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Eco-functional intensification through natural and organic farming of groundnut (*Arachis hypogaea*)

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ABSTRACT

The primary challenge for sustainable intensification of agriculture is to increase food and feed production while minimising greenhouse gas emissions, biodiversity loss and nutrient leaching. The experiment was conducted during winter (*rabi*) seasons of 2019–20 and 2020–21 at Zonal Agricultural and Horticultural Research Station, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Navile, Shivamogga, Karnataka to compare different farming systems, i.e. natural farming (NF), organic farming (OF), conventional farming (CF) and farmer practices (FP) in groundnut (*Arachis hypogaea* L.). The results revealed that conventional farming recorded significantly higher pod yield, pod weight/plant, and shelling percentage compared to natural and organic farming systems. The number of pods/plant under natural farming was statistically comparable to conventional farming; however, this did not translate into higher pod yield. Haulm yield was significantly higher under natural farming, however, the organic carbon and micronutrients were significantly higher in the OF. Higher amounts of major and secondary nutrients were recorded in the CF, followed by OF. However, higher soil microbial activity was observed in NF which was comparable to OF. Pod yield was significantly lower in NF and OF; while, soil nutrient levels and soil microbial activity were higher. Practicing OF and NF over a long period could reduce the yield gap. Both natural and organic farming increase soil organic carbon and improve the stability of soil abiotic and biotic characteristics and they are expected to play important roles in long-term sustainable agriculture.

Keywords: Conventional farming, Farming systems, Groundnut, Organic carbon, Sustainability

Farming systems based on agroecological and organic principles have delivered relatively stable yields and were more adaptable to adverse weather conditions. In addition to organic farming, natural farming (NF) follows similar principles, primarily relying on naturally available inputs such as cow dung and cow urine (Smith *et al.* 2020, Veeranna *et al.* 2023c). NF emphasises the importance of agricultural production and animal husbandry to leverage the various locally available components of the system, which enhances crop growth by improving soil microbial activity and increasing soil fertility (FAO 2019, Khadse and Rosset 2019, Veeranna *et al.* 2023b). The NF system excludes the external use of agrochemicals, viz. herbicides, pesticides and fertilisers, thereby avoiding purchases from the market. The NF system is built on 'four wheels' or principles: *Jeevamrutha* is used to stimulate soil microbial activity to improve plant nutrient uptake and provide protection against soil-borne pathogens; *Beejamrutha* is used to protect seeds and seedlings from soil-borne pathogens; *Acchadana* (mulching) stabilises soil organic matter and conserves topsoil; and *Whapasa,* soil aeration is improved by improving the soil structure (Khadse and Rosset 2019). These NF principles can reduce pests and diseases, conserve soil moisture, improve nutrient use efficiency and enhance overall soil health (Veeranna *et al.* 2023a). Considering the potentiality of organic and natural farming, in the present investigation, we evaluated different farming systems such as natural farming, organic farming, conventional farming and farmer practices for the production of groundnut (*Arachis hypogaea* L.) and the current agricultural situation.

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MATERIALS AND METHODS

The experiment was conducted during winter (*rabi*) seasons of 2019–20 and 2020–21 at Zonal Agricultural and Horticultural Research Station, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Navile, Shivamogga (13º96' N, 75º58' E; at an elevation of 650 m amsl), Karnataka. The treatments comprised four farming systems, viz. T_1, Natural Farming (NF) in which seeds were treated with *Beejamrutha*, *Ghanajeevamrutha* was applied to the soil at the rate of 1,000 kg/ha and *Jeevamrutha* was applied as a foliar spray at 500 L/ha; T_2, Organic Farming (OF) treatment involved soil application of vermicompost at 4,000 kg/acre, calculated on a phosphorus-equivalent basis, and seed treatment was done using *Rhizobium* culture at 150 g/acre along with phosphate-solubilising bacteria (PSB) at 1000 g/ha; T_3, Conventional Farming system (CF) consisted farmyard manure (FYM) at 10×10^3 kg/ha applied in combination with recommended doses of inorganic fertilisers ($N:P_2O_5:K_2O$) at 25:75:37.5 kg/ha, and seeds were treated with *Rhizobium* at 375 g/ha and PSB at 1000 g/ha; and T_4, Farmers' Practice (FP) consisted of the application of chemical fertilisers ($N:P_2O_5:K_2O$) at 40:45:0 kg/ha. The experiment was laid out in a randomised complete block design (RCBD) with five replications. The crop was grown according to the recommendations given by the University of Agricultural Sciences, Bengaluru. The field was prepared by ploughing, then passed through a cultivator and harrowed before sowing. Bold, healthy TMV-2 seeds were selected for sowing. The seeds were treated with *Beejamrutha* in NF, with *Rhizobium* (4 g/kg) + PSB (4 g/kg) OF and CF, whereas no seed treatment was done in FP. One week after seeding, gap-filling was used to maintain a stable plant population. To ensure a homogeneous plant population, thinning was performed at 20 days after sowing (DAS). Mulching was performed for the crop under NF with a 5 cm thickness. For nutrient management, *Ghanajeevamrutha* (1,000 kg/ha), *jeevamrutha* (500 L/ha) at 30 days intervals in NF, farmyard manure (FYM) and vermicompost as per P equivalent basis in OF, FYM and NPK at 25:75:37.5 kg/ha and gypsum (1,000 kg/ha) at 40 DAS in CF and only NPK at 40:45:00 kg/ha in FP were applied. For biometric observations**,** 10 plants were randomly selected and labelled from each plot, and observations were documented, including the number of leaves/plant and plant height (cm) at various plant developmental stages (30 DAS, 60 DAS and at harvest). Yield-attributing characteristics such as the number of pods/plant had been documented in each replication and statistically analysed.

Physiochemical properties of soil: Prior to the initiation of the experiment, the soil at the experimental site had a bulk density of 1.41 g/cm³ and a particle density of 2.10 g/cm³, determined using a core sampler and a pycnometer, respectively. The maximum water-holding capacity was 11.40% (Keen's cup method) and soil porosity was 32.75%, calculated from bulk and particle density values. The soil reaction was slightly acidic with a *p*H of 5.58 (1:2.5 soil-water suspension) and the electrical conductivity was 0.093 dS/m (1:2 soil-water extract) indicating non-saline conditions (Jackson 1974). The soil was low in organic carbon with a value of 0.45 g/kg, determined by the Walkley and Black wet oxidation method (Walkley and Black 1934). The soil contained 257.60 kg/ha of available nitrogen determined by the alkaline $KMnO_4$ method (Subbiah and Asija 1956). The available phosphorus content was 113.81 kg P_2O_5/ha, estimated using Bray's/Olsen's method, while available potassium was 263.16 kg K_2O/ha, estimated by flame photometry (Jackson 1974). The available sulphur content was 18.54 mg/kg determined by the turbidometric method (Chaudhary and Cornfield 1966). The soil had exchangeable calcium and magnesium contents of 3.33 and 1.67 cmol(p^+)/kg, respectively, determined by EDTA titration (Jackson 1974). The DTPA-extractable micronutrients namely iron, manganese, copper and zinc were 19.25, 12.64, 1.20, and 1.82 mg/kg, respectively, estimated using an atomic absorption spectrophotometer. The water-soluble boron content was 0.35 mg/kg, determined by the hot-water extraction method (Page 1982).

The following formula was employed to calculate the amount of nutrients that various parts of the plant absorbed:

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{\% Nutrient content} \times \text{Grain or dry matter yield}}{100}$$

Soil enzymatic activity: Samples of moist soil were collected at regular intervals at 0–15 cm depth. The sample was air-dried, then filtered through a 2 mm sieve and subsequently analysed for enzymatic activity.

Dehydrogenase activity measured using method by Casida *et al.* (1964), where the production of 2,3,5-triphenyl formazan (TPF) is quantified. Acid and alkaline phosphatase activities assessed using the method from Eivazi and Tabatabai (1977). The intensity of the yellow colour of supernatant computated via spectrophotometer at 420 nm wavelength. Urease activity was estimated by measuring the colour intensity at 630 nm following Hofman (1965) method.

Statistical analysis: Data on growth parameters, yield, soil physicochemical properties, nutrient uptake and soil microbial populations were statistically analysed using a two-way analysis of variance (ANOVA) with farming system and year as the two fixed factors at $p<0.05$ using R software (version 4.0.3). Where treatment effects were significant, mean separation was performed using appropriate post-hoc tests. Correlation analyses among selected variables were also carried out using R software. Physiological, agro-physiological and economic use efficiencies were calculated using the equations described by Baligar *et al.* (2001).

Physiological efficiency (PE) (kg/kg):

$$PE = \frac{B_f - B_c}{NU_f - NU_c}$$

Where B_f, Biological yield in fertilised plot (kg/ha); B_c, Biological yield in control plot (kg/ha); NU_f, Amount of nutrients taken up by a crop in a fertilised plot (kg/ha); NU_c, Amount of nutrients taken up by a crop in a control plot (kg/ha).

Agro-physiological efficiency (APE) (kg/kg):

$$APE = \frac{G_f - G_c}{NU_f - NU_c}$$

Where G_f , Grain yield in fertilised plot (kg/ha); G_c, Grain yield in the control plot (kg/ha); NU_f, Amount of nutrients taken up by a crop in a fertilised plot (kg/ha); NU_c, Amount of nutrients taken up by a crop in a control plot (kg/ha).

Economic nutrient use efficiency (ENUE) (kg/₹):

$$\text{ENUE} = \frac{\text{Grain yield (kg)}}{\text{Amount invested on the nutrient (₹)}}$$

RESULTS AND DISCUSSION

The interaction effect between year and farming system (year × treatment) was non-significant (p>0.05) for all measured parameters; therefore, data were pooled across years and treatment main effects are discussed.

Yield parameters of groundnut: Pooled data of two years revealed significant variation among treatments for yield parameters of groundnut. The number of pods/plant was significantly higher in NF and CF treatments (32.58), which were statistically at par with each other followed by OF (32.12) while the lowest number of pods/plant was recorded under FP (29.56). The differences among treatments exceeded the critical difference value at the 5% level (CD = 2.88) (Fig. 1A). Pod weight/plant and kernel weight/plant were significantly influenced by nutrient management practices. The CF treatment recorded the highest pod weight (26.11 g/plant) and kernel weight (14.97 g/plant), which were significantly superior to OF (21.20 and 14.82 g/plant, respectively) and NF (20.85 and 13.85 g/plant, respectively). The lowest pod weight and kernel weight were observed under FP (18.57 and 11.07 g/plant, respectively). The observed differences exceeding the critical differences of 2.07 g for pod weight and 1.27 g for kernel weight (Fig. 1A). Shelling percentage was significantly higher under CF (68.05%) followed by NF (65.97%) and OF (64.48%) with the differences surpassing the critical difference value at the 5% level (CD = 6.01). Similarly, total pod yield was significantly higher in the CF treatment (1951.00 kg/ha) compared to FP (1856.50 kg/ ha) as the yield difference exceeded the critical difference value at the 5% (CD = 65.689). Haulm yield was highest under NF (1561.50 kg/ha) (Fig. 1B). Overall, yields under OF were consistently lower than those under CF. These results corroborated earlier findings that organic crop yields are generally about 15% lower than conventional yields, particularly during the initial years of transition (Seufert *et al.* 2012).

Yields under organic farming tend to increase over time as soil fertility gradually improves, enabling the soil to better meet crop nutrient requirements (Mader *et al.* 2002). A higher plant height was observed in NF, as reported by Lakshmipathi (2012) for finger millet with the application of *jeevamrutha*. In the OF, the organic content was given by the FYM and vermicompost where the decomposition rate is four times slower (Levi-Minzi *et al.* 1990) and provided a stable nutrient supply over time compared with the easily degradable *jeevamrutha* of the NF; thus, the plant height was highest in the NF but the pod yield was higher in the OF.

Soil properties and nutrient status: The treatments that received inorganic fertilisers i.e. CF and FP recorded significantly higher available phosphorus, nitrogen and potassium, and the lowest values were observed in the NF and OF (Fig. 2). A similar trend was observed for secondary nutrients, where the highest Ca, Mg and S content were observed in the CF followed by those in the OF. The secondary nutrients in the two treatments did not differ significantly. However, the micronutrients, viz. Mn, Fe, B, Zn and Cu were significantly higher in OF. There was no significant difference in CF and OF for micronutrients.

Nutrient uptake by pod and haulm: Pooled data of two years were presented on nutrient uptake by pod and haulm, evaluated after harvest. In the pod, a higher N uptake was recorded with CF (62.94 kg/ha), which was at par with OF (55.51 kg/ha). There was no significant difference between FP (52.97 kg/ha), OF and NF (51.27 kg/ha). In contrast, P and K uptake have been the highest in the CF (13.23 and 41.78 kg/ha) followed by the FP (11.16 and 31.00 kg/ha) and OF (10.03 and 29.62 kg/ha). Among the treatments, the lowest N, P and K uptake were observed in NF (51.27, 9.24 and 26.66 kg/ha, respectively) (Fig. 3A).

In haulm, higher N uptake was recorded in the CF (25.18 kg/ha), followed by the OF (22.15 kg/ha), NF (22.14 kg/ha) and FP (20.24 kg/ha). A similar trend was observed for K, with higher uptake in CF (24.02 kg/ha), followed by OF (21.39 kg/ha), NF (22.24 kg/ha) and FP (17.61 kg/ha). Although P uptake was highest in the CF treatment (15.38 kg/ha), it was lowest in the NF treatment (8.94 kg/ha). A significant difference in P uptake was detected between OF (10.06 kg/ha) and FP (13.20 kg/ha) (Fig. 3B). The soil physical properties (bulk density, particle density, maximum water holding capacity and porosity), pH and

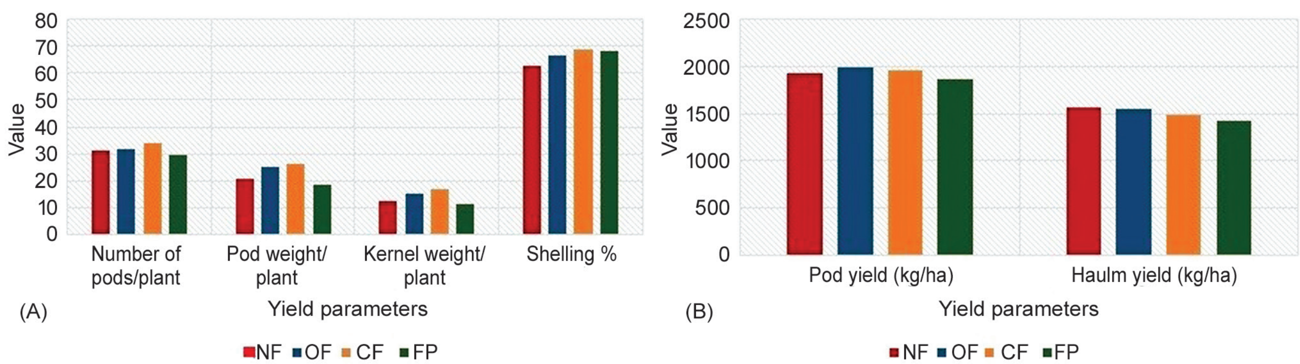

Fig. 1 Effect of different farming systems on yield parameters of groundnut.
NF, Natural farming; OF, Organic farming; CF, Conventional farming; FP, Farmer practice.

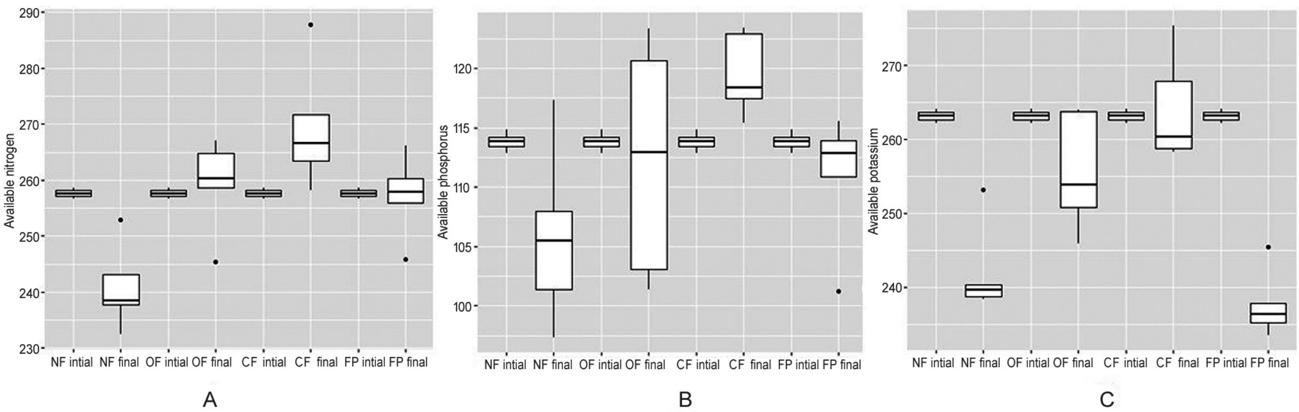

Fig. 2 Available major nutrients in soil under different farming systems. (A) Nitrogen, (B) Phosphorus and (C) Potassium. NF, Natural farming; OF, Organic farming; CF, Conventional farming; FP, Farmer practice.

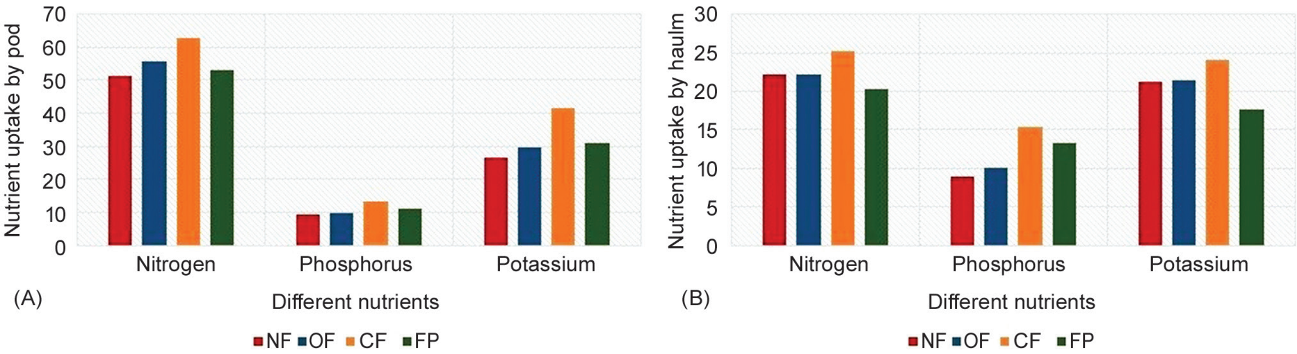

Fig. 3 Nutrient uptake by groundnut under different farming systems in (A) pod and (B) haulm. NF, Natural farming; OF, Organic farming; CF, Conventional farming; FP, Farmer practice.

EC were not influenced by the different farming methods during the study. According to Miller and Miller (2000), adding organic materials might alter soil characteristics but these changes take time to become apparent. Soil microbes such as actinomycetes, fungi, bacteria and microalgae play substantial roles in nutrient cycling, decomposition of organic matter and transformation of other soil chemicals (Murphy *et al.* 2007).

The soil nutrients from the different farming systems were estimated and the results revealed that the CF and FP systems presented showed significantly higher available N, P, and K contents, and the lowest values have been observed in the NF and OF systems as the NF and OF systems received only organic fertilisers which resulted in slow decomposition of the FYM system and higher retention of organic carbon in the soil. Smith *et al.* (2020) reported that, without the application of additional nutrients such as manure and compost, the NF system is more deficient in N than in conventional farming. They also postulated that if N fixation is lower than estimated in NF or if N immobilisation is not prevented by straw incorporation, the N deficiency in the crop will be more pronounced.

In this study, a relatively high P content was recorded in the CF, and the lowest in the NF. Similarly, higher K content was observed in the CF than in the OF and NF. The supply of P and K is crucial in OF and NF because of their limited sources (Reimer *et al.* 2020), as the sources of P and K are limited in these systems and the available external rock phosphate fails to meet the demand due to their lower activity at *p*H values > 5.5–6.0 (Moller *et al.* 2018). One of the major obstacles to achieving higher yields in organic and natural farming is the limited availability of suitable nitrogen sources (Berry *et al.* 2002, Moller *et al.* 2006, Askegaard *et al.* 2011).

The supply of nitrogen is often found to be limiting for the conversion of farms from conventional to organic systems (Reimer *et al.* 2020). In the converted organic/natural system, nitrogen availability is primarily determined by short-term effects from previous crops, green leaf manures and organic fertilisers; however, previous conventional farming and the supply of organic inputs have limited effects on plant nitrogen supply. The main sources of P and K for plants are soil reserves and processes, and not applying P and K-based fertilisers regularly has minimal impact on crop growth and yield in the first year after switching to organic farming (Loes and Ogaard 2001). According to Cooper *et al.* (2018), the absence of P application leads to a decline in soil P levels. This decrease in soil P, K and S hinders the capability of legumes to fix atmospheric N_2 (Scherer *et al.* 2008). P, K and S play crucial roles in overall N supply through biological N_2 fixation in natural and organic farming systems, underscoring the importance of providing these nutrients for sustainable crop production (Reimer *et al.* 2020).

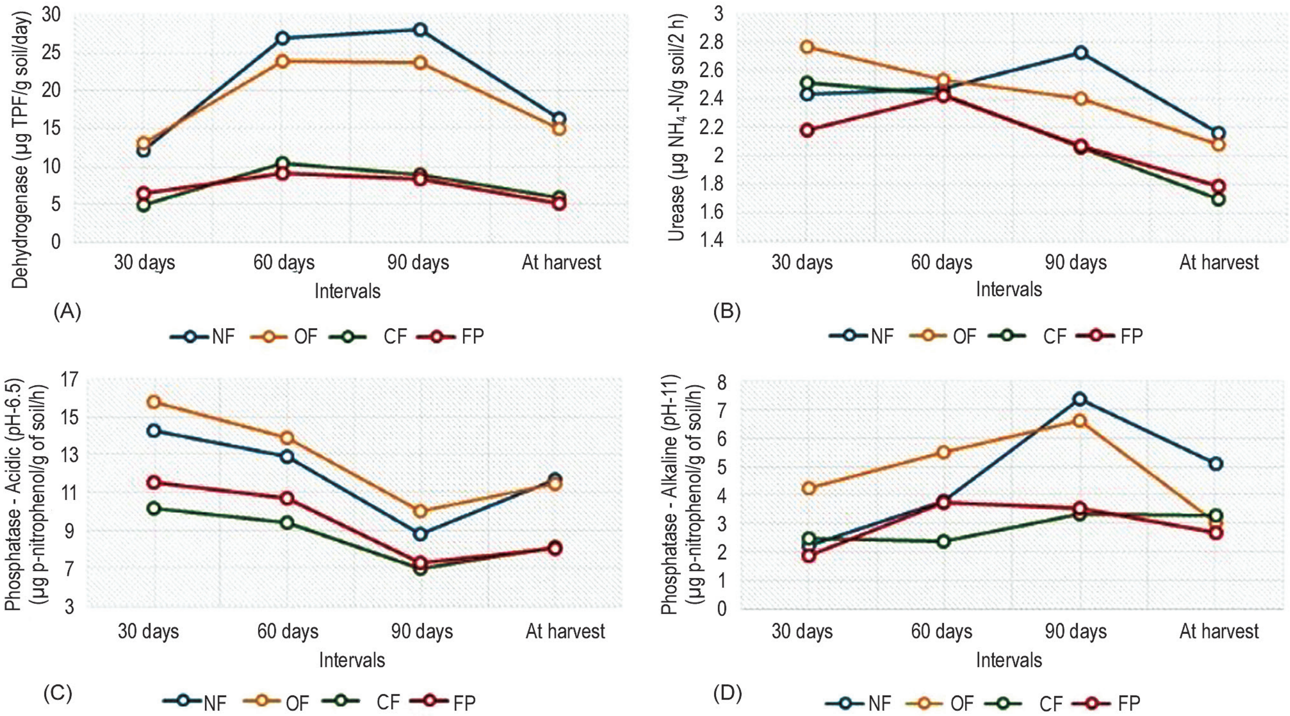

Fig. 4 Effect of different farming systems on activity of soil enzymes (A) Dehydrogenase, (B) Urease, (C) Acid Phosphatase and (D) Alkaline Phosphatase.
NF, Natural farming; OF, Organic farming; CF, Conventional farming; FP, Farmer practice.

Soil microbial activity: In pooled data of two years, the highest dehydrogenase activity was recorded in the OF (13.10 µg TPF/g soil/day) followed by the NF treatment (12.11 µg TPF/g soil/day) at 30 days, whereas at 60 days, 90 days and at harvest, maximum activity was in the NF (27.00, 28.11 and 16.27 µg TPF/g soil/day, respectively) which was on par with the OF (23.82, 23.77 and 14.96 µg TPF/g soil/day, respectively) treatment, and the lowest activity had been seen in the FP treatment in both years (Fig. 4A).

The maximum urease activity was recorded in the OF treatment at 30 days (2.76 µg NH_4-N/g soil/2 h) and 60 days (2.53 µg NH_4–N/g soil/2 h). However, the activity had been significantly lower in the FP (23.18 and 2.42 µg NH_4-N/g soil/l2 h). At 90 days and harvest, activity was highest in the NF (2.72 and 2.16µg NH_4-N/g soil/l2 h, respectively) and lowest in the CF (2.06 and 1.69µg NH_4-N/g soil/l2 h) (Fig. 4B).

A relatively high acid phosphatase activity (15.77 and 13.86, µg p-nitrophenol/g of soil/h) and alkaline phosphatase (4.25 and 5.52 µg p-nitrophenol/g of soil/h) were detected at 30 and 60 days in the OF treatment. In contrast**,** the acid phosphatase activity was highest in OF (9.99 µg p-nitrophenol/g of soil/h) and alkaline phosphatase activity in NF (7.37µg p-nitrophenol/g of soil/h) at 90 days. At harvest, the acid and alkaline phosphatase activities were highest in the NF (11.64 and 5.12, µg p-nitrophenol/g of soil/h, respectively) (Fig. 4C and D).

Correlations between yield and nutrient uptake: A phenotypic correlation was computed between haulm and pod yield and nutrient uptake (Fig. 5A). In haulm yield and nutrient uptake, a significant positive association have been seen between N and K uptake (r=0.85) (Fig. 5A). Similarly, positive correlations have been also observed for N (r=0.53), P (r=0.04) and K (r=0.72) with haulm yield. Pod yield and nutrient uptake were significantly positively associated with P and K (r=0.89), N and K (r=0.81) and N and P (r=0.70) uptake. Similarly, positive correlations were observed for nitrogen (r=0.38), phosphorus (r=0.20) and potassium (r=0.27) with pod yield (Fig. 5B).

Efficiency of different farming systems: The NF was found to be efficient in terms of physiological, agro-physiological and economic use efficiency (Table 1). Compared with other systems, the OF system was efficient in terms of physiological and agro-physiological efficiency; however, it has less economic use efficiency. There was no significant difference in agro-physiological efficiency between OF and FP. However, the FP had the lowest physiological use efficiency.

The total bacterial, fungal and actinomycete contents were highest in OF and NF. Similarly, beneficial microbes such as N-fixers, P-solubilising bacteria, *P. fluorescens,* zinc-potash and silicon-solubilising microorganisms and *Trichoderma* were dominant in the OF and NF. Previous studies have shown increased microbial diversity across different crops following the application of organic materials and the avoidance of agrochemicals (Wang *et al.* 2016, Liao *et al.* 2018, Vibha *et al.* 2023). However, there is no direct correlation between the activity and abundance of soil microbial population and productivity, which was 20% lower in the organic farming systems (De Ponti *et al.* 2012, Seufert *et al.* 2012).

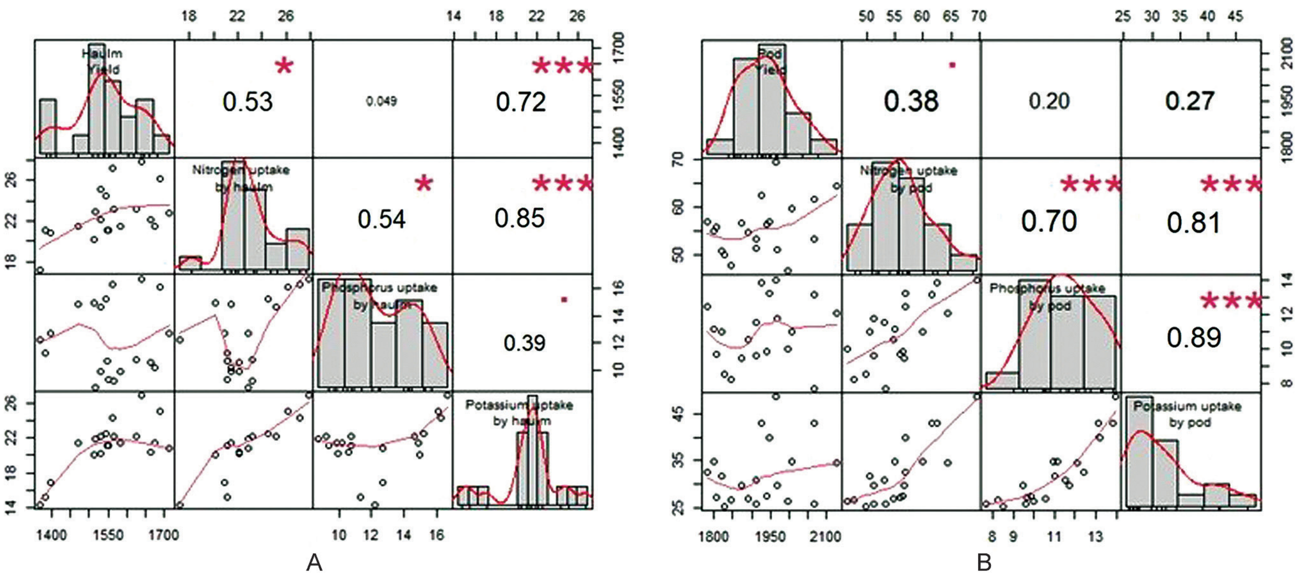

Fig. 5 Correlation matrix plot of nutrient uptake and yield. (A) Groundnut haulm yield and nutrient uptake; (B) Groundnut pod yield and nutrient uptake.

Table 1 Efficiency of different farming systems under study

Treatments	Agro-physiological use efficiency (kg/kg)	Physiological use efficiency (kg/kg)	Economic nutrient use efficiency (kg/₹)
NF	15.87	6.80	0.22
OF	5.07	5.82	0.06
CF	2.92	4.86	0.12
FP	7.06	4.24	0.17
SEM±	1.18	1.11	1.89
CD (p=0.05)	3.56	NS	NS

SEM±, Standard error of the mean; CD Critical difference at the 5% probability level. NF, Natural farming; OF, Organic farming; CF, Conventional farming; FP, Farmer practice; NS, Non-significant. NS indicates that differences among treatment means (farming systems) were not statistically significant at p = 0.05 based on two-way ANOVA.

In the present study, the physiological and agro-physiological efficiency was highest in NF, followed by OF. Soil organic matter (SOM) is responsible for maintaining proper aggregation and enhancing the soil's ability to retain water, as well as its exchangeable potassium, calcium and magnesium. The NF and OF systems provide SOM to the soil and reports the effects of SOM on physical properties, nutrient dynamics and nutrient use efficiency (Baligar *et al.* 2001). SOM is a good source of mineralisable phosphorus, nitrogen, sulphur and other nutrients (Baldock and Broos 2011) and the incorporation of OM into the soil via NF and OF improves the efficiency of systems in supplying nutrients over time.

The growth and yield of groundnut were higher under conventional farming; however, improved soil physicochemical and microbial properties were observed in OF and NF. The addition of organic matter such as crop residues, livestock manures and livestock-based formulations like *jeevamrutha*, *beejamrutha*, *ghanajeevamrutha* and composts to the soil through the practice of organic and natural farming has various benefits including micronutrient nutrition. These systems improve ion-exchange capacity and enhance soil structure, aeration, water-holding capacity and drainage. Additionally, they reduce soil salinity. These systems also stimulate beneficial microbial activity in the soil, thereby preventing various soil-borne diseases and facilitating the development of better roots and plants. Although the OF has the lowest economic efficiency at the beginning of the transition, practicing NF and OF over time will be beneficial.

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