (T10) and 75% RDF + 5 t/ha FYM + PGPR in peanut and 100% RDF in wheat (T11), respectively (Table 6). Higher soil enzymatic activities under T10 and T11 led to higher nutrient availability under these treatments and hence higher nutrient uptake by the crops. Soil extracellular enzymes, predominantly hydrolases and secreted by rhizospheric microbes, decompose organic matter [51] which releases C, N and P into the soil–plant interface [52]. In treatments T10 and T11, having PGPR and FYM, there was an upward spike in soil available P_2O_5, possibly due to the release of P from fixed native-P (insoluble calcium phosphates) and organic-P [45]. FYM acts as a source of carbon and energy for the heterotrophs leading to increased microbial activity and diversity [53–55]. This resulted in increased activities of dehydrogenase, acid phosphatase and alkaline phosphatase enzymes with treatments T10 and T11 over all other treatments. Similar findings were also observed by Myint et al. (2010) [56] and Sharma and Sharma (2002) [57]. A significant increase in enzymatic activities in the soil was also reported by Karad et al. (2016) [58] with INM practices in the peanut–wheat system.

Treatment 75% RDF + 5 t/ha FYM + PGPR in peanut and 100% RDF in wheat (T11) improved available N, P_2O_5, K_2O, and SOC over all other treatments after three years of the experimentation, except for the available P which was at par in T10 and T11. Furthermore, S-INM based options of T5, T6, T8 and T10 also performed better in terms of soil available N, P_2O_5 and K_2O, and SOC than that of control (T1), traditional practice (T12) and all inorganic nutrient management-based options (T2, T3 and T4). The addition of nutrients through both organic and inorganic sources increased adsorption and the consequent slow release of nutrients by FYM and ex-situ GM, as well as the role played by biofertilizers in the augmentation of the nutrient supply have together improved the soil fertility in S-INM-based practices. An increase in SOC is ascribed to the addition of organic matter through organic manures and higher root biomass (data not given here). Higher SOC with INM practices was also reported by Karad et al. (2016) [58].

5. Conclusions

System-based integrated nutrient management (S-INM) is as an appropriate approach to achieving higher productivity, profitability, and nutrient use efficiency on a long-term basis. However, little information is available especially on S-INM strategy in the peanut–wheat cropping sequence. Hence, the present study was carried out to identify suitable S-INM options for the peanut–wheat cropping sequence in the Saurashtra region of India. The treatments were designed to study the effect of FYM, GM and PGPR, in conjunction with chemical fertilizers in the peanut–wheat system and identify the suitable S-INM options. Our results revealed that S-INM practices performed better in terms of productivity, profitability, net energy gain and soil fertility improvement over both farmers' practice and chemical fertilizer-based nutrient management practices. Application of 100% RDF + 5 t/ha FYM + PGPR in peanut and 75% RDF in wheat produced higher pod and haulm yield of peanut while, 75% RDF + 5 t/ha FYM + PGPR in peanut and 100% RDF in wheat gave a higher yield of wheat as well as system productivity. Furthermore, 75% RDF + 5 t/ha FYM + PGPR in peanut and 100% RDF in wheat also improved system net returns and net energy over 100% RDF in both peanut and wheat and farmers' practice. The greatest soil fertility improvement with respect to available N, P_2O_5 and K_2O, and SOC was also observed under 75% RDF + 5 t/ha FYM + PGPR in peanut and 100% RDF in wheat. It was also found that the S-INM practice of 50% RDF + 5 t/ha ex situ GM in peanut and 100% RDF in wheat improved productivity, net returns and soil fertility over 100% RDF in both peanut and wheat and farmers' practice. A reduction in fertilizer doses was found to decrease yield and net returns in the system. To conclude, the application of 75% RDF in integration with FYM@5 t/ha and PGPR in peanut and 100% RDF in wheat is the sustainable approach for a higher system yield, better financial returns and to improve soil fertility under the peanut–wheat system in the light black calcareous soils of the Saurashtra region of India. Furthermore, there is a need for study of the residual effect of organic manures applied in crops preceding peanut on the productivity of peanut in the region.

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References

1. Directorate of Economics and Statistics. *Agricultural Statistics at a Glance*; Ministry of Agriculture and Farmer Welfare: New Delhi, India, 2021.
2. FAOSTAT. Available online: http://www.fao.org/faostat/en/#data/QC (accessed on 6 October 2020).
3. Veeramani, P.; Subrahmaniyan, K. Nutrient management for sustainable groundnut productivity in India—A review. *Int. J. Eng. Sci. Technol.* **2011**, *3*, 8138–8153.
4. Mahrous, N.M.; Safina, S.A. Integrated use of organic, inorganic and bio fertilizers on yield and quality of two peanut cultivars grown in a sandy saline soil. *Am.-Eurasian J. Agric. Environ. Sci.* **2015**, *15*, 1067–1074.
5. Mukhtar, A.A.; Odion, E.C.; Ahmed, A.; Babaji, B.A.; Aminu-Mukhtar, M.; Arunah, U.L. Comparative effects of organic manure sources and rates on performance of peanut varieties. In Proceedings of the 4th ISOFAR Scientific Conference on 'Building Organic Bridges' during Organic World Congress, Istanbul, Turkey, 13–15 October 2014.
6. Serpil, S. An Agricultural Pollutant: Chemical Fertilizer. *Int. J. Environ. Sci. Technol.* **2012**, *3*, 77–80.
7. Roy, R.; Sultana, S.; Wang, J.; Mostofa, M.G.; Sarker, T.; Rahman Shah, M.M.; Hossain, M.S. Revegetation of coal mine degraded arid areas: The role of a native woody species under optimum water and nutrient resources. *Environ. Res.* **2022**, *204*, 111921. [CrossRef] [PubMed]
8. Jat, R.A.; Wani, S.P.; Sahrawat, K.L.; Singh, P.; Dhaka, S.R.; Dhaka, B.L. Recent approaches in nitrogen management for sustainable agricultural production and eco-safety. *Arch. Agron. Soil Sci.* **2012**, *58*, 1033–1060. [CrossRef]

9. Hepperly, P.; Lotter, D.; Ulsh, C.Z.; Seidel, R.; Reider, C. Compost, Manure and Synthetic Fertilizer Influences Crop Yields, Soil Properties, Nitrate Leaching and Crop Nutrient Content. *Compos. Sci. Util.* **2013**, *17*, 117–126. [CrossRef]
10. Deshmukh, K.K.; Khatik, S.K.; Dubey, D.P. Effect of Integrated use of inorganic, organic and bio fertilizers on production, Nutrient availability of plateau and Satpura hills. *J. Soils Crops* **2005**, *15*, 21–25.
11. Thorave, D.S.; Dhonde, M.B. Morphological indices and yield attributes as influenced by integrated nutrient management in summer groundnut. *Ann. Plant Physiol.* **2007**, *21*, 186–188.
12. Jat, R.A.; Ahlawat, I.P.S. Effect of organic manure and sulphur fertilization on productivity, nutrient uptake, sulphur use efficiency and economics in pigeonpea (Cajanuscajan) + groundnut (*Arachis hypogaea*) intercropping system. *Indian J. Agron.* **2011**, *55*, 24–29.
13. Selim, M.M. Introduction to the integrated nutrient management strategies and their contribution to yield and soil properties. *Int. J. Agron.* **2020**, *2020*, 2821678. [CrossRef]
14. Purbajanti, E.D.; Slamet, W.; Fuskhah, E.; Rosyida, D. Effects of organic and inorganic fertilizers on growth, activity of nitrate reductase and chlorophyll contents of peanuts (*Arachis hypogaea* L). *Earth Environ. Sci.* **2019**, *250*, 012048. [CrossRef]
15. Singh, N.J.; Athokpam, H.S.; Devi, K.N.; Chongtham, N.; Singh, N.B.; Sharma, P.T.; Dayananda, S. Effect of farm yard manure and press mud on fertility status of alkaline soil under maize-wheat cropping sequence. *Afr. J. Agric. Res.* **2015**, *10*, 2421–2431.
16. Meena, B.L.; Fagodiya, R.K.; Prajapat, K.; Dotaniya, M.L.; Kaledhonkar, M.J.; Sharma, P.C.; Meena, R.S.; Mitran, T.; Kumar, S. *Legume Green Manuring. Legumes for Soil Health and Sustainable Management*; Springer: Singapore, 2018; pp. 387–408.
17. Dey, R.; Pal, K.K. *Biofertilizers for Enhancing Groundnut Productivity*; ICAR-Directorate of Groundnut Research: Junagadh, Gujarat, 2014; p. 30.
18. Kumar, A.; Meena, V.S. *Plant Growth Promoting Rhizobacteria for Agricultural Sustainability*; Springer: Berlin, Germany, 2019; pp. 978–981.
19. Yadav, R.L.; Subba Rao, A.V.M. *Atlas of Cropping Systems in India*; Project Directorate for Cropping Systems Research, Indian Council of Agricultural Research: Uttar Pradesh, India, 2011; p. 43.
20. Sharma, B.M.; Singh, R.V. Soil test and crop need based fertilizer recommendations for field crops. In *Proceedings of the Training Workshop on Soil Testing for Balanced and Integrated Use of Fertilizers and Manures*; Punjab Agricultural University: Ludhiana, Punjab, 2003; pp. 106–121.
21. Firouzi, S.; Aminpanah, H. Energy Use Efficiency for Groundnut (*Arachis hypogaea* L.) Production in a Semi-mechanized Cultivation System. *Ann. Biol. Res.* **2012**, *3*, 3994–3997.
22. Koocheki, A.; Ghorbani, R.; Mondani, F.; Alizade, Y.; Moradi, R. Pulses production systems in term of energy use efficiency and economic analysis in Iran. *Int. J. Energy Econ. Policy* **2011**, *1*, 95–106.
23. Firouzi, S.; Nikkhah, A.; Rosentrater, K.A. An integrated analysis of non-renewable energy use, GHG emissions, carbon efficiency of groundnut sole cropping and groundnut-bean intercropping agro-ecosystems. *Environ. Prog. Sustain. Energy* **2017**, *36*, 1832–1839. [CrossRef]
24. Mohanty, P.; Pany, B.K.; Sahu, G.; Mohapatra, S.; Nayak, B.K. Effect of Integrated Nutrient Management on Growth, Yield Attributes, Yield and Quality Parameters of Groundnut (*Arachis hypogaea*) in an Acidic Upland of Odisha. *Indian J. Ecol.* **2022**, *49*, 119–123. [CrossRef]
25. Osman, A.K. *Groundnut Production in Traditional Rain Fed Sector*; ARC Publication: Wadmadni, Sudan, 2003.
26. Mulvaney, M.J.; Devkota, P. Adjusting Crop Yield to a Standard Moisture Content. Document SS-AGR-443 in a Series of the Agronomy Department, UF/IFAS Extension. 2020. Available online: https://edis.ifas.ufl.edu/publication/AG442#:~{}:text=It%20would%20make%20sense%20to,1%2C240%20lb%20water%2Fac (accessed on 1 February 2022).
27. Shelke, D.K. *Research Techniques in Agronomy*; Kalyani Publishers: New Delhi, India, 2007; pp. 1–89.
28. Devasenapathy, P.; Senthilkumar, G.; Shanmugam, P.M. Energy management in crop production. *Indian J Agron.* **2009**, *54*, 80–90.
29. Mittal, J.P.; Dhawan, K.C. *Research Manual on Energy Requirements in Agricultural Sector*; Indian Council of Agricultural Research: New Delhi, India, 1988; p. 150.
30. Subbiah, B.V.; Asija, G.L. A rapid method for estimation of available N in soil. *Curr. Sci.* **1956**, *25*, 259–260.
31. Koening, H.A.; Johnson, C.R. Method for estimating phosphorus. *Ind. Eng. Chem. Anal. Ed.* **1942**, *14*, 155–156.
32. Kalra, Y. *Handbook of Reference Methods for Plant Analysis*; CRC Press Taylor & Francis Group: New York, NY, USA, 1997; pp. 115–118.
33. Olsen, S.R.; Cole, C.V.; Watanabe, F.S.; Dean, L. *Estimation of Available Phosphorus in Soil by Extraction with Sodium Carbonate*; US Department of Agriculture: Washington, DC, USA, 1954; p. 933.
34. Hanway, J.; Heidal, H.S. Soil analysis methods as used in Iowa State College Soil Testing Laboratory. *Iowa State Coll. Agric. Bull.* **1952**, *57*, 1–13.
35. Walkley, A.; Black, I.A. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* **1934**, *37*, 29–37. [CrossRef]
36. Tabatabai, M.A. Soil enzymes. In *Methods of Soil Analysis: Microbiological and Biochemical Properties*; Bottomley, P.J., Angle, J.S., Weaver, R.W., Eds.; Soil Science Society of America: Madison, WI, USA, 1994; pp. 775–833.
37. Schinner, F.; Ohlinger, R.; Kandeler, E.; Margensin, R. *Methods in Soil Biology*; Springer Lab Manual; Springer: Berlin, Germany, 1996; p. 426.
38. Gomez, K.A.; Gomez, A.A. *Statistical Procedures for Agricultural Research*, 2nd ed.; John Wiley and Sons: New York, NY, USA, 1984; p. 680.

39. Patil, S.R.; Kadam, S.R.; Kalegore, N.K.; Dadgale, P.R. Effect of inorganic and bio-fertilizers on growth and yield of summer peanut. *Adv. Res. J. Crop Improv.* **2014**, *5*, 23–25.
40. Rahevar, H.D.; Patel, P.P.; Patel, B.T.; Joshi, S.K.; Vaghela, S.J. Effect of FYM, iron and zinc on growth and yield of summer peanut (*Arachis hypogaea* L.) under North Gujarat Agro-climatic conditions. *Indian J. Agric. Res.* **2015**, *49*, 294–296. [CrossRef]
41. Hati, K.M.; Mandal, A.K.; Misra, A.K.; Ghosh, P.K.; Bandyopadhyay, K.K. Effect of inorganic fertilizer and farmyard manure on soil physical properties, root distribution, and water-use efficiency of soybean in Vertisols of central India. *Bioresour. Technol.* **2006**, *97*, 2182–2188. [CrossRef]
42. Zhang, J.B.; Yang, J.S.; Yao, R.J.; Yu, S.P.; Li, F.R.; Hou, X.J. The effects of Farmyard Manure and Mulch on soil physical properties in a reclaimed coastal tidal flat salt-affected soil. *J. Integr. Agric.* **2014**, *13*, 1782–1790. [CrossRef]
43. Borrás, L.; Slafer, G.A.; Otegui, M.E. Seed dry weight response to source–sink manipulations in wheat, maize and soybean: A quantitative reappraisal. *Field Crops Res.* **2004**, *86*, 131–146. [CrossRef]
44. Sanepara, D.P.; Vekariya, P.D.; Vora, V.D.; Gajera, M.S.; Akbari, K.N. Effect of Tillage and Organic Manures on Soil Moisture and Performance of Rainfed Groundnut (*Arachis hypogea* L.). *Int. J. Bio-Resour. Stress Manag.* **2015**, *6*, 452–456. [CrossRef]
45. Gupta, G.; Parihar, S.S.; Ahirwar, N.K.; Snehi, S.K.; Singh, V. Plant growth promoting rhizobacteria (PGPR): Current and future prospects for development of sustainable agriculture. *J. Microb. Biochem. Technol.* **2015**, *7*, 96–102.
46. Yasodha, M.; Chinnusamy, C. Direct and residual effect of organic manures and inorganic fertilizer application in brinjal + onion-cowpea-sunnhemp cropping system. *J. Pharmacogn. Phytochem.* **2019**, *8*, 2335–2339.
47. Sharma, K.L.; Neelaveni, K.; Katyal, J.C.; Srinivasa Raju, A.; Srinivas, K.; Kusuma Grace, J.; Madhavi, M. Effect of combined use of organic and inorganic sources of nutrients on sunflower yield, soil fertility and overall soil quality in rainfed Alfisol. *Commun. Soil Sci. Plant Anal.* **2008**, *39*, 1791–1831. [CrossRef]
48. Kumar, M.; Jatav, M.K.; Trehan, S.P.; Lal, S.S. Integrated nutrient management in potato-based cropping systems for eastern Indo-Gangatic plains of India. *Potato J.* **2009**, *6*, 136–142.
49. Singh, G.; Virk, H.; Khanna, V. Integrated nutrient management for high productivity and net returns in lentil (*Lens culinaris*). *J. Appl. Nat. Sci.* **2017**, *9*, 1566–1572. [CrossRef]
50. Rafiee, S.; Avval, S.H.M.; Mohammadi, A. Modeling and sensitivity analysis of energy inputs for apple production in Iran. *Energy* **2010**, *35*, 3301–3306. [CrossRef]
51. Burns, R.G.; DeForest, J.L.; Marxsen, J.; Sinsabaugh, R.L.; Stromberger, M.E.; Wallenstein, M.D.; Zoppini, A. Soil enzymes in a changing environment: Current knowledge and future directions. *Soil Biol. Biochem.* **2013**, *58*, 216–234. [CrossRef]
52. Tiemann, L.K.; Billings, S.A. Indirect effects of nitrogen amendments on organic substrate quality increase enzymatic activity driving decomposition in a mesic grassland. *Ecosystems* **2011**, *14*, 234–247. [CrossRef]
53. Selvi, D.; Santhy, P.; Dhakshinamoorthy, M.; Maheshwari, M. Microbial population and biomass in Rhizoshpere influenced by continuous intensive cultivation and fertilization in an Inceptisol. *J. Indian Soc. Soil Sci.* **2004**, *52*, 254–257.
54. Qureshi, A.A.; Narayanasamy, G.; Chhonkar, P.K.; Balasundram, V.R. Direct and residual effect of phosphate rocks in presence of phosphate solubilizers and FYM on the available P, organic carbon and viable counts of phosphate solubilizers in soil after soybean, mustard and wheat crops. *J. Indian Soc. Soil Sci.* **2005**, *53*, 97–100.
55. Liang, Q.; Chen, H.Q.; Gong, Y.S.; Yang, H.F.; Fan, M.S.; Kuzyakov, Y. Effect of 15 years of manure and mineral fertilizers on enzyme activities in particle-size fractions in a North China Plain soil. *Eur. J. Soil Biol.* **2014**, *60*, 112–119. [CrossRef]
56. Myint, A.K.; Yamakawa, T.; Kajihara, Y.; Zenmyo, T. Application of different organic and mineral fertilizers on the growth, yield and nutrient accumulation of rice in a Japanese ordinary paddy field. *Sci. World J.* **2010**, *5*, 47–54. [CrossRef]
57. Sharma, S.K.; Sharma, S.N. Integrated nutrient management for sustainability of rice (*Oryza sativa*)-wheat (*Triticum aestivum* L.) cropping system. *Indian J. Agric. Sci.* **2002**, *72*, 573–576.
58. Karad, G.U.; Babariya, N.B.; Viradiya, M.B.; Parmar, J.K.; Deshmukh, S.D.; Polara, K.B. Effect of integrated nutrient management on yield and active pools of soil organic carbon under groundnut-wheat system of typic Haplustept in long term fertilizer experiment. *J. Pure Appl. Microbiol.* **2016**, *10*, 787–794.