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Improving Pea Growth and Nutrient Efficiency in Calcareous Soils through the Synergy of Organic Amendments and Chemical Fertilizers

Javed Anjum[1], Mustajab Ahmed Khan[1], Juma Khan Babar[2], Faheem Ahmed[2], Meraj Khan Domar[2], Muhammad Ejaz[2], Tariq Ziad[2], Syed Rehan Fareed[2*], Hidayatullah Kakar[2]

[1]*Department of Soil Science, Balochistan Agriculture College Quetta, Pakistan;*
[2]*Agriculture Research Institute (ARI), Sariab Quetta, Balochistan, Pakistan*

Abstract: Introduction Soil fertility in Pakistan is hindered by insufficient and unstable organic matter, leading to stagnation and a decline in overall agricultural productivity. **Methodology** A pot study was conducted in 2018-19 comprised of four treatments including T_1 = Recommended NPK fertilizer, T_2 = NPK+FYM, T_3 = NPK + Poultry manure, and T_4 = NPK + Plant residue based on Complete Randomized Design (CRD) and was replicated thrice. **Result** The results exhibited significant differences in peas' growth, yield, and nutrient use efficiency across the organic amendments. Among them, the higher plant height (70.63 cm), pod length (9.37 cm), and pod yield (158.63 g pot^{-1}) was observed in T_3 followed by T_2. Regarding nutrient concentration and uptake, both T2 and T3 treatments elevated leaf tissue levels of N (4.76% and 5.03%), P (1.01% and 0.98%), and K (2.27% and 2.31%). These values were statistically comparable, accompanied by higher but non-significant P uptake (0.61 and 0.67 g pot-1) and K uptake (1.13 and 1.21 g pot-1) for the respective treatments. Further, higher nitrogen, phosphorus, and potassium use efficiency (49.4, 5.20, and 42.0%) were recorded in T_3 followed by T_2. Together with that significantly positive correlation between soil properties and pod yield was found which reflects the nutrient-supplying power of soil under organic amendments. **Conclusion** Consequently, it is suggested that the joint utilization of organic additives of any source and chemical fertilizer is necessary for increasing yield and nutrient use efficiency over sole chemical fertilizer application in calcareous soils.

Keywords: chemical fertilizer, crop residues, manures, growth traits, nutrient uptake, peas

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***Correspondence:** Rehan Fareed, Agriculture Research Institute (ARI), Sariab Quetta, Balochistan, Pakistan, Tel: +923337840534. Email: syedrehan.hashmi@yahoo.com

Introduction

Peas (*Pisum sativum*) are an important leguminous crop consumed by both humans and animals as seeds [1]. In many countries including Afghanistan, Iran, India, and Pakistan field peas are grown and consumed as a vegetable. Like pulses, peas are enriched with minerals including elements like iron (Fe), calcium (Ca), magnesium (Mg), potassium (K), copper (Cu), manganese (Mn), molybdenum (Mo), selenium (Se), and zinc (Zn), along with a rich protein source. The consumption of peas also supplies thiamine, niacin, folate, and many more essential vitamins and antioxidants [2]. It has been grown the world over, China, India, and the United States are the largest peas-producing countries including Pakistan which ranked 9th [3]. In Pakistan, a total of 144,422 tons of peas were harvested from a cultivated area spanning 22,436 hectares with province-wise contributions including Punjab producing 112,267 tons of peas from 17,644 ha, Sindh 7368 tons from 1869 ha, KPK 1,250 tons from 1,852 ha and Balochistan producing 12,286 tons peas from 1,071 ha [4].

Field peas are an easy-to-grow and adaptable crop that can thrive in different soil types and environmental conditions [5, 6]. Peas in crop rotation helps improve soil fertility, which in turn benefits subsequent crops by increasing soil nitrogen levels [1]. However, nutrient availability is a major challenge in agriculture production in Pakistan, particularly for small-scale farmers with limited resources. Other challenges include limited access to improved crop varieties and a lack of modern farming practices to sustain soil fertility. To maintain optimal and sustainable crop productivity, replenishing the soil with balanced nutrients is crucial. Management tools, such as BMPs (Best Management Practices), RCTs (Resource Conservation Technologies), and the use of transformed waste products like compost, bio fertilizers, and other practices that improve input use efficiency, are used to restore soil health and fertility and impact crop growth and yield [7-9].
Low soil fertility has a significant impact on sustainable and improved agriculture production [10]. The use of fertilizers, which supply plants with essential nutrients like nitrogen, phosphorus, and potassium, is key to maintaining sustainable food production. However, the improper and excessive use of fertilizers can lead to environmental problems like water contamination in lakes, rivers, and groundwater [11]. Additionally, low soil organic matter content can decrease the effectiveness of added fertilizer and the high cost of fertilizers is becoming a barrier to agriculture production. Waste from agriculture, food processing, municipal, and other industries can be used as organic amendments to increase soil carbon [12]. These wastes can be converted into compost, which contains beneficial microbes and nutrients, and used as a safe organic fertilizer. Biofertilizers, made up of beneficial microbes, can also be used as an environmentally friendly and cost-effective alternative to traditional fertilizers [13]. It is important to establish a practical relationship between the environment and fertilizers while conducting research on fertilizers and plant essential nutrients [12].
Enhancing soil fertility can be achieved by introducing synthetic fertilizers that contain vital plant nutrients like nitrogen, phosphorus, and potassium. These nutrients are essential for promoting plant growth productivity [14]. Apart from synthetic fertilizers, utilizing organic carbon from agricultural waste can also improve nutrient use efficiency. Optimal outcomes are attained by combining organic and inorganic fertilizers in an integrated approach, leading to enhanced soil health and increased crop productivity. [15]. The use of poultry manure in agriculture has gained significance as it not only provides nutrients, but also enhances soil health by creating a balanced ecosystem with organisms, plants, animals, and humans [11]. The soil type, land use, and local climate conditions determine the best type of fertilizer to be used for a specific crop [14]. Research has shown that farmyard manure is effective as an organic fertilizer and promotes sustainable crop growth [16]. The current research was carried out to assess how different organic amendments, when combined with inorganic fertilizers, impact on soil characteristics, the efficiency of nutrient utilization, and the yield of peas in calcareous soil.

Materials and Materials

Description of Experimental

A pot study was conducted during 2018-2019 in the shed house of the Department of Soil Science, Balochistan Agriculture College Quetta. The experiment comprised four treatments including T_1 = Recommended NPK fertilizer, T_2 = NPK+FYM, T_3 = NPK + Poultry manure, and T_4 = NPK + Plant residue based on a Complete Randomized Design (CRD) and was replicated thrice. The pots having 20 kg capacity were used in this study. The soil utilized in the experiment was obtained from the agricultural field of Balochistan Agriculture College Quetta, sieved, and then weighted as 20 kg per pot. The organic sources like poultry manure, farmyard manure, and crop residues were arranged locally and their required quantity was calculated for 20 kg soil. The recommended fertilizer and organic amendments as per treatments were mixed in the soil before filling the pot.

Soil Sampling and Preparation

Soil sampling was done to determine soil physicochemical properties and nutrient status before the application of different treatments. For this purpose, a composite soil sample from the experimental site was obtained using a soil auger, carefully packaged, identified, and transported to the soil science laboratory at Balochistan Agriculture College, Quetta. In the laboratory, the soil samples were air-dried, pulverized using a mortar and pestle before passing through 2 mm sieve. After completion of the experiment, soil from each replicated treatment was collected, air-dried, ground, labelled, sieved, and then stored for target analysis.

Soil Analysis

The soil was divided into its constituent components of sand, silt, and clay content, following the particle size analysis procedure outlined by Bouyoucos [17]. The soil was dispersed by adding 10% sodium hexa-meta-phosphate and allowing it to sit for 8-10 hours. The suspension was then transferred into a 1000 ml cylinder, thoroughly mixed, and the measurement for silt and clay content was taken after four minutes. The clay reading was recorded after 2 hours. Each time, adjustments were made to account for a temperature of 68°F, and the percentages of sand, silt, and clay were subsequently calculated [18] based on these measurements, the textural category was determined by employing the textural triangle.

To assess pH and electrical conductivity, a soil-water mixture with 1:2 ratio was created. The solution was then filtered through Whatman filter paper No.42 [19, 20]. The transparent extracts were analysed using an electrical conductivity meter (Model HI 8033), which had been previously calibrated with 0.01 N KCl at 25°C, following the specifications outlined by Richards, with a standard reading of electrical conductivity at 1.413 dS m-1 before sample measurements. [21] and Estefan [18]. The pH meter, equipped with a glass electrode (Model WTW pH 720), was calibrated using pH 7.0 and 9.2 buffer solutions, and the measurements were recorded.

To determine organic matter content, 1.0 gram of soil was mixed with 10 ml of 1.0 N potassium dichromate and 20 ml of concentrated sulphuric acid in a 500 ml conical flask. An identical process without soil, serving as a control was also prepared. The flasks were gently swirled and left undisturbed for 30 minutes [22]. The mixture in the flask was thinned by adding 200 ml of distilled water, along with 10 ml of orthophosphoric acid, 0.2 grams of sodium fluoride, and 20 drops of diphenylamine. The flask's contents were subsequently subjected to a reverse titration using 0.5N ferrous ammonium sulphate. Initially, the colour transitioned from a murky green to blue, and eventually settled at a vibrant green hue.

The assessment of total nitrogen in the soil was conducted using the Jones method [23]. One gram of soil, previously dried in an oven, was combined with a 5-gram catalyst mixture consisting of potassium sulphate, copper sulphate, and selenium in a ratio of 10:1:0.1. Additionally, a few pumice stones were introduced into a digestion tube containing 15 ml of sulfuric acid. The contents within the tubes were gently swirled and allowed to sit overnight. The following day, the tube contents were digested until they became clear. Throughout the digestion process, the temperature was gradually increased to reach 370°C and maintained for approximately 1 hour. Following digestion, approximately 15-20 ml of distilled water were added, and the contents were distilled after incorporating 50 ml of 40% sodium hydroxide into the digested material. A receiving flask was prepared, containing 1 ml of Toshiro indicator and 1 ml of distilled water, and placed below the distillation unit's condenser in such a way that the delivery pipe's tip was submerged in the flask. The distillation process lasted for 4 minutes. About 150 ml of the distillate was titrated against a standard hydrochloric acid solution.

Phosphorus and potassium, available in the soil, were extracted using the Ammonium bicarbonate-diethylenetriaminepentaacetic acid (AB-DTPA) method, following the procedures outlined in Soltanpour and Schwab [24]. The soil and AB-DTPA were mixed in a 1:2 ratio, agitated for 30 minutes on an orbital shaking machine operating at 180 rpm, and subsequently filtered through Whatman filter paper No. 42. These filtrates were then utilized to quantify the levels of phosphorus and potassium. Phosphorus in the samples was measured using spectrophotometry, following the guidelines specified in Olsen et al. [25]. Concurrently, the quantity of potassium (K) in the extracts was measured using emission spectroscopy [26].

Leaf and Grain Tissue Nutrient Concentration

For the determination of the N, P, and K contents in the leaf and grain tissue of peas, 0.5g of dry plant material was weighed and put in a 100-mL digestion tube. Then, 3-4 boiling granules and 5 mL of concentrated H_2SO_4 were added and mixed well, left overnight. The tubes were then heated on a block digester at a moderate temperature of 100-150°C. After cooling, 2 mL of 30% H_2O_2 was added and heated for 10 minutes at a high temperature of 280°C. This process was repeated until the white colour fumes stopped and the solution became clear. Distilled water was added, and the solution was filtered and made to the mark in 100 mL volumetric flasks. The clear filtrate was used to determine the total nitrogen, phosphorus, and potassium using standard procedures [27].

In the clear digest, total nitrogen was determined in two steps i.e. distillation and titration as described for soil N [23, 28]. Before starting distillation, heat up the steam generator and steam the distillation apparatus for at least 5 minutes to eliminate any leftover impurities. Use a grade 'A' pipette to transfer 10 ml of the digest into the still (Markham) and then wash it with 10 ml distilled water into the reaction chamber. Add 10 ml of NaOH and again wash with distilled water into the reaction chamber. Pour 20 ml of 1% H_3BO_3 solution into a series of 250 ml conical flasks and connect one of them to the distillation limb, close the steam exit, and distil the released ammonia for 4 minutes. Remove the flask, wash the distillation limb with distilled water, open the steam exit, and remove the heat source from the steam generator. The distilled sample should drain to waste. Flush the reaction chamber with distilled water, and repeat the procedure for the next sample. Titrate the distillate with 0.02M $KH(IO_3)_2$ and a few drops of the mixed indicator until the green solution turns blue/purple. Calculate the concentration by distilling a blank sample (B) in a similar manner and subtracting it from the sample's (T) value, then use the following formula for the N concentration in any sample.

$$\%N=(T-B) \times 0.280134 \times 50/10 \times 100/\text{sample weight in mg}$$

For the determination of P contents in the clear digest, first mix reagent was prepared by dissolving 22.5 g of Ammonium Heptamolybdate in 400 ml of distilled water separately, and 1.25 g of Ammonium Vanadate in 300 ml distilled water distillate and mixing both solutions in 1L volumetric flasks, added 250 concentrated HNO_3 and make the volume up to the mark. The working standards containing 2.5, 5.0, 7.5, 10.0, and 12.5 mg kg^{-1} P was prepared from P stock solution. In 25 ml test tubes, added 1 ml of each of the samples, standards, and blank, was added 2.5 ml Molybdovanadate Ammonium reagent and 2.5 ml distilled water. Kept them for 30 minutes to develop color and stirred intermittently on the vortex mixture and then run the working standards with blanks followed by the samples on a spectrophotometer at 410 nm wavelength [18, 29]. Meanwhile, the concentration of potassium (K) in the digested samples was directly assessed using flame photometry with emission spectroscopy [26].

Statistical Analysis and Interpretation of the Data

The data gathered from the pot experiment, conducted using a completely randomized design (CRD), was subjected to variance analysis [30] using the software Statistics 8.1 [31]. The parameters with statistical significance were subsequently subjected to a comparison of means through the LSD test at a significance level of $p<0.05$.

Results

Physicochemical properties of the soil before the experiment

The soil used in the experiment revealed that the three soil fractions were comprised of 57.4% sand, 15.9% silt, and 26.7% clay which constituted the textural class of sandy clay loam. The chemical properties indicated that the soil was alkaline (8.12), and non-saline (1.35 dSm^{-1}) with a low level of organic matter contents (0.57%). The nutrient status of soil exhibited a low level of total nitrogen (0.028%) and AB-TDTPA extractable phosphorus (2.17 mg kg^{-1}). However, the AB-DTPA extractable potassium was found in the medium range (96.5 mg kg^{-1}).

Peas' growth traits and yield

Peas growth parameters such as plant height, number of pods $plant^{-1}$ and pod length manifested highly significant differences across treatments. Overall plant height ranged from 63.20 to 72.3 cm with mean of 68.08 cm, the number of pods pot^{-1} from 11.0 to 23.0 with a mean of 17.25 and pod length from 7.10 to 9.70 cm with a mean of 8.58 cm (Table 1). The LSD test for mean comparison ($p<0.05$) revealed comparatively greater plant height (70.63 cm) in T_3 when poultry manure along with recommended nitrogen-phosphorus-potassium (NPK) fertilizer was added as compared to other organic amendments as well as to the sole application of NPK fertilizer. Statistically, the application of farmyard manure and crop residue integrated with NPK fertilizer resulted in non-significant variation in plant height. While the number of pods pot^{-1} was statistically found at par across all organic amendments with higher over sole NPK fertilizer. However, a higher pod length (9.37 cm) was recorded in the treatment where poultry manure+NPK fertilizer was applied followed by 8.77 cm where farmyard manure+NPK fertilizer were used. These results indicate that without the integration of organic amendments, the sole application of NPK fertilizer is less effective in terms of peas' growth and yield contributing factors (Table 2).

Analysis of variance for green pods, straw and grain yield showed significant changes across organic amendments integrated with NPK fertilizer. Overall pod yield was ranged from 115.86 to 168.38 g pot^{-1} with mean of 141.15 g pot^{-1}, straw yield from 20.40 to 30.10 g pot^{-1} with mean of 25.47 g pot^{-1} and grain yield from 30.20 to 48.50 g pot^{-1} respectively (Table 1). The LSD test for mean comparison ($p<0.05$) noted higher but non-significant pod yield of 158.63 and 143.10 g pot^{-1} in poultry and crop residue amended pots closely followed by 141.13 g pot^{-1} in farmyard manure amendment while NPK fertilizer application without organic amendment produced lower pod yield. In case of straw yield, poultry manure+NPK fertilizer recorded maximum straw yield (28.93 g pot^{-1}) and other two organic amendment exhibited at par differences in straw yield but higher over sole NPK fertilizer application which produced lowest straw yield of 21.77 g pot^{-1}. However, all organic amendments produced higher but statistically at par grain yield which were significant over sole NPK fertilizer application (Table 2). As our soil is deficient in organic matter, such amendments in soil increased efficiency of NPK fertilizer.

Leaf Tissue Nutrient Concentration (n, p AND K%)

Statistically, the leaf tissue N concentration of peas varied significantly across organic amendments but P and K concentration were found non-significant. Overall leaf tissue N concentration ranged from 4.0 to 5.3% with mean of 4.64%, P from 0.93 to 1.03% with mean of 0.98% and K was from 2.11 to 2.35% with mean of 2.25% (Table 1). The LSD test for mean comparison ($p<0.05$) revealed that the application of ppoultry and farmyard manure integrated with NPK fertilizer recorded higher but non-significant leaf tissue N concentration (4.76 and 5.03%) followed by crop residues and lower N concentration was noted in sole NPK fertilizer application. Whereas, in case of leaf tissue P concentration, poultry manure application produced higher P concentration (1.01%) and other two organic amendments expressed statistically at par differences. But leaf tissue K concentration was maximum in farmyard manure+NPK fertilizer and other two amendments resulted in statistically at par leaf tissue K concentration (Table 2). As our soil is deficient in organic matter, such amendments in soil increased efficiency of NPK fertilizer. Poultry manure contains higher N level as compared to farmyard manure and crop residue but farmyard manure possesses higher K level that might be resulted in enhancement of leaf K accumulation.

Grain Tissue Nutrient Concentration (N, P and K %)

Analysis of variance for grain tissue N, P and K concentration exhibited statistically non-significant differences across organic amendments with and without NPK fertilizer. Overall grain tissue N concentration ranged from 1.54 to 2.62% with mean of 2.07%, P from 0.73 to 0.95% with mean of 0.85% and K was from 1.08 to 1.38% with mean of 1.24% respectively (Table 1). The LSD test for mean comparison ($p<0.05$) of grain tissue N, P and K concentration showed statistically at par differences against organic amendments with and without NPK fertilizer (Table 1). Poultry manure integrated with NPK fertilizer revealed higher but non-significant grain tissue N and P concentration (2.23, 0.86 %) and higher non-significant grain K concentration (1.27%) was obtained in the application of farmyard manure + NPK fertilizer. However, the lowest non-significant grain N,P and K concentration were noted in sole NPK fertilizer application.

Nutrient Uptake (G POT^{-1})

Analysis of variance for nutrient uptake (N, P and K) displayed statistically significant differences across organic amendments integrated with NPK fertilizer (Table 1). Overall N uptake ranged from 1.28 to 2.87 g pot^{-1} with mean of 2.03 g pot^{-1}, P from 0.41 to 0.73 g pot^{-1} with mean of 0.59 g pot^{-1} and K was from 0.76 to 1.35 g pot^{-1} with mean of 1.07 g pot^{-1} (Table 1). The LSD test for mean comparison ($p<0.05$) of nutrient uptake presented statistically significant differences against organic amendments with NPK fertilizer (Table 2). Maximum N uptake (2.46 g pot^{-1}) was observed in the treatment where poultry manure + NPK fertilizer was applied followed by farmyard manure and crop residue which were at par from one another while, lower N uptake (1.54 g pot^{-1}) was recoded in treatment where sole NPK fertilizer was applied. In case of P and K uptake, both farmyard and poultry manure along with NPK fertilizer application produced higher but statistically non-significant P uptake (0.61 and 0.67 g pot^{-1}) and K uptake (1.13 and 1.21 g pot^{-1}) while sole NPK fertilizer application expressed lower P and K uptake. However, the application of crop residue + NPK fertilizer also enhanced P and K uptake over sole NPK fertilizer application. These results demonstrate that under calcareous soil the combine application of organic amendments and chemical fertilizer increased nutrient availability in term of enhancement of N, P and K uptake.

Table 1. Overall mean, minimum, maximum and F-value of the studied parameters of peas under influence of different organic amendments integrated with NPK fertilizer

Parameters	Overall mean	Minimum	Maximum	F-value
Peas growth traits				
Plant height (cm)	68.08	63.20	72.30	4.00*
Number of pods pot^{-1}	17.25	11.0	23.00	6.35*
Pod length (cm)	8.58	7.10	9.70	12.4**
Pod yield (g pot^{-1})	141.15	115.86	168.38	5.77*
Straw yield (g pot^{-1})	25.47	20.40	30.10	13.8**
Grain yield (g pot^{-1})	39.67	30.20	48.50	6.28*
Leaf tissue nutrient concentration (%)				
Nitrogen (N)	4.64	4.0	5.30	5.69*
Phosphorus (P)	0.98	0.93	1.03	2.71^{NS}
Potassium (K)	2.25	2.11	2.35	2.80^{NS}

Grain tissue nutrient concentration (%)				
N	2.07	1.54	2.62	0.55^{NS}
P	0.85	0.73	0.95	0.69^{NS}
K	1.24	1.08	1.38	0.18^{NS}
Nutrient uptake (g pot^{-1})				
N	2.03	1.28	2.87	3.71^{*}
P	0.59	0.41	0.73	4.53^{*}
K	1.07	0.76	1.35	3.80^{*}
Post soil properties after completion of production of cycle of peas				
Organic matter (%)	0.69	0.53	0.80	32.3^{**}
pH	8.03	7.95	8.11	91.2^{**}
$EC_{1:2}$ (dSm^{-1})	1.56	1.42	1.85	16.1^{**}
Total nitrogen	0.03	0.03	0.04	40.7^{**}
AB-DTPA extractable P	3.53	3.05	3.96	24.3^{**}
AB-DTPA extractable K	118.97	98.20	130.50	7.39^{*}

Table 2. Effect of different organic amendments integrated with NPK fertilizer on soil peas growth, leaf and grain tissue nutrient concentration, and uptake of peas

Parameters	Organic amendments integrated with NPK fertilizer				S.E. ±	LSD (p<0.05)
	NPK	NPK+ FYM	NPK + PM	NPK + CR		
Peas growth traits						
Plant height (cm)	65.50 b	68.23 ab	70.63 a	67.97 ab	1.484	3.422
Number of pods pot^{-1}	12.67 b	17.33 a	20.67 a	18.33 a	1.886	4.348
Pod length (cm)	7.56 c	8.77 ab	9.37 a	8.63 b	0.301	0.694
Pod yield (g pot^{-1})	121.70b	141.13ab	158.63 a	143.10 a	8.916	20.560
Straw yield (g pot^{-1})	21.77 c	25.83 b	28.93 a	25.33 b	1.119	2.581
Grain yield (g pot^{-1})	32.73 b	41.83 a	44.00 a	40.10 a	2.759	6.326
Leaf tissue nutrient concentration (%)						
Nitrogen (N)	4.20 b	4.76 a	5.03 a	4.57 ab	0.208	0.480
Phosphorus (P)	0.95 b	0.98 ab	1.01 a	0.96 ab	0.021	0.049
Potassium (K)	2.19 b	2.31 a	2.27 ab	2.24 ab	0.042	0.096
Grain tissue nutrient concentration (%)						
N	1.87 a	2.13 a	2.23 a	2.07 a	0.309	0.713
P	0.81 a	0.84 a	0.86 a	0.83 a	0.069	0.161
K	1.12 a	1.27 a	1.26 a	1.24 a	0.090	0.208
Nutrient uptake (g pot^{-1})						
N	1.54 b	2.14 ab	2.46 a	1.98 ab	0.282	0.649
P	0.47 b	0.61 a	0.67 a	0.58 ab	0.056	0.128
K	0.88 b	1.13 a	1.21 a	1.06 ab	0.103	0.238

In each row, means followed by a common letter are not significantly different at 5% probability level

Nutrient use efficiency (%)

The results revealed that all organic amendments increased nutrient use efficiency but with different extent and magnitude (Figure 1). Among them, poultry manure+NPK fertilizer recorded higher NUE (49.4%), PUE (5.2%) and KUE (42.0%) followed by farmyard manure+NPK fertilizer. However, the incorporation of crop residue+NPK fertilizer resulted in comparatively low NUE (23.9%). In Crop residue + NPK fertilizer also contributed in the enhancement of PUE (3.0%) but to lesser extent. This demonstrates that the application of poultry manure as organic amendment increase both NUE and PUE that might be due to higher contents of N and P in poultry manure along with other acidic compound that helped in changing soil chemical properties like pH. The organic amendment of farmyard manure and crop residue integrated with NPK fertilizer showed closely related NUE and KUE but poultry manure + NPK fertilizer expressed different NUE and KUE.

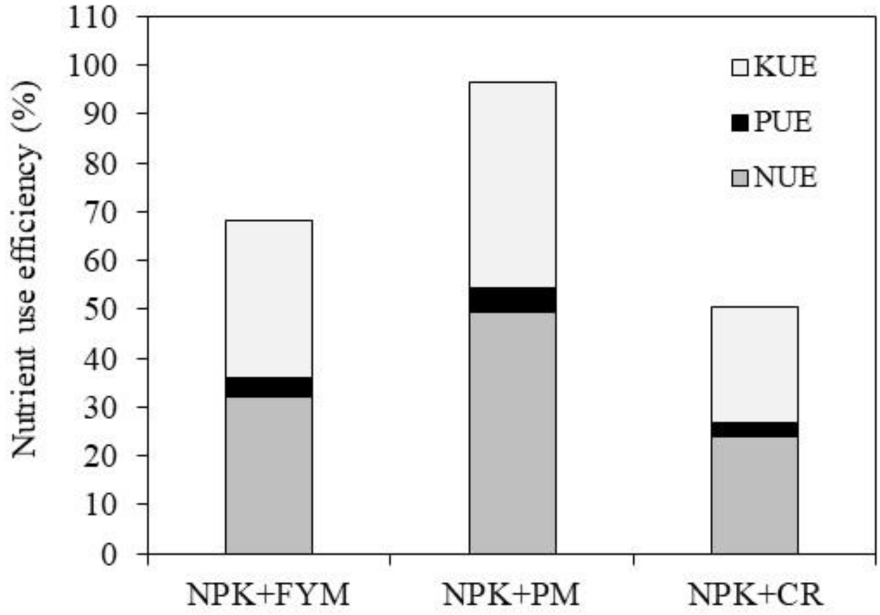

Figure 1. Effect of different organic amendments integrated with NPK on nutrient use efficiency (%) of peas

Post- Soil Physicochemical Properties

The analysis of variance for various soil parameters, including soil organic matter (OM), pH, electrical conductivity (EC), total nitrogen (TN), and the concentrations of available phosphorus (P) and potassium (K), influenced by different organic amendments in combination with NPK fertilizer, revealed highly significant variations as indicated in Table 1. The range for soil organic matter was observed to be between 0.53% and 0.83%, with an average of 0.69%. pH values ranged from 7.95 to 8.11, with a mean of 8.03. Electrical conductivity (EC) varied from 1.42 to 1.85 dSm^{-1}, with an average of 1.56 dSm^{-1}. Total nitrogen (TN) showed variations between 0.03% and 0.04%, with an average of 0.03%. The AB-DTPA extractable phosphorus (P) ranged from 3.05 to 3.96 mg kg^{-1}, with an average of 3.53 mg kg^{-1}, while AB-DTPA extractable potassium (K) ranged from 98.20 to 130.50 mg kg^{-1}, with an average of 118.97 mg kg^{-1} (Table 1).

The post-soil properties revealed significant variations ($p<0.05$) as affected by organic amendments combined with chemical fertilizer. The integrated use of PM and chemical fertilizer expressed the highest soil OM contents (0.76%) in comparison to sole NPK fertilizer. But all the sources of organic amendments enhanced soil OM non-significantly demonstrating that the addition of whatever source of organic source augment soil OM (Figure 2a). Soil pH was also significantly affected by the application organic amendments and poultry manure helped in reduction of pH (7.97) but increase EC significantly (1.74 dSm^{-1}) as compare to other organic amendments (Figure 2b &c). In case of total nitrogen (Figure 2d) and AB-DTPA extractable K, all organic amendments integrated with NPK fertilizer enhanced soil total N and K contents

(Figure 2f) which were statistically at par from one another but high significantly differed over sole NPK fertilizer application. However, higher AB-DTPA extractable soil phosphorus (3.85 mg kg^{-1}) (Figure 2e) was noted in treatment where poultry manure + NPK fertilizer was applied and comparatively lower P contents (3.10 mg kg^{-1}) was observed in pot where sole NPK fertilizer was used. But the application of farmyard manure and crop residue integrated with NPK fertilizer resulted in statistically similar soil P contents. These post soil N, P and K status demonstrates that organic amendments irrespective of source and origin improved nutrient availability under calcareous soil.

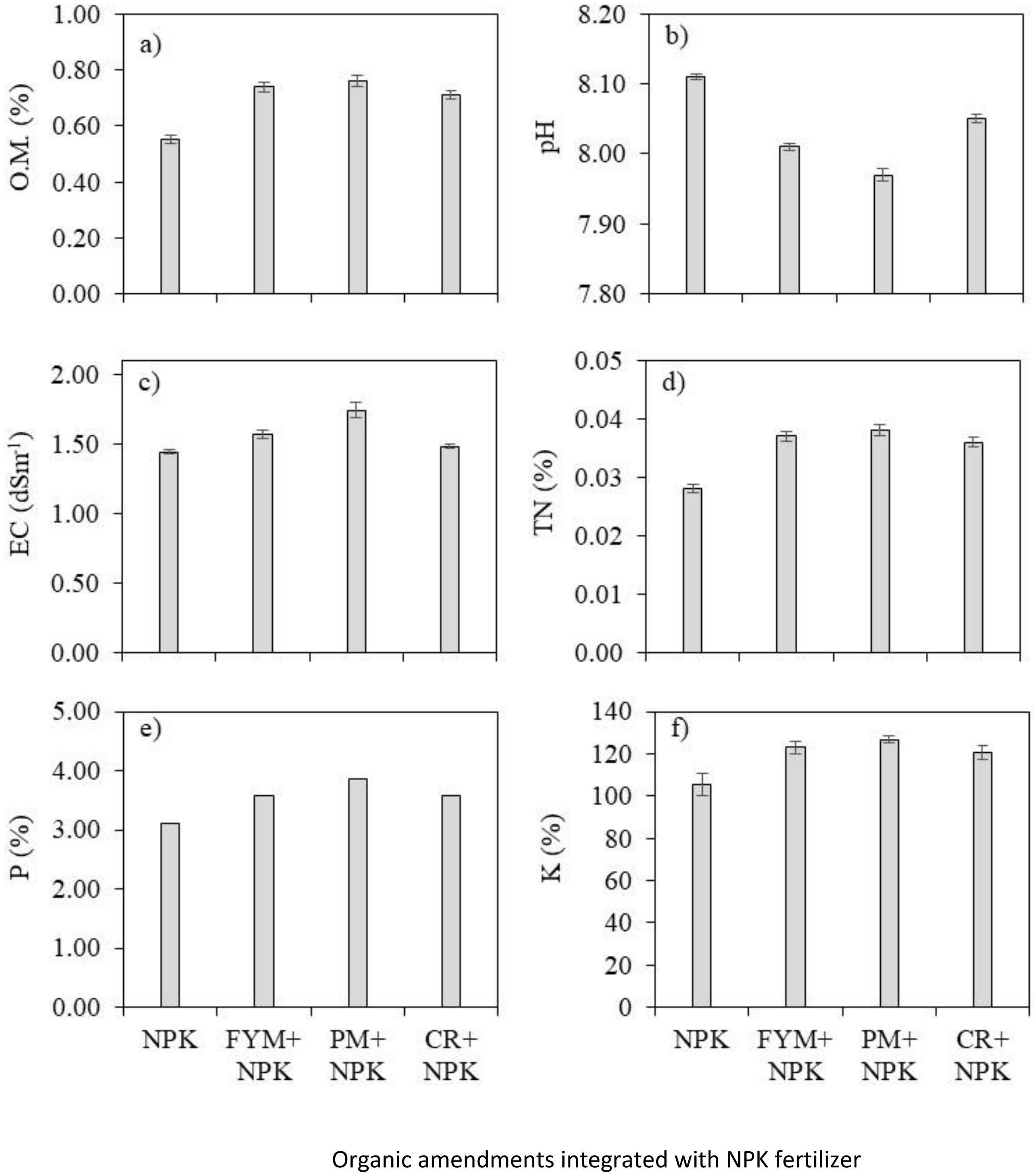

Figure 2. Effect of different organic amendments integrated with NPK fertilizer on soil organic matter (a), pH (b), EC (c), TN (d), available P (e), and K (f) after peas growth. The error bar represents the standard error of the mean

Pearson correlation

The correlation among various studied parameters as shown in Table 3 were found significant and positive except soil pH which expressed significant but negative relationship with other parameters. Among them, soil organic matter revealed positive and highly significant association with soil EC (R^2 = 0.75), soil total N (R^2 = 1), soil P (R^2 = 0.96), soil K (R^2 = 0.95), leaf N (R^2 = 0.89), leaf P (R^2 = 0.75), leaf K (R^2 = 0.77) and pod yield (R^2 = 0.88) but significantly and negatively correlated with soil pH (R^2 = -0.86). The nutrient supplying capacity of soil to pea crop under organic amendments manifested that leaf N concentration was positively and significantly correlated with soil N concentration (R^2 = 0.89), leaf P with soil P (R^2 = 0.813) and leaf K with soil K (R^2 = 0.85). Likewise, the relationship between pod yield of pea and soil properties was found positive and significant as indicated that pod yield with soil organic matter (R^2 = 0.88), EC (R^2 = 0.86), soil total N (R^2 = 0.88), soil P (R^2 = 0.94) and soil K (R^2 = 0.90). Such a relationship evidenced the important role of soil organic amendments that increased the nutrient availability in soil and resulted in higher pod yield. Above all, soil pH showed a negative relationship but significant with all studied parameters which means that the addition of organic amendments like farmyard manure, poultry and crop residue affected soil pH leading to increased plant nutrient accumulation and ultimately increased crop yield.

Table 3. Pearson correlation among soil properties, leaf nutrient concentration and pod yield of pea under the influence of various organic amendments integrated with NPK fertilizer

	OM	**pH**	**EC**	**Soil total N**	**Soil P**	**Soil K**	**Leaf N Conc.**	**Leaf P Conc.**	**Leaf K conc.**	**Pod yield pot^{-1}**
OM	1									
pH	-0.86	1								
EC	0.75	-0.82	1							
Soil total N	1.00	-0.86	0.75	1						
Soil P	0.96	-0.87	0.85	0.96	1					
Soil K	0.95	-0.77	0.75	0.95	0.935	1				
Leaf N Conc.	0.89	-0.77	0.89	0.89	0.928	0.92	1			
Leaf P Conc.	0.75	-0.65	0.87	0.75	0.813	0.84	0.954	1		
Leaf K conc.	0.77	-0.55	0.59	0.77	0.688	0.85	0.838	0.82	1	
Pod yield pot^{-1}	0.88	-0.74	0.86	0.88	0.942	0.90	0.960	0.92	0.73	1

Discussion

Poor soil fertility is a common issue in Balochistan province and in Pakistan as a whole, which contributes to low crop production compared to other countries. The low soil organic matter and the alkaline nature of the soil reduce nutrient availability. A significant number of farmers in Pakistan depend on chemical fertilizers and abstain from utilizing organic sources, primarily due to low levels of literacy and insufficient awareness. However, the addition of organic amendments improves the soil physical, chemical, and biological properties, leading to improved soil health and an increase in soil organic carbon [32].

As this study results evidenced that the application of three amendments viz. FYM, PM and CR increased plant height by 4.17, 7.83 and 3.77%; pods plant^{-1} by 36.78, 63.14 and 44.67% and pod length by 16.01, 23.14 and 14.15% over sole NPK fertilizer. Similarly, Metha *et al.* [33] found better peas' growth when added farmyard manure (20 t ha^{-1}) along with chemical fertilizer (40-80-40 NPK kg ha^{-1}). Further, application of organic sources significantly affected yield contributing factors particularly the pods plant^{-1} and pod length that might be due to improvement in overall soil properties. Fatahi *et al.*, [34] also observed changes in soil properties leading to an increase in peas growth and production under influence of organic sources including compost, vermicompost, and dry leaf powder. Likewise, pod and grain yield pot^{-1} were obtained on all three organic amendments statistically the same but higher over sole NPK fertilizer application. Such yield improvement might be due to nutrient availability which is demonstrated by higher leaf tissue N, P, and K concentrations. These results are in line with the findings of Adekiya and Agbede [35] that the integrated application of poultry manure and chemical fertilizer significantly augmented the yield of tomatoes in comparison to the single application of chemical fertilizer or manure. According to Husson [36] that organic amendments supply organic acids which help in reducing soil pH locally, and increase soil carbon and biological activities that resulted in the availability of nutrients.

The influence of organic amendments on peas leaf tissue N, P, and K concentration showed no significant differences among the treatments, but farmyard and poultry manure showed slightly higher values compared to crop residues and NPK fertilizer alone. Similar results were reported by Ewulo *et al.* [15] who recorded higher level of nutrients in the leaf tissue of tomato crop when well supplied with poultry manure over control treatment. The process of mineralization of added manure not only supplies essential nutrients to the plants, but also enhances the overall soil properties [37, 38]. In case of nutrient uptake, the application of poultry manure integrated with NPK fertilizers manifested increased uptake of N (2.46 g pot^{-1}), P (0.67 g ha^{-1} and K uptake (1.21 g pot^{-1}) immediately followed by farmyard manure (2.14, 0.61 and 1.13 g pot^{-1}). The combined effect of organic and inorganic fertilizer is due to improved soil properties, as soil analysis showed increased organic matter and improved nutrient availability, particularly phosphorus, in soils amended with farmyard and poultry manure. These results are in line with those reported by Dorado *et al.* [39]. Another group of researchers found that residual soil P is increased under integrated nutrient management using both organic and chemical fertilizers [40]. The existence of soil carbon is crucial for sustainable agriculture and contributes to environmental stability. The use of organic sources benefits the entire system, not just the single crop [41].

The integration of poultry manure and chemical fertilizer (NPK) resulted in a 49.4%, 5.2% and 42.0% increase in N, P, and K use efficiency and improved the overall growth and yield of peas. According to Rahman [42], poultry manure has a slower biodegradation and mineralization compared to other organic amendments, but its sustainable nature improves soil structure and promotes plant growth. Poultry manure also has higher concentrations of nutrients, particularly N, P, and K, compared to other organic sources. Other scientists also observed similar effects of poultry manure on soil properties and plant growth [43]. The uptake of P was enhanced when organic and inorganic fertilizer (P) was integrated in comparison to the control and the other agronomic and physiological efficiency of P were also increased. Whereas, the sole application of inorganic P fertilizer (DAP) revealed low P recovery (%) as compared to the P recovery from poultry manure [44].

The study found a positive and significant relationship between soil nutrients and pea growth. Leaf tissue N, P, and K concentrations were found to be positively associated with soil N, P, and K concentrations, respectively. Similarly, pod yield was positively associated with soil organic matter, EC, soil total N, P, and K. These results indicate that soil organic amendments play an important role in increasing nutrient availability and improving pod yield. Dean *et al*. [45] also noted a relationship between soil carbon and soil N concentration ($r = 0.98$), while soil carbon also expressed a positive association with carbohydrate concentration in soil ($r = 0.96$). The availability of nutrients is mostly limited by low soil carbon content. The addition of different sources of organic agents replenishes carbon for soil microbiota that ultimately improve soil health and plant growth [46, 47]. The integration of organic sources with chemical fertilizer has now become an approved intervention and ensures food security and safety while the traditional production system contains much inefficiency and is not sustainable [48, 49]. The findings of this study demonstrate that organic amendments despite its type have improved soil properties and growth and yield of peas. When they were integrated with NPK fertilizer resulted in increased N, P and K use efficiency of pea crop.

Conclusion

From this study it is inferred that all organic amendments helped in enhancement of nutrient availability by increasing soil organic matter, affecting chemical properties like pH leading to increased leaf tissue NPK accumulation and uptake of peas. All such changes in soil properties contributed to increased pod yield. When organic amendments were compared, poultry manure integrated with NPK fertilizer recorded higher pod yield and nutrient use efficiency over sole NPK fertilizer application. Together with that significantly positive correlation between soil properties and pod yield was found which reflects the nutrient-supplying power of soil under organic amendments. This study suggests that the combined application of organic amendments of any source and chemical fertilizer is necessary for increasing yield and nutrient use efficiency over sole chemical fertilizer application in calcareous soil.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

HUMAN AND ANIMAL RIGHTS

No animals were used in this study. The study on humans was conducted in accordance with the ethical rules of the Helsinki Declaration and Good Clinical Practice.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

None.

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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