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Depth-wise Variation in Soil Chemical Properties and Available Macronutrients under Diverse Cropping Systems in a Semi-Arid Agroecosystem

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Abstract— *Soil chemical properties and nutrient availability are important indicators of soil fertility and sustainable crop production, particularly under semi-arid conditions. The present investigation was conducted at the Research Farm of Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana, during Rabi (winter) 2024–25 to evaluate the effect of ten diverse cropping systems on soil pH, electrical conductivity (EC) and available macronutrients at two soil depths (0–10 and 10–20 cm). The experiment was laid out in a randomized block design with three replications. Soil samples were collected after crop harvest and analysed for pH, EC, available nitrogen (N), phosphorus (P) and potassium (K) using standard analytical methods. Data were analysed using analysis of variance, and treatment means were compared using the critical difference (C.D.) at the 5% level of significance. The results revealed significant variations in soil chemical properties and available nutrients among cropping systems. Soil pH ranged from 7.60 to 7.76 in the surface layer, while differences at 10–20 cm depth were non-significant. Electrical conductivity ranged from 0.455 to 0.501 dS m^{-1} and 0.433 to 0.474 dS m^{-1} in the surface and subsurface layers, respectively. The highest available N (169.0 kg ha^{-1}) and K (319.7 kg ha^{-1}) in the surface soil were recorded under green gram–vegetable pea–Sesbania, whereas the highest available P (35.4 kg ha^{-1}) was observed under sorghum–berseem. Available N, P and K generally decreased with increasing soil depth. The findings indicate that diverse cropping systems influence soil chemical fertility differently, with legume inclusion, green manuring and organic nutrient inputs associated with comparatively higher nutrient availability under certain cropping systems.*

Keywords— Cropping systems, soil fertility, soil pH, electrical conductivity, available nitrogen, available phosphorus, available potassium, soil depth.

I. INTRODUCTION

Soil is a fundamental natural resource that supports agricultural production by providing essential nutrients, water and a suitable environment for plant growth. Maintaining soil fertility is particularly important in semi-arid regions, where irregular rainfall, high evaporative demand and intensive agricultural practices can influence nutrient availability and soil chemical properties (Sahrawat et al., 2010). The sustainability of crop production in these regions therefore depends not only on crop productivity but also on maintaining the chemical fertility of soil over time. Soil pH, electrical conductivity (EC) and the availability of essential macronutrients such as nitrogen (N), phosphorus (P) and potassium (K) are important indicators for assessing soil fertility and nutrient-supplying capacity (Gudla et al., 2023).

Cropping systems play an important role in regulating soil nutrient availability through differences in crop rooting patterns, nutrient uptake, residue production, biological nitrogen fixation and the addition of organic materials. Cereal-based systems generally have substantial nutrient requirements, whereas legume-based cropping systems can contribute nitrogen through biological nitrogen fixation. Similarly, the inclusion of vegetables, fodder crops and crops receiving farmyard manure (FYM) may influence nutrient cycling and the distribution of available nutrients in soil. Long-term studies in the pearl millet–wheat system have demonstrated that organic manure and integrated nutrient management can improve soil fertility, including available N, P and K (Yadav et al., 2000; Yadvinder-Singh et al., 2004). Research in semi-arid India has also highlighted the importance of combining organic and inorganic nutrient management for maintaining soil fertility and crop productivity.

Soil chemical properties and nutrient availability also vary with soil depth. Surface soil generally receives a greater proportion of crop residues, root-derived organic materials and externally applied organic amendments, which can influence nutrient cycling and nutrient availability. In contrast, nutrient distribution in subsurface layers is influenced by root activity, nutrient uptake, leaching, mineral transformations and soil characteristics. Therefore, evaluating soil fertility only in the surface layer may not provide a complete understanding of nutrient distribution within the soil profile. Previous studies have reported depth-related variations in available N, P and K under different cropping and nutrient-management systems. Thakur et al. (2010), for example, reported greater available N and P in the upper soil layer than in deeper layers under a soybean–wheat–maize fodder sequence.

The response of soil chemical properties to cropping systems is not necessarily uniform because different crops vary in their nutrient requirements, rooting characteristics, biomass production and residue-management practices. Legume inclusion, diversified crop sequences and organic manure application may contribute to differences in nutrient availability among cropping systems. A recent study in semi-arid eastern Rajasthan (Choudhary et al., 2024) also reported variations in the depth-wise distribution of soil macronutrients under different cropping systems, highlighting the importance of crop diversification in maintaining soil fertility. However, the magnitude and direction of these changes depend on the cropping sequence, soil characteristics and management practices followed at a particular location. Thus, location-specific assessment of soil chemical properties and available macronutrients is necessary to understand the influence of diverse cropping systems on soil fertility.

In view of this, the present investigation was undertaken at the Agronomy Research Farm of Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana, during Rabi 2024–25. The study evaluated ten diverse cropping systems to assess their influence on soil pH, electrical conductivity and available nitrogen, phosphorus and potassium at two soil depths (0–10 and 10–20 cm). The investigation aimed to determine the variations in soil chemical properties and available macronutrient status under different cropping systems and to identify the cropping systems associated with comparatively favourable soil fertility status under semi-arid agroecosystem conditions.

TABLE 1

INITIAL SOIL PROPERTIES OF THE EXPERIMENTAL SITE (0–15 cm depth, Kharif 2018)

Property	Value
Texture	Sandy loam
pH (1:2 soil:water)	7.78
EC (dS m^{-1})	0.44
Organic carbon (Walkley-Black), %	0.62
Available N (kg ha^{-1})	150
Available P (kg ha^{-1})	25
Available K (kg ha^{-1})	275
Bulk density (Mg m^{-3})	1.47

II. MATERIALS AND METHODS

2.1 Location

The present investigation was carried out at the Research Farm of the Department of Agronomy, Chaudhary Charan Singh Haryana Agricultural University (CCS HAU), Hisar, Haryana, India. The experimental site is geographically located at 29°14′9″ N latitude and 75°68′2″ E longitude, with an elevation of 215.2 m above mean sea level. It is situated in the western part of Haryana, India.

2.2 Climate and Weather Conditions of the Experimental Site

Hisar experiences a typical semi-arid climate characterized by hot, dry summers and cold winters, with scanty and irregular rainfall. Summer temperatures range from 40–46°C, while winter temperatures may fall to 1.5–4°C. The annual average maximum and minimum temperatures are 32.3°C and 15.4°C, respectively. Relative humidity ranges from 5–100%, and the average annual rainfall is approximately 400 mm, most of which occurs during July and August.

2.3 Experimental Design and Treatment Details

The experiment was laid out in a randomized block design with three replications. Ten cropping systems were evaluated (Table 2). The details of the cropping systems and the recommended dose of fertilizers (RDF) for the different crops are presented in Tables 2 and 3, respectively.

TABLE 2
DETAILS OF THE TEN CROPPING SYSTEMS EVALUATED IN THE EXPERIMENT

No.	Cropping system
T1	Cotton – wheat
T2	Pearl millet – wheat
T3	Green gram – mustard – green gram
T4	Green gram – vegetable pea – Sesbania (GM)
T5	Green gram – wheat (desi) + mustard
T6	Green gram – barley
T7	Sorghum – berseem
T8	Maize + cowpea – oat – sweet Sudan grass
T9	Okra – cauliflower – onion
T10	Cowpea (veg.) – potato – cucurbits

TABLE 3
RECOMMENDED DOSE OF FERTILIZERS (RDF) FOR DIFFERENT CROPS

Sr. No.	Crop	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})
1	Wheat	150	60	25
2	Barley	60	30	0
3	Maize	60	16	0
4	Vegetable pea	50	48	0
5	Mustard	150	60	25
6	Berseem	25	70	0
7	Oat	115	30	0
8	Potato	189	62	25
9	Onion	104	50	88
10	Cauliflower	245	48	25
11	Okra	138	8	0
12	Cucurbits	104	50	88
13	Pearl millet	155	60	25
14	Cotton	172	60	0
15	Green gram	18	16	0
16	Cowpea	138	8	0
17	Sorghum	50	0	0
18	Sweet Sudan grass	76	16	0

All crops received the university-recommended fertilizer doses. Sesbania in T4 was incorporated in situ as green manure. T9 and T10 received FYM at 15 t ha^{-1} annually during the Kharif season, along with recommended fertilizers.

2.4 Collection, Preparation and Analysis of Soil Samples

Soil samples were collected from each of the ten cropping systems at two depths (0–10 and 10–20 cm) after the Rabi crop harvest in April 2025. From each plot, composite samples were prepared from five randomly selected points. The samples were air-dried, ground and passed through a 2-mm sieve before chemical analysis.

2.5 Soil Reaction (pH) and Electrical Conductivity (EC)

Soil pH: Soil pH was determined potentiometrically in a 1:2 soil–water suspension following Jackson (1973). A 20-g soil sample was mixed with 40 ml of distilled water, stirred intermittently for 30 minutes, and the pH was measured using a calibrated digital pH meter.

Electrical Conductivity (EC): EC was measured in the same 1:2 soil–water extract using a conductivity meter, following Richards (1954). The meter was calibrated with 0.01 N KCl, and the results were expressed as dS m^{-1}.

2.6 Available Nitrogen (N)

Available nitrogen was determined using the alkaline potassium permanganate method of Subbiah and Asija (1956). The liberated ammonia was absorbed in boric acid containing a mixed indicator and titrated against 0.02 N H_2SO_4. The nitrogen content was expressed as kg ha^{-1}.

2.7 Available Phosphorus (P)

Available phosphorus was estimated using Olsen's (1954) method. Soil samples were extracted with 0.5 M sodium bicarbonate (pH 8.5), and phosphorus was determined colorimetrically using ammonium molybdate and stannous chloride at 660 nm. The results were expressed as kg ha^{-1}.

2.8 Available Potassium (K)

Available potassium was extracted using neutral 1 N ammonium acetate (pH 7.0), following Hanway and Heidel (1952). Potassium concentration in the extract was measured using a flame photometer and expressed as kg ha^{-1}.

2.9 Statistical Analysis

Data were analysed using analysis of variance (ANOVA) for a randomized block design. Treatment means were compared using the critical difference (C.D.) at the 5% level of significance. The standard error of the mean (SEm±) was calculated for each parameter. All analyses were performed using standard statistical software.

III. RESULTS AND DISCUSSION

3.1 Soil pH and EC

Soil pH varied significantly among cropping systems in the surface layer (0–10 cm), ranging from 7.60 to 7.76. The highest pH (7.76) was recorded under T_2 (pearl millet–wheat), while the lowest (7.60) was observed under T_7 (sorghum–berseem). At 10–20 cm depth, pH ranged from 7.80 to 8.00, with non-significant differences among treatments. Overall, pH increased slightly with soil depth (Table 4). Similar variations in soil pH under different cropping systems have been reported by Choudhary et al. (2024).

EC differed significantly among cropping systems at both soil depths. In the surface layer, it ranged from 0.455 to 0.501 dS m^{-1}, with the highest value under T_{10} (cowpea–potato–cucurbits) and the lowest under T_7 (sorghum–berseem). At 10–20 cm depth, EC ranged from 0.433 to 0.474 dS m^{-1}, with the highest values under T_4 and T_{10} and the lowest under T_2. EC decreased with increasing soil depth (Table 4). The comparatively higher EC under vegetable-based systems may be associated with differences in nutrient and FYM application. Similar variations in soil chemical properties under different cropping systems have been reported by Choudhary et al. (2024).

TABLE 4

EFFECT OF DIFFERENT CROPPING SYSTEMS ON pH AND ELECTRICAL CONDUCTIVITY OF SOIL AT DIFFERENT DEPTHS

Treatment	pH (0–10 cm)	pH (10–20 cm)	EC (dS m^{-1}) (0–10 cm)	EC (dS m^{-1}) (10–20 cm)
T1: Cotton – wheat	7.72	7.89	0.463	0.437
T2: Pearl millet – wheat	7.76	7.88	0.463	0.433
T3: Green gram – mustard – green gram	7.74	7.9	0.496	0.473
T4: Green gram – vegetable pea – Sesbania (GM)	7.65	7.89	0.494	0.474
T5: Green gram – wheat (desi) + mustard	7.75	8	0.463	0.442
T6: Green gram – barley	7.74	7.98	0.456	0.436
T7: Sorghum – berseem	7.6	7.89	0.455	0.436
T8: Maize + cowpea – oat – sweet Sudan grass	7.61	7.97	0.46	0.435
T9: Okra – cauliflower – onion	7.74	7.98	0.498	0.472
T10: Cowpea (veg.) – potato – cucurbits	7.65	7.8	0.501	0.474
SEm±	0.03	0.06	0.005	0.007
C.D. (p = 0.05)	0.09	NS	0.014	0.02

Note: NS = non-significant.

3.2 Available N

Available nitrogen differed significantly among cropping systems at both soil depths. In the surface layer (0–10 cm), it ranged from 111.0 to 169.0 kg ha^{-1}. The highest value (169.0 kg ha^{-1}) was recorded under T_4 (green gram–vegetable pea–Sesbania), followed by T_3 (160.3 kg ha^{-1}), whereas the lowest (111.0 kg ha^{-1}) was observed under T_{10} (cowpea–potato–cucurbits).

At 10–20 cm depth, available nitrogen ranged from 99.0 to 146.9 kg ha^{-1}, with the highest value under T_4 and the lowest under T_9 (Table 5). Overall, available nitrogen decreased with increasing soil depth. The higher nitrogen availability under T_4 may be attributed to legume inclusion and in-situ incorporation of Sesbania as green manure, which contributes nitrogen through biological fixation and decomposition of plant biomass. Similar findings have been reported by Chaudhary et al. (2023) and Tiwari et al. (1995), who observed improved soil nitrogen availability under legume-based cropping systems and Sesbania green manuring. The lowest available N under T_{10} may be associated with high nitrogen uptake by potato and cucurbits and possible losses through leaching or denitrification.

TABLE 5

EFFECT OF DIFFERENT CROPPING SYSTEMS ON AVAILABLE NITROGEN (kg ha^{-1}) IN SOIL AT DIFFERENT DEPTHS

Treatment	Available N (0–10 cm)	Available N (10–20 cm)
T1: Cotton – wheat	144.7	126.4
T2: Pearl millet – wheat	130.7	112.3
T3: Green gram – mustard – green gram	160.3	138
T4: Green gram – vegetable pea – Sesbania (GM)	169	146.9
T5: Green gram – wheat (desi) + mustard	138.3	122.1
T6: Green gram – barley	139	120.3
T7: Sorghum – berseem	159	137.5
T8: Maize + cowpea – oat – sweet Sudan grass	138.7	112.7
T9: Okra – cauliflower – onion	122.3	99
T10: Cowpea (veg.) – potato – cucurbits	111	107.8
SEm±	4.1	4
C.D. (p = 0.05)	12.1	11.8

3.3 Available P

Available phosphorus differed significantly among cropping systems at both soil depths. In the surface layer (0–10 cm), it ranged from 21.3 to 35.4 kg ha^{-1}. The highest value (35.4 kg ha^{-1}) was recorded under T_7 (sorghum–berseem), followed by T_3 (green gram–mustard–green gram) with 35.0 kg ha^{-1}. The lowest value (21.3 kg ha^{-1}) was observed under T_8 (maize + cowpea–oat–sweet Sudan grass).

At 10–20 cm depth, available phosphorus ranged from 18.6 to 30.3 kg ha^{-1}. The highest value (30.3 kg ha^{-1}) was recorded under T_3, whereas the lowest (18.6 kg ha^{-1}) was observed under T_2 and T_6. Available phosphorus generally decreased with increasing soil depth, except under T_{10}, where a slight increase was recorded (Table 6). Higher phosphorus availability under certain legume-based systems may be associated with root activity, organic matter decomposition and changes in phosphorus transformations. Similar findings regarding the influence of legume inclusion and cropping sequences on soil phosphorus availability were reported by Dutta et al. (2024) and Chen et al. (2025). The slight increase in available P with depth under T_{10} warrants further investigation and may be related to the deeper root activity of potato and cucurbits or to leaching of P from the surface layer.

TABLE 6
EFFECT OF DIFFERENT CROPPING SYSTEMS ON AVAILABLE PHOSPHORUS (kg ha^{-1}) IN SOIL AT DIFFERENT DEPTHS

Treatment	Available P (0–10 cm)	Available P (10–20 cm)
T1: Cotton – wheat	26	22.6
T2: Pearl millet – wheat	21.7	18.6
T3: Green gram – mustard – green gram	35	30.3
T4: Green gram – vegetable pea – Sesbania (GM)	24.8	21
T5: Green gram – wheat (desi) + mustard	34.6	29.9
T6: Green gram – barley	21.5	18.6
T7: Sorghum – berseem	35.4	29.7
T8: Maize + cowpea – oat – sweet Sudan grass	21.3	19.2
T9: Okra – cauliflower – onion	28.2	27
T10: Cowpea (veg.) – potato – cucurbits	25.8	26.3
SEm±	1.3	0.9
C.D. (p = 0.05)	4	2.5

3.4 Available K

Available potassium differed significantly among cropping systems at both soil depths. In the surface layer (0–10 cm), it ranged from 235.3 to 319.7 kg ha^{-1}. The highest value (319.7 kg ha^{-1}) was recorded under T_4 (green gram–vegetable pea–Sesbania), followed by T_{10} (cowpea–potato–cucurbits) with 317.5 kg ha^{-1}. The lowest value (235.3 kg ha^{-1}) was observed under T_7 (sorghum–berseem).

At 10–20 cm depth, available potassium ranged from 226.7 to 300.8 kg ha^{-1}. The highest value (300.8 kg ha^{-1}) was recorded under T_4, followed by T_{10} (300.0 kg ha^{-1}), whereas the lowest value (226.7 kg ha^{-1}) was observed under T_8 (maize + cowpea–oat–sweet Sudan grass) (Table 7).

Available potassium decreased with increasing soil depth under all cropping systems. The mean reduction was approximately 6.7%, indicating greater K availability in the surface layer. This may be attributed to the accumulation of crop residues, organic inputs and greater nutrient cycling near the soil surface. Higher available K under T_4 and T_{10} may be associated with green manuring and FYM application, respectively. Similar improvements in soil K availability under organic nutrient management and residue retention have been reported by Saritha et al. (2021) and Rani et al. (2023). The lower K under T_9, despite FYM application, suggests that crop K uptake and residue management may also influence K availability.

TABLE 7

EFFECT OF DIFFERENT CROPPING SYSTEMS ON AVAILABLE POTASSIUM (kg ha^{-1}) IN SOIL AT DIFFERENT DEPTHS

Treatment	Available K (0–10 cm)	Available K (10–20 cm)
T1: Cotton – wheat	251.3	242.7
T2: Pearl millet – wheat	255	245.2
T3: Green gram – mustard – green gram	284.3	280.7
T4: Green gram – vegetable pea – Sesbania (GM)	319.7	300.8
T5: Green gram – wheat (desi) + mustard	283	280.3
T6: Green gram – barley	268.3	247.7
T7: Sorghum – berseem	235.3	228.7
T8: Maize + cowpea – oat – sweet Sudan grass	238	226.7
T9: Okra – cauliflower – onion	304.2	297
T10: Cowpea (veg.) – potato – cucurbits	317.5	300
SEm±	7.9	7.2
C.D. (p = 0.05)	23.4	21.4

IV. CONCLUSION

The study revealed that different cropping systems significantly influenced soil chemical properties and available macronutrient status at different soil depths. Soil pH showed comparatively small variations, while electrical conductivity remained low under all cropping systems. The highest available nitrogen and potassium were recorded under green gram–vegetable pea–Sesbania, whereas sorghum–berseem recorded the highest available phosphorus in the surface soil. Available N, P and K generally decreased with increasing soil depth. Overall, the findings highlight the importance of cropping system diversification, legume inclusion, green manuring and organic nutrient inputs in maintaining soil chemical fertility under semi-arid conditions. Among the evaluated systems, green gram–vegetable pea–Sesbania showed comparatively favourable availability of nitrogen and potassium, while different cropping systems performed differently with respect to phosphorus availability. However, these results are based on a single-season assessment, and long-term studies are needed to confirm the trends observed. Future research should also integrate data on crop yields, nutrient uptake and soil physical and biological properties to provide a more comprehensive understanding of the effects of cropping systems on soil fertility.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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