Plant Archives Vol. 26, Supplement 2, 2026 pp. 619-632 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.supplement-2.070

IMPACT OF DIVERSE CROPPING SYSTEMS ON SOIL FERTILITY DYNAMICS AND DEPTH-WISE PHYSICO-CHEMICAL PROPERTIES UNDER NSP-6 EXPERIMENTAL FARM

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(Date of Receiving : 04-03-2026; Date of Revision : 18-04-2026; Date of Acceptance : 11-05-2026)

ABSTRACT

The study evaluated the effect of different cropping systems on soil fertility dynamics and depth-wise physico-chemical properties at the NSP-6 Experimental Farm at Acharya Narendra Deva University of Agriculture &Technology, Ayodhya. Total 120 soil samples were collected from 12 plots under cropping systems such as Paddy-Oat, Paddy-Wheat, Paddy-Berseem, Paddy-Wheat-Maize and Paddy-Vegetables at two depths (0-15 cm and 15-30 cm). Results showed that soil texture remained silty loam across all systems with sand (14.94-24.70%), silt (50.52-56.56%) and clay (22.87-29.43%), indicating no effect of cropping system on texture. Bulk density ranged from 1.52-1.58 Mg m^{-3} (mean 1.55), particle density from 2.62-2.68 Mg m^{-3} and porosity from 39.79-43.30%. Soil pH ranged from 8.25 to 8.91 (mean 8.62), showing alkaline nature, while EC remained low (0.28-0.41 dS m^{-1}). Organic carbon varied from 2.12 to 4.45 g kg^{-1}, higher in surface soils. Among cropping systems, Paddy-Wheat-Maize (C1) recorded the highest nutrient availability with nitrogen 237.41 kg ha^{-1}, phosphorus 16.85 kg ha^{-1}, potassium 263.51 kg ha^{-1}, sulphur 11.36 mg kg^{-1} and zinc 0.39 mg kg^{-1} at 0-15 cm depth. Similarly, Paddy-Berseem showed high organic carbon (up to 4.42 g kg^{-1}) and improved soil properties. In contrast, Paddy-Oat systems recorded higher pH (up to 8.91), ESP (up to 28.57%) and SAR (up to 26.19), indicating greater sodicity risk. pH and ESP (r=0.895**) and SAR (r=0.898**) had a substantial positive link according to correlation analysis, while organic carbon had a significant positive correlation with available nitrogen (r=0.831**) and sulphur (r=0.827**). On the other hand, soil pH showed a negative connection with zinc (r=-0.619*), sulphur (r=-0.654*) and nitrogen (r=-0.765**) suggesting decreased nutrient availability under higher alkalinity. A strong positive correlation between ESP and SAR (r = 0.989**) further confirmed the sodic nature of soils. Diversified cropping systems improved soil fertility and nutrient availability, whereas continuous cereal-based systems increased alkalinity and sodium accumulation. Soil properties also showed clear depth-wise variation with better fertility in surface layers.
***Keywords*:** Cropping systems, Correlation coefficient, Depth-wise variation, Nutrient availability, Physico-chemical properties, Soil fertility, Sodicity and Sustainable agriculture.

Introduction

A vital component of maintaining agricultural production and ecosystem stability, soil is a dynamic and complex natural resource that serves as both a source and a sink for nutrients, water and gases. It includes a broad range of biological, chemical, mineralogical and physical characteristics that interact to affect the growth and development of plants. Soil fertility and quality, which are essential for guaranteeing long-term agricultural productivity, are determined by the balance of these characteristics. Out of the 329 million hectares geographical area of India, 175 million hectare is degraded and 6.74 million hectares is salt affected land with excess amounts of soluble (saline) and/or sodic salts, which adversely affect crop/vegetation growth and yield (Singh *et al.,* 2025).

Around 24% of the world's total geographic area approx 3500 Mha) is severely affected by land degradation. Around 20% of cropland, 10% of grassland and 30% of forests are under the process of land degradation throughout the world. In India, around 36.7% of total geographical area 120.7 Mha is under different types of land degradation such as soil erosion, soil acidity, soil salinity and alkalinity, and waterlogging and soil salinity and alkalinity alone affect 6.73 Mha in different arid, semi-arid, and sub-humid areas (Malav *et al.,* 2022).

Soil is a finite resource essential for food production, carbon sequestration, water and nutrient regulation, contaminant filtering, biodiversity and climate regulation. However, it is increasingly degraded due to population growth, economic development and climate change (Panagos *et al.,* 2020).

Some estimates suggest that by 2050, about half of arable land might be impacted by salt. A significant percentage of this afflicted land is found in the Indo-Gangetic plains with Uttar Pradesh accounting for 1.37 million hectares. Crop growth and yield are negatively impacted by these soils' high pH, excessive sodium buildup, poor structure and decreased nutrient availability (Singh and Sharma, 2020). Alfisols and Vertisols are dominant soils of the peninsular India and Aridisols occur in extremely dry climates along with some Entisols and Inceptisols. In terms of land use and management, alluvial (Inceptisols) soils are the most dominant (93.1 Mha), followed by red (Alfisols, 79.7 Mha), black (Vertisols, 55.1 Mha), desert (Entisols, Aridisols, 26.2 Mha) and lateritic (Plinthic horizon, 17.9 Mha) soils (Rao *et al.,* 2015).

Inceptisols, Alfisols, Entisols, Vertisols and Mollisols are among the soil orders that comprise the majority of the alluvial soils found in eastern Utta r Pradesh. They comprise soil types including Bhat, Bhangar and Dhuh and show a great deal of variety. These areas' salt-affected soils are known locally as "Usar" or "Reh." are characterized by deteriorated structure, poor permeability and surface salt encrustations. Reduced infiltration, aeration and microbial activity result from these circumstances which eventually lower soil production. Soil degradation has been hastened by intensive agricultural methods such as the overuse of chemical fertilizers, poor irrigation management and insufficient soil conservation measures. These methods worsen soil health by causing salinization, alkalization and nutrient imbalance. The ability of the soil to provide vital nutrients to plants in sufficient quantities and appropriate ratios is known as soil fertility and it is intimately related to soil quality. Important physical characteristics (such as texture, bulk density and porosity), chemical characteristics (such as pH, electrical conductivity, soil organic carbon and cation exchange capacity) and biological characteristics (such as microbial biomass and enzyme activity) are all considered when assessing soil fertility (Lal, 2004).

Because sodium ions predominate in salt-affected soils, especially sodic soils, the dispersion of soil particles results in poor structure, decreased hydraulic conductivity and restricted root growth. Important nutrients including nitrogen, phosphate, iron, zinc and magnesium are also less accessible in high pH environments. Therefore, in order to recover production, these soils require proper management options such as reclamation techniques and appropriate cropping systems. Cropping systems have a significant impact on the fertility dynamics and characteristics of the soil. Crop rotation patterns, resource use and general soil management techniques are all determined by them. Crops in salt-affected areas are frequently chosen according to how well they tolerate salinity and sodicity. Higher tolerance is shown by crops like sugarbeet, barley, paddy and some grasses. Cropping systems including crop diversification, crop rotation and intercropping along with associated agronomic practices, significantly influence soil health and quality across spatial and temporal scales. While these systems were initially designed to maximize agricultural productivity, their role in promoting environmental sustainability is now increasingly emphasized. Soil health maintenance aims to ensure long-term, stable productivity and is commonly assessed using five key functional criteria-nutrient cycling, water relations, biodiversity and habitat provision, filtering and buffering capacity and physical stability and support (Yang *et al.,* 2020).

Pulses and other crops are particularly vulnerable. Paddy-Wheat, Paddy-Berseem, Paddy-Maize and Paddy-Vegetable cropping systems are popular in eastern Uttar Pradesh; each has unique effects on soil health and nutrient cycling.

Soil health maintenance and improvement under continuous land-use systems are critical for sustaining future agricultural productivity. This not only ensures stable income for farmers but also helps protect land from degradation. Most land-use changes are driven by agricultural activities, including pasture development and farming practices, which alter the physical, chemical and biological properties of soil and affect its fertility. These changes are primarily associated with deforestation, cropland expansion, dryland degradation, urbanization, pasture expansion and agricultural intensification (Muhammad Auwal and David, 2015).

A comprehensive understanding of the effects of land-use systems on soil chemical, physical and biological properties is essential for evaluating soil quality and enhancing the sustainability of cropping systems. Soil physico-chemical properties and nutrient status studies is important in order to evaluate the quality of soil under the effect of different agricultural land uses of the soil fertility status (Pandey *et al.,* 2023).

Pore space measurements are increasingly used to quantify soil structural changes resulting from agricultural activities, complementing traditional indicators such as aggregate stability and hydraulic conductivity. These measurements effectively characterize soil structure, as pore size, shape and continuity influence many key soil processes (Virginia Aparicio and José Luis Costa, 2007).

Additionally, soil provides a home for a variety of microbes that aid in the breakdown of organic matter, nutrients cycling and preservation of the soil structure. Therefore, maintaining soil fertility and productivity depends heavily on the biological component of the soil. Acharya Narendra Dev University of Agriculture and Technology's NSP-6 Experimental Farm in Kumarganj, Ayodhya is a special location with alkaline and sodic soil. This farm which is spans around 6.1 hectares with numerous sub-plots, offers a perfect setting for researching how various farming patterns affect soil characteristics. Evaluating soil properties is crucial for sustainable management and increased productivity because the land is undergoing progressive growth.

Materials and Methods

Investigation Sites

The investigation or sampling was carried out at the NSP-6 Farm situated at Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (U.P.) at a distance of 42 kms from Ayodhya city on Ayodhya-Raebareli Road. The Farm is situated at 26°32´ N latitude, 81°50´E longitude and at an altitude of 113.0 meters from the mean sea level. The farm is affected by salt infestation and has been recently developed. It lies in the university campus in an area of 6.1 million hectare. The area distribution of different plots in the farm with their GPS coordinates i.e. A_1: (Paddy-Oat), A_2: (Paddy-Oat), A_3: (Paddy-Oat), A_4: (Paddy-Oat), A_5: (Paddy-Oat), A_6: (Paddy-Wheat), B_1: (Paddy-Berseem), B_2: (Paddy-Berseem), B_3: (Paddy-Berseem), B_4: (Paddy-Berseem), C1: (Paddy-Wheat-Maize), C2: (Paddy-Vegetables).

Table 1 : Details of Cropping systems of different plots of the farm NSP-6 and their GPS Coordinate in 2020-21

S. No.	Plot	Area (ha)	Cropping System	GPS Coordinates
1	A1	0.3420	Paddy-Oat	26°32’23’’N,81°50’40’’E
2	A2	0.3557	Paddy-Oat	26°32’21’’N,81°50’41” E
3	A3	0.3225	Paddy-Oat	26°32’19” N,81°50’43” E
4	A4	0.3225	Paddy-Oat	26°32’19” N, 81°50’44” E
5	A5	0.3100	Paddy-Oat	26°32’19” N,81°50’45” E
6	A6	0.40	Paddy -Wheat	26°32’19” N,81°50’44” E
7	B1	0.575	Paddy-Berseem	26°32’20” N,81°50’39” E
8	B2	0.3425	Paddy-Berseem	26°32’21” N,81°50’40” E
9	B3	0.3145	Paddy-Berseem	26°32’19” N,81°50’41” E
10	B4	0.3050	Paddy-Berseem	26°32’18” N, 81°50’42” E
11	C1	0.3050	Paddy-Wheat-Maize	26°32’17” N,81.50’39” E
12	C2	0.32	Paddy-Vegetables	26°32’19” N,81.50’38” E

Soil Sampling & Preparation for Analysis:

The soil samples were collected from all the twelve plots of the NSP-6 farm during the year 2021. The spots were selected by using the Geographical Positioning System (GPS) for collection of soil samples. The samples were withdrawn with the help of post whole Auger at surface (0-15 cm) and sub-surface (15-30 cm) depths. The total 120 samples were collected from the field. For one depth, five samples were collected randomly from each plot. The composite samples collected from different spots was brought to the laboratory and air dried, processed with the help of mortar and pestle and sieved through 20 mesh sieve and was kept in cool, dry and dark place in laboratory. The samples were determined to study the physico-chemical and biological analysis.

Table 2 : The procedures employed for estimating physico-chemical properties of soil

S. No.	Physico-chemical properties	Methods adopted
1.	Soil Texture	Bouyoucos Hydrometer Method (1962)
2.	Bulk density (Mg m^{-3})	Core sampler Method (Black, 1965)
3.	Particle density (Mg m^{-3})	Pycnometer Method (Edward Y.H. Keng, 1969)
4.	Porosity (%)	Calculated from formula
5.	pH	Glass Electrode pH meter (Jackson, 1973)
6.	EC (dS m^{-1} at 25C^{o})	EC meter (Bower and Wilcox, 1965)
7.	Organic carbon (g kg^{-1})	Walkley and Black Rapid Titration Method (1934).
8.	$CaCO_3$ (%)	Rapid titration method (Puri, 1930)
9.	CEC (C mol(p^+) kg^{-1})	Black, C.A., Ed. Methods (H. D. Chapman, 1965)
10.	**Soluble Cations**	
a.	Na^+	Richards, 1954
b.	K^+	Richards, 1954
c.	Ca^{2+} and Mg^{2+}	Titration with EDTA (Richard, 1954)
11.	**Soluble Anions**	
a.	CO_3^{2-} and HCO_3^-	Titration with 0.01N H_2SO_4 (Richard, 1954)
b.	Cl^-	Titration with 0.01N $AgNO_3$ solution (Richard, 1954)
c.	SO_4^{2-}	1 N $BaCl_2$ (Richard, 1954)
12.	Exchangeable sodium Percentage (ESP)	Bains and Fireman, 1964
`13.	Sodium Absorption Ratio (SAR)	Calculated from formula
14.	Available Nitrogen (kg ha^{-1})	Alkaline Permanganate Method (Subbiah and Asija, 1956)
15.	Available Phosphorus (kg ha^{-1})	Olsen's Method (Olsen *et al.,* 1954)
16.	Available Potassium (kg ha^{-1})	Flame Photometer Method (Jackson, 1967)
17.	Available Sulphur (mg kg^{-1})	$CaCl_2$ -Extractable S (Williams and Steinbergs,1959)
18.	Available Zn (mg kg^{-1})	DTPA extractant and estimated on AAS (Lindsay and Norvell, 1978)

Physico-chemical Analysis

Soil Texture

The data regarding the proportion of sand, silt, clay and soil texture in each plot under different cropping systems have been presented in the Table 3. The data revealed that the maximum mean sand ranged from (14.94-24.70%), silt (50.52-56.56%), and clay ranged (22.87-29.43%). The soil texture was silty loam of all the plots under study. Thus, there was no change in in soil texture of the soils of different cropping system. This might be due to the fact that cropping system cannot change the soil texture. The similar findings were also reported by (Sharma *et al.,* 2004a), (Kumar *et al*., 2002), (Singh *et al.,* 2011) and (Srinivasaro *et al.,* 2013).

Table 3 : Mean Particle Size distribution of soils of NSP-6 Farm under different cropping systems.

Cropping System	Plot	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture
Paddy –Oat	**A1**	0-15	23.00	51.63	25.37	Silty Loam
		15-30	22.47	53.86	23.67	Silty Loam
	A2	0-15	23.30	52.54	24.16	Silty Loam
		15-30	20.50	54.76	24.74	Silty Loam
	A3	0-15	23.66	50.52	25.82	Silty Loam
		15-30	24.70	52.43	22.87	Silty Loam
	A4	0-15	18.83	54.52	26.65	Silty Loam
		15-30	18.78	55.06	26.16	Silty Loam
	A5	0-15	22.61	52.85	24.54	Silty Loam
		15-30	22.64	53.54	23.82	Silty Loam
Paddy -Wheat	**A6**	0-15	19.49	52.75	27.76	Silty Loam
		15-30	20.03	53.32	26.65	Silty Loam
Paddy -Berseem	**B1**	0-15	20.20	51.37	28.43	Silty Loam
		15-30	19.43	52.64	27.93	Silty Loam
	B2	0-15	14.94	55.63	29.43	Silty Loam
		15-30	14.96	56.47	28.57	Silty Loam
	B3	0-15	17.47	53.67	28.86	Silty Loam
		15-30	17.33	54.63	28.04	Silty Loam
	B4	0-15	20.10	51.47	28.43	Silty Loam
		15-30	19.44	52.63	27.93	Silty Loam
	B5	0-15	18.62	54.64	26.74	Silty Loam
		15-30	18.60	55.76	25.64	Silty Loam
Paddy + Wheat + Maize	**C1**	0-15	15.84	55.52	28.64	Silty Loam
		15-30	15.68	56.56	27.76	Silty Loam
Paddy-Vegetables	**C2**	0-15	17.39	54.52	28.09	Silty Loam
		15-30	15.48	55.76	28.76	Silty Loam
Max			**24.70**	**56.56**	**29.43**	
Min			**14.94**	**50.52**	**22.87**	
Total Mean			**19.49**	**53.83**	**26.65**	
S.D.			**2.57**	**1.65**	**1.81**	

Bulk density, Particle density and Porosity

The soil physical parameters such as bulk density, particle density and porosity were analysed and are presented in the table 4 and fig 1. The data revealed that the mean Bulk density ranged (1.52-1.58 Mg m^{-3})

with an average of 1.55 Mg m^{-3}, particle density ranged (2.61-2.69 Mg m^{-3}) with an average of 2.65 Mg m^{-3} and porosity ranged (39.79-43.30%) with an average of 41.56%. The Standard deviation of BD, PD and Porosity were 0.02,0.02, and 1.07, respectively. Thus, there was not much difference in the range of bulk density and particle density.

The bulk density generally increased with increasing depth of soil from surface to sub-surface soil horizon due to the presence of less organic matter, more compact subsurface layer and less aggregation which led to less pore space. The soil density as well as porosity was not affected by different cropping systems. This might be due to early stage of cropping in barren soil. The porosity generally varies indirectly with bulk density of soil. These findings were validated with (Sharma *et al.*, 2003) and (Shiva *et al.,* 2017).

Table 4 : Bulk Density, Particle Density and Porosity of NSP-6 Farm under different cropping systems.

Cropping System	Plot	Depth (cm)	BD (Mg m^{-3})	PD (Mg m^{-3})	Porosity (%)
Paddy–Oat	**A1**	0-15	1.56	2.66	41.30
		15-30	1.56	2.63	40.77
	A2	0-15	1.55	2.67	42.11
		15-30	1.56	2.63	40.63
	A3	0-15	1.55	2.67	42.15
		15-30	1.58	2.62	39.79
	A4	0-15	1.54	2.67	42.23
		15-30	1.57	2.64	40.30
	A5	0-15	1.53	2.68	42.89
		15-30	1.57	2.65	40.80
Paddy -Wheat	**A6**	0-15	1.55	2.68	42.02
		15-30	1.56	2.64	40.92
Paddy -Berseem	**B1**	0-15	1.52	2.67	43.15
		15-30	1.56	2.63	40.80
	B2	0-15	1.54	2.66	42.21
		15-30	1.58	2.62	39.93
	B3	0-15	1.52	2.67	43.30
		15-30	1.56	2.65	41.24
	B4	0-15	1.52	2.66	42.86
		15-30	1.57	2.65	40.60
	B5	0-15	1.52	2.67	43.07
		15-30	1.55	2.66	41.82
Paddy + Wheat + Maize	**C1**	0-15	1.53	2.67	42.74
		15-30	1.57	2.62	40.09
Paddy -Vegetables	**C2**	0-15	1.54	2.66	42.00
		15-30	1.56	2.64	40.84
Max			**1.58**	**2.68**	**43.30**
Min			**1.52**	**2.62**	**39.79**
Total Mean			**1.55**	**2.65**	**41.56**
S.D.			**0.02**	**0.02**	**1.07**

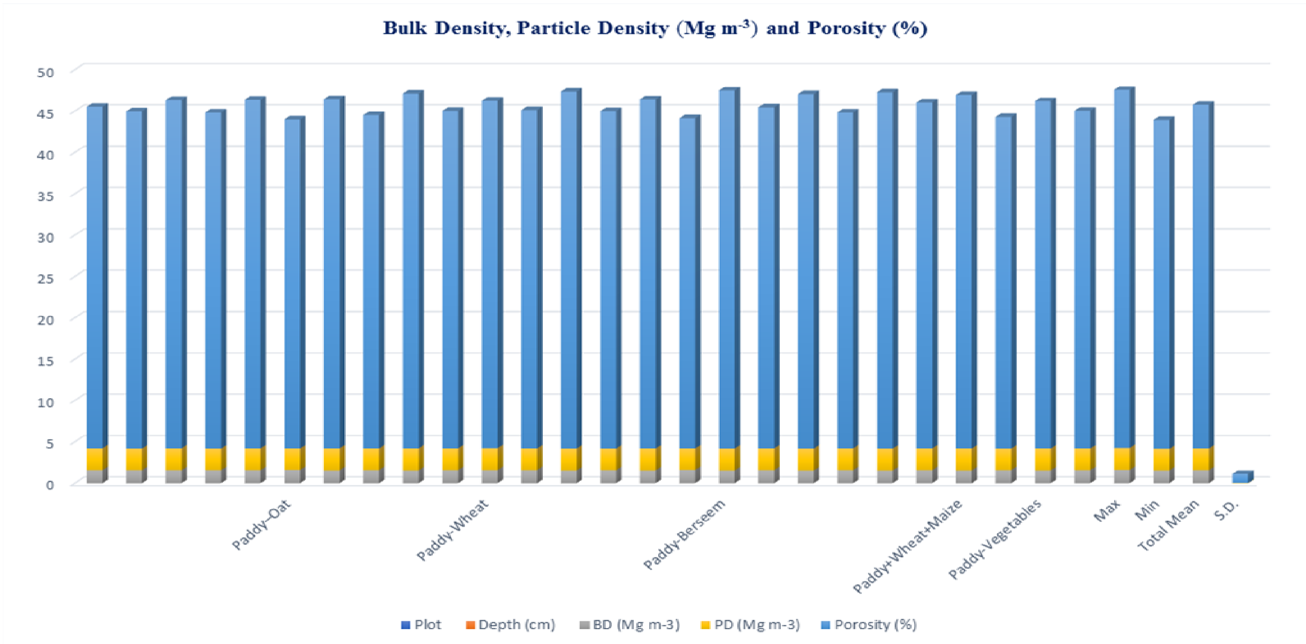

Fig. 1 : Bulk Density, Particle Density and Porosity of NSP-6 Farm under different cropping systems.

Soil physico-chemical and chemical properties.

The soil parameters such as soil pH, Electrical Conductivity (EC), Organic Carbon (OC), Calcium Carbonate Percentage ($CaCO_3$%), Cation Exchange Capacity (CEC) and Exchangeable Sodium percentage (ESP) were determined and presented in the table 5 and fig 2. The data revealed that the maximum mean pH (8.91) was recorded in A3 plot at 15-30 cm depth under Paddy-Oat cropping system which was closely followed by pH (8.90) in A5 plot at 15-30 cm depth under Paddy-Oat cropping system and minimum mean pH (8.25) was recorded in C1 plot at 0-15 cm depth under Paddy + Wheat + Maize cropping system. The maximum mean EC (0.41 dS m^{-1}) was recorded in A3 plot at 0-15 cm depth under Paddy-Wheat cropping system closely followed by EC (0.37 dS m^{-1}) in A5 plot at 0-15 cm depth under the Paddy-Oat and B2 plot at 0-15 cm depth under Paddy-Berseem cropping system and minimum mean EC (0.28 dS m^{-1}) was recorded from A1 plot at 15-30 cm depth under Paddy-Oat cropping system. The maximum mean O.C. (4.45 g kg^{-1}) was recorded in C1 plot at 0-15 cm depth under Paddy + Wheat + Maize cropping system which was closely followed by O.C. (4.42 g kg^{-1}) in B1 plot at 0-15 cm depth under Paddy-Berseem cropping pattern and minimum mean O.C. (2.12 g kg^{-1}) was recorded in A5 plot at 15-30 cm depth under Paddy-Wheat cropping system. The maximum mean $CaCO_3$ percentage (4.64%) was recorded in A3 plot at 15-30 cm depth under Paddy-Oat cropping system which was closely followed by $CaCO_3$ percentage (4.53%) in A5 plot at 15-30 cm depth under Paddy-Wheat cropping system and minimum mean $CaCO_3$ percentage (3.72%) was observed in B1 plot at 0-15 cm depth under Paddy-Berseem cropping system. The maximum mean CEC (19.86 C mol (p+) kg^{-1}) was recorded in A5 plot at 15-30 cm depth under Paddy-Oat cropping system which was closely followed by CEC (19.62 C mol(p+) kg^{-1}) in A2 plot at 15-30cm depth under Paddy-Wheat and minimum mean CEC (16.43C mol(p+) kg^{-1}) was recorded in C1 plot at 0-15cm depth under Paddy+Wheat+Maize cropping system. The maximum mean ESP (28.57) was found in A3 plot at 15-30 cm depth under Paddy-Oat cropping system which was closely followed by ESP (27.41) in A5 plot at 15-30 cm depth under Paddy-Oat cropping system and minimum mean ESP (14.46) was observed in C2 plot at 0-15 cm depth under Paddy-Vegetables cropping system.

The pH ranged (8.25-8.91) with an average of 8.62, organic carbon ranged (2.12-4.45 g kg^{-1}) with an average mean of 3.48, Electrical conductivity ranged (0.28 to 0.41 dS m^{-1}) with an average of 0.34 dS m^{-1}, $CaCO_3$ ranged (3.72-4.64%) with an average of 4.19% and CEC ranged (16.43-19.86 C mol(p+) kg^{-1}) with an average of 18.39 C mol(p+) kg^{-1} and ESP ranged (14.46-28.57) with an average of 20.16. The Standard deviation of pH, Electrical conductivity, Organic Carbon, $CaCO_3$ percentage, CEC and ESP were 0.19,0.03,0.68 ,0.26,0.89 and 3.60, respectively.

The soil pH and EC generally increase with increasing soil depth due to more sodium salts present in the lower horizon of soil profile and leaching of salts from upper surface to lower surface of soil. The soil pH was less at upper soil layer due to the addition of farmyard manure and plant residues at surface horizons and release of organic acids due to decomposition of plant residues. This was in accordance with (Sen, 2014), and (Najjar, 2002). The organic carbon decreased with increasing soil depth. This may be due to less availability of SOC pool. The similar trend in organic carbon content was observed by (Sheikh *et al.,* 2009), (Dinakaran and Krishnayya, 2008). The similar findings were also recorded by Bharadwaj *et al.* (2001), (Gurumurthy *et al.,* 2009), (Wankhede *et al.,* 2008), (Kumar *et al*., 2016) and (Kumar, 2020). The $CaCO_3$ content increased with the increasing soil depth which might be accredited due to the leaching of calcium carbonate down the soil layers from upper surface layers. The results were in conformity with findings of (Karwade *et al.,* 2020) and (Farooq *et al.,* 2021). The cation exchange capacity generally increases with increase in soil pH. The CEC of soil is mainly dependent on soil pH, type of soil and amount of organic matter present in the soil. The CEC of the soil showed an increasing trend depth-wise vowing to variation in organic Carbon in the sub-surface soils. The similar findings were validated with (Wani *et al.,* 2010) and (Takele *et al.,* 2010). The ESP decreases due to an increase in organic carbon content of the soils and increase with high pH. The CO_2 released from the respiration of roots might have converted calcium carbonate to soluble calcium bicarbonate, which displaced sodium with calcium and thus reduced the ESP (Shiferaw *et al.,* 2021) and (Nerwas *et al.,* 2012).

Table 5 : Soil physico-chemical properties and chemical properties of NSP-6 Farm under different cropping systems.

Cropping System	Plot	Depth (cm)	pH	EC (dS m^{-1})	OC (g kg^{-1})	$CaCO_3$ (%)	CEC (C mol (p+) kg^{-1})	ESP (%)
Paddy–Oat	**A1**	0-15	8.78	0.31	3.23	3.93	17.36	23.34
		15-30	8.82	0.28	2.48	4.36	19.52	24.92
	A2	0-15	8.76	0.36	4.21	3.83	18.58	21.34
		15-30	8.88	0.31	3.39	4.25	19.62	24.64
	A3	0-15	8.71	0.41	2.86	4.27	18.12	20.21

		15-30	8.91	0.37	2.55	4.64	19.54	28.57
	A4	0-15	8.69	0.32	3.19	4.26	18.29	22.82
		15-30	8.73	0.30	2.82	4.43	19.25	23.02
	A5	0-15	8.62	0.37	3.01	4.18	17.88	18.49
		15-30	8.90	0.34	2.12	4.53	19.86	27.41
Paddy-Wheat	**A6**	0-15	8.54	0.34	3.14	3.93	18.32	19.36
		15-30	8.65	0.35	2.73	4.38	19.24	17.98
Paddy-Berseem	**B1**	0-15	8.42	0.37	4.42	3.72	17.32	15.75
		15-30	8.65	0.33	4.21	4.19	18.52	19.14
	B2	0-15	8.44	0.37	4.25	4.16	17.64	16.35
		15-30	8.57	0.32	3.92	4.47	18.48	18.94
	B3	0-15	8.46	0.36	4.15	3.74	17.39	18.89
		15-30	8.57	0.32	3.92	4.26	18.56	18.59
	B4	0-15	8.48	0.35	3.72	3.92	17.48	17.32
		15-30	8.76	0.33	3.32	4.42	18.22	21.87
	B5	0-15	8.46	0.36	3.29	3.84	17.82	18.40
		15-30	8.73	0.32	3.15	4.34	18.95	19.52
Paddy + Wheat + Maize	**C1**	0-15	8.25	0.32	4.45	3.93	16.43	17.10
		15-30	8.46	0.31	3.98	4.24	17.47	16.44
Paddy-Vegetables	**C2**	0-15	8.25	0.32	3.85	3.86	17.46	14.46
		15-30	8.46	0.29	3.14	4.30	18.37	16.72
Max			**8.91**	**0.41**	**4.45**	**4.64**	**19.86**	**28.57**
Min			**8.25**	**0.28**	**2.12**	**3.72**	**16.43**	**14.46**
Total Mean			**8.62**	**0.34**	**3.48**	**4.19**	**18.39**	**20.16**
S.D.			**0.19**	**0.03**	**0.68**	**0.26**	**0.89**	**3.60**

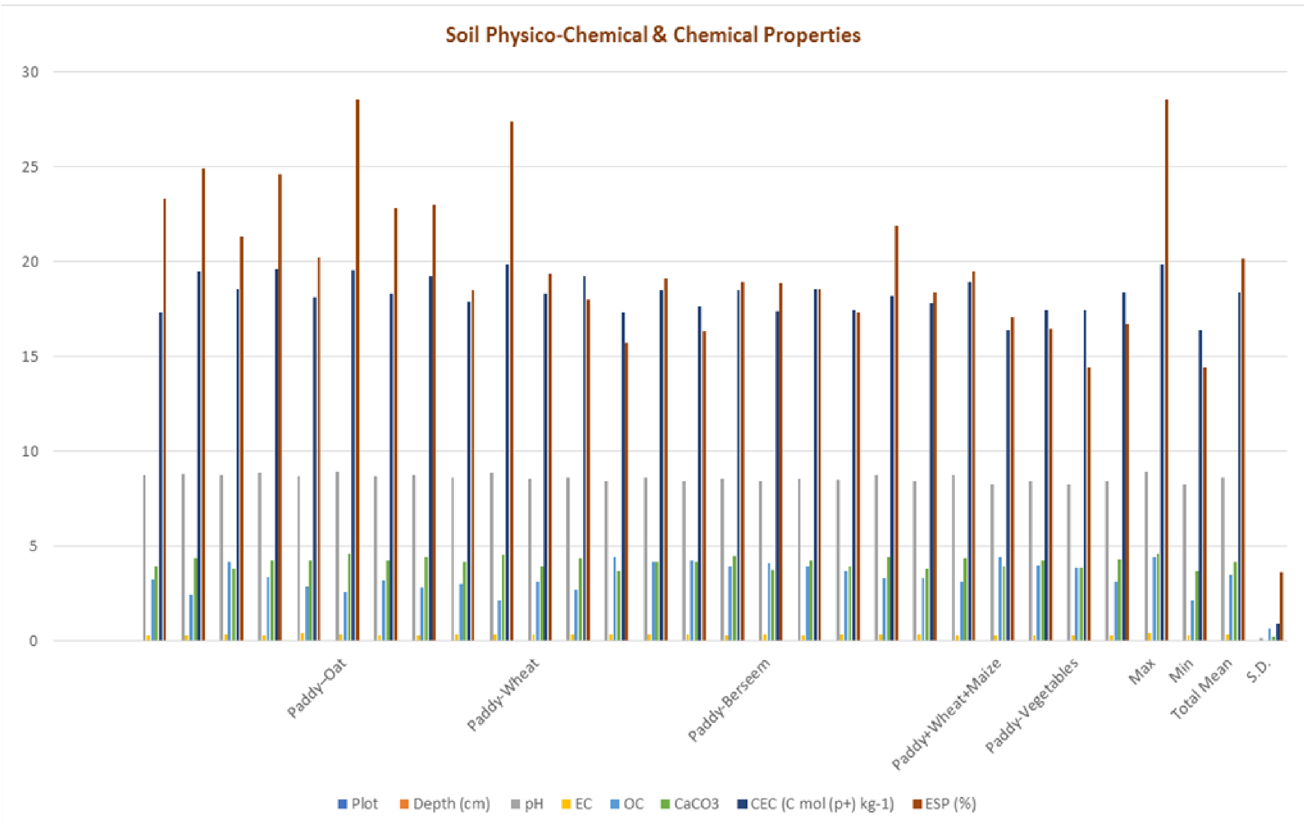

Fig. 2 : Soil physico-chemical properties and chemical properties of NSP-6 Farm under different cropping systems.

Soluble Cations, Soluble Anions and SAR.

The soil parameters such as Soluble Cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and Soluble anions (HCO_3^-, CO_3^{2-}, Cl^-, SO_4^{2-}) and Sodium Absorption Percentage (SAR) were determined and presented in the table 6 and fig 3. The data revealed that the maximum mean soluble Ca^{2+} (6.73 me L^{-1}) was recorded in B4 plot at 0-15 cm depth under Paddy-Berseem cropping system closely followed by 6.66 me L^{-1} in C1 plot a 0-15 cm depth under Paddy + Wheat + Maize cropping system and minimum mean soluble Ca^{2+} (5.16 me L^{-1}) was recorded in A6 plot at 15-30 cm depth under Paddy-Wheat cropping system. The maximum mean solubleMg^2 (7.54 me L^{-1}) was recorded in C1 plot at 0-15 cm depth under Paddy + Wheat + Maize cropping system closely followed by 7.43 me L^{-1} in C2 plot at 0-15 cm depth under Paddy-Vegetable cropping system and minimum mean soluble Mg^{2+} (5.19 me L^{-1}) was observed in A1 plot at 15-30 cm depth under Paddy-Oat cropping system. The maximum mean soluble Na^+(59.62 me L^{-1}) was recorded in A4 plot at 0-15 cm depth under Paddy-Oat cropping system closely followed by 57.36 me L^{-1} in A5 plot at 0-15 cm depth under Paddy-Oat cropping system and minimum mean soluble Na^+ (42.58 me L^{-1}) was observed in B2 plot at 15-30cm in Paddy-Berseem cropping system. The maximum mean soluble K^+ (7.05me L^{-1}) was noted in C1 plot at 0-15 cm depth under Paddy + Wheat + Maize cropping system closely followed by 6.90 me L^{-1} in B1 plot at 0-15 cm depth under Paddy-Berseem cropping system and minimum mean soluble K^+ (6.00 me L^{-1}) was observed in A2 plot at 0-15 cm depth under Paddy-Oat cropping system. The maximum mean SAR (26.19) was found in A3 plot at 15-30 cm depth under Paddy-Oat cropping system which was closely followed by SAR (25.74) in A5 plot at 15-30cm depth under Paddy-Oat cropping system and minimum mean SAR (12.14) was recorded in C2 plot at 15-30 cm depth under Paddy-Vegetable cropping system. The maximum mean soluble CO_3^{2-} (8.63 me L^{-1}) was recorded in C1 plot at 0-15cm depth under Paddy + Wheat + Maize cropping system which was closely followed by 8.47 me L^{-1} in B1 plot at 0-15 cm depth under Paddy-Berseem cropping system and minimum mean soluble CO_3^{2-} (7.34 me L^{-1}) was recorded in A2 plot at 0-15 cm depth under Paddy-Oat cropping system. The maximum mean soluble HCO_3^- (10.85 me L^{-1}) was recorded in A4 plot at 0-15cm depth under Paddy-Oat cropping system which was closely followed by 10.54me L^{-1} in A4 plot at 15-30cm depth under Paddy-Oat cropping system and minimum mean soluble HCO_3^- (5.74 me L^{-1}) was observed in B5 plot at 15-30cm depth under Paddy-Berseem cropping system. The maximum mean soluble Cl^- (9.55 me L^{-1}) was recorded in A3 plot at 0-15 cm depth under Paddy-Oat cropping system closely followed by 9.32 me L^{-1} in A3 plot at 15-30 cm depth under Paddy-Oat cropping system and minimum mean soluble Cl^- (4.32 me L^{-1}) was observed in B4 plot at 15-30 cm depth under Paddy-Berseem cropping system. The maximum mean soluble SO_4^{2-} (18.45 me L^{-1}) was analysed in A5 plot at 0-15cm depth under Paddy-Oat cropping system which was closely followed by 16.85 me L^{-1} in C1 plot at 0-15cm depth under Paddy + Wheat + Maize cropping system and minimum mean soluble SO_4^{2-} (10.84 me L^{-1}) was observed in A1 plot at 15-30cm depth under Paddy-Oat cropping system.

The soluble Ca^{2+} under different cropping system ranged (5.16-6.73 me L^{-1}) with an average of 5.76 me L^{-1}, Mg^{2+}ranged (5.19-7.54 me L^{-1}) with an average of 6.48 me L^{-1}, Na^+ ranged (42.58-59.62 me L^{-1}) with an average of 51.16 me L^{-1}, K^+ ranged (6.00-7.05 me L^{-1}) with an average of 6.49 meL^{-1}, and SAR ranged (12.14-26.19) with an average of 18.12. The CO_3^{2-} ranged from (7.34-8.63 meL^{-1}) with an average of 7.95 me L^{-1}, HCO_3^- ranged (5.74-10.85 me L^{-1}) with an average of 7.97 me L^{-1}, Cl^- ranged from (4.32-9.55 me L^{-1}) with an average of 7.38 me L^{-1}, SO_4^{2-} ranged (10.84-18.45 me L^{-1}) with an average of 14.56 me L^{-1}. The Standard deviation of Ca^{2+}, Mg^{2+}, Na^+, K^+, SAR, CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-} were 0.49, 0.63, 4.55, 0.28, 3.72, 0.35, 1.07, 1.35 and 1.82, respectively.

The increase in soil pH decreases the solubility of cations (Ca^{2+}, Mg^{2+}, Na^+ & K^+) and anions (CO_3^{2-}, HCO_3^- , Cl^- & SO_4^{2-}) in the soil profile. The change in soil pH by acid or base amendment changes the concentration of cations and anions in soil solution. The SAR value generally increase with increase in soil pH. The similar findings were also reported by (Sharpley, 1991).

Table 6 : Plot-wise status of Soluble Cations, Soluble anions and SAR of NSP-6 Farm

Cropping System	Plot	Depth (cm)	Soluble cations (me L^{-1})				SAR	Soluble anions (me L^{-1})			
			Ca^{2+}	Mg^{2+}	Na^+	K^+		CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}
	A1	0-15	5.65	5.92	50.47	6.34	21.99	7.75	9.93	7.78	12.53
		15-30	5.17	5.19	48.32	6.28	23.55	7.69	9.67	7.61	10.84
	A2	0-15	5.56	6.63	50.93	6.00	20.36	7.34	8.45	8.75	14.53
		15-30	5.24	6.17	48.58	6.11	22.37	7.48	8.38	8.54	13.47
	A3	0-15	5.74	5.62	53.64	6.88	18.52	8.42	9.62	9.55	15.42

Paddy–Oat		15-30	5.26	5.24	56.45	6.73	26.19	8.29	9.38	9.32	14.86
	A4	0-15	5.64	6.52	59.62	6.55	20.40	8.02	10.85	8.24	16.78
		15-30	5.17	6.17	46.22	6.49	20.84	7.98	10.54	8.16	15.83
	A5	0-15	5.37	6.23	57.36	6.40	16.70	7.86	9.02	7.97	18.45
		15-30	5.92	5.83	43.58	6.31	25.74	7.83	8.92	7.28	16.76
Paddy-Wheat	**A6**	0-15	5.53	6.46	52.33	6.48	17.39	7.98	9.03	8.32	13.87
		15-30	5.16	5.92	44.52	6.26	16.29	7.74	8.56	7.64	12.73
Paddy-Berseem	**B1**	0-15	5.82	7.26	55.48	6.90	14.00	8.47	9.34	8.17	16.65
		15-30	5.34	6.97	50.32	6.44	16.53	7.94	8.97	7.68	16.28
	B2	0-15	5.92	7.32	47.56	6.72	13.88	8.26	9.25	7.93	14.32
		15-30	5.27	6.84	42.58	6.20	16.47	7.64	8.37	6.52	13.28
	B3	0-15	6.36	6.95	55.63	6.47	17.27	7.95	8.54	6.83	15.83
		15-30	5.92	6.36	49.45	6.21	17.51	7.64	7.43	5.41	14.57
	B4	0-15	6.73	6.78	56.47	6.98	15.79	8.57	8.69	5.16	14.24
		15-30	6.36	6.29	52.42	6.87	19.96	8.44	7.35	4.32	12.31
	B5	0-15	5.62	6.82	55.35	6.69	16.17	8.23	7.46	5.94	14.97
		15-30	5.25	6.38	49.42	6.32	17.39	7.76	5.74	4.76	13.84
Paddy + Wheat + Maize	**C1**	0-15	6.66	7.54	56.37	7.05	14.92	8.63	9.54	8.27	16.85
		15-30	6.19	7.05	50.72	6.49	14.86	7.96	8.26	7.62	14.33
Paddy-Vegetables	**C2**	0-15	6.42	7.43	50.28	6.32	12.14	7.72	9.18	8.15	13.36
		15-30	6.19	6.83	46.24	6.24	13.02	7.64	7.84	6.82	11.54
Max			**6.73**	**7.54**	**59.62**	**7.05**	**26.19**	**8.63**	**10.85**	**9.55**	**18.45**
Min			**5.16**	**5.19**	**42.58**	**6.00**	**12.14**	**7.34**	**5.74**	**4.32**	**10.84**
Total Mean			**5.76**	**6.48**	**51.16**	**6.49**	**18.16**	**7.97**	**8.75**	**7.38**	**14.56**
S.D.			**0.49**	**0.63**	**4.55**	**0.28**	**3.72**	**0.35**	**1.07**	**1.35**	**1.82**

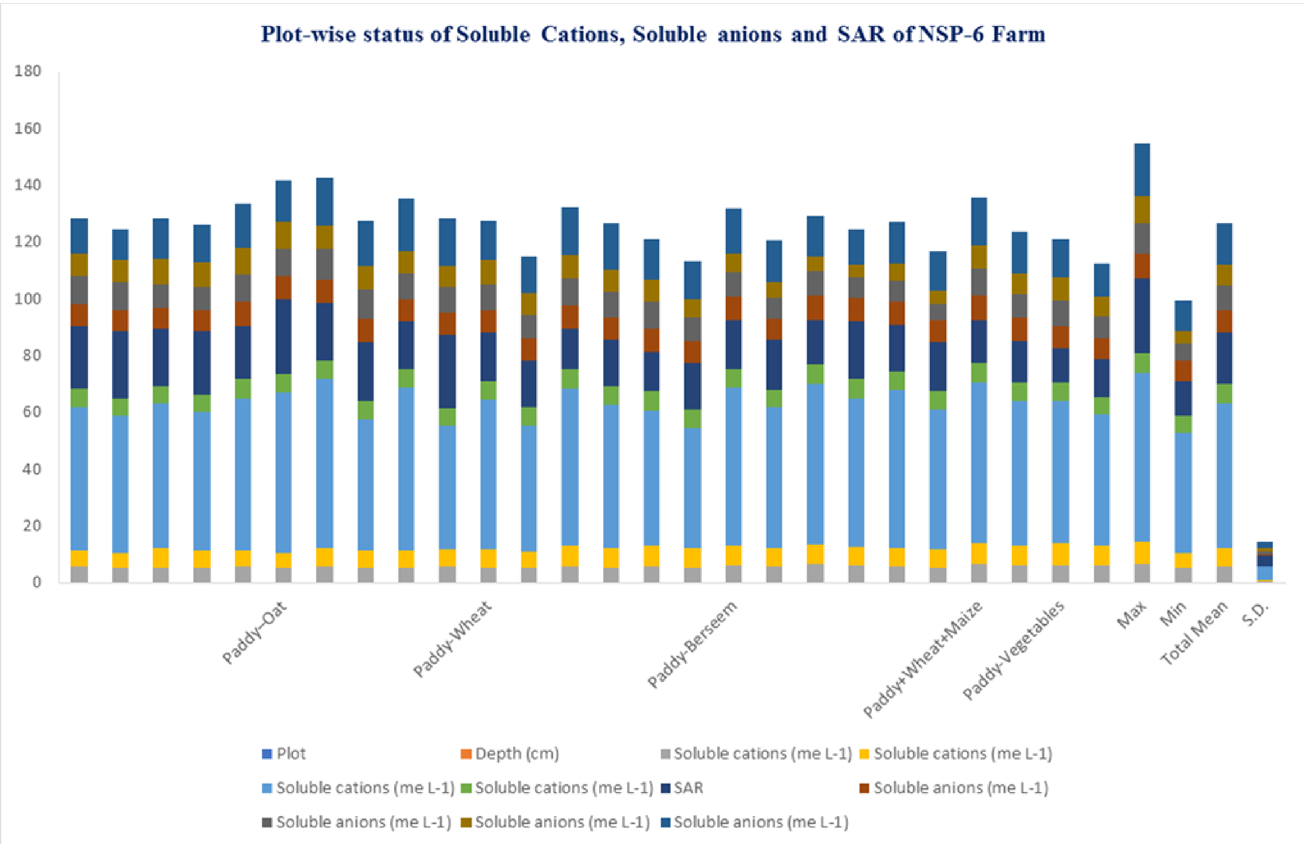

Fig. 3 : Plot-wise status of Soluble Cations, Soluble anions and SAR of NSP-6 Farm

Available Nutrient Status

The data pertaining to soil available nutrients in soil under different cropping systems have been presented in the table 7 and fig 4. The maximum mean soil available nitrogen (237.41 kg ha^{-1}) was recorded in C1 plot at 0-15 cm depth under Paddy+Wheat+Maize cropping system closely followed by nitrogen (230.59 kg ha^{-1}) at 0-15 cm depth in B1 plot under Paddy-Berseem and minimum mean soil available nitrogen (176.24 kg ha^{-1}) was recorded at 15-30 cm depth in A5 plot under Paddy-Oat cropping system. The maximum mean available phosphorus (16.85 kg ha^{-1}) was observed in C1 plot at 0-15 cm depth under Paddy+ Wheat+ Maize cropping system followed by phosphorus (115.85 kg ha^{-1}) at 0-15 cm depth in B1 plot under Paddy-Berseem cropping system and minimum mean available phosphorus (12.51 kg ha^{-1}) was recorded at 15-30 cm depth in A6 Plot under Paddy-Wheat cropping system.The maximum mean available potassium (263.51 kg ha^{-1}) was in C1 plot at 0-15 cm depth under Paddy+Wheat+Maize cropping system which was closely followed by potassium (258.87 kg ha^{-1}) in B1 plot at 0-15 cm depth under Paddy-Berseem cropping system and minimum mean available potassium (244.53 kg ha^{-1}) was observed at 15-30 cm depth in C1 plot under Paddy-Berseem cropping system. The maximum mean available Sulphur (11.36 mg kg^{-1}) was observed in C1 plot at 0-15 cm depth under Paddy+ Wheat+ Maize cropping system which was closely followed by Sulphur (10.92 mg kg^{-1}) in B1 plot at 0-15 cm depth under Paddy-Berseem cropping system and minimum mean available Sulphur (7.63 mg kg^{-1}) were recorded in A5 plot at 15-30 cm depth under Paddy-Wheat cropping system. The maximum mean available Zn (0.39 mg kg^{-1}) was observed in C1 plot at 0-15 cm depth under Paddy+ Wheat+ Maize followed by Zn (0.38 mg kg^{-1}) in B2 plot at 15-30 cm depth from Paddy-Berseem cropping system and minimum mean available Zn (0.32 mg kg^{-1}) was recorded in A6 plot at 15-30 cm depth from Paddy-Wheat cropping system.

The available contents of nitrogen ranged (176.24-237.41 kg ha^{-1}) with an average of 206.83 kg ha^{-1}, phosphorus ranged (12.51-16.85 kg ha^{-1}) with an average of 14.54 kg ha^{-1}, potassium ranged (244.53-263.51 kg ha^{-1}) with an average of 253.42 kg ha^{-1} and Sulphur ranged (7.63-11.36 mg kg^{-1}) with an average of 9.40 mg kg^{-1} and Zinc ranged (0.32-0.39 mg kg^{-1}) with an average of 0.36 mg kg^{-1}. The Standard deviation of soil available N, P, K, S and Zn were 20.87, 1.07, 4.27, 1.15, 0.02, respectively.

The nutrient availability is mainly related with the organic matter content in the soil. In general, the organic matter is high in surface horizon or top soil than sub-surface horizon which favours its decomposition and increases the availability of macro and micro-nutrients by increasing their solubilization. The availability of the nutrients decreases due to the less organic carbon content down the soil profile. The findings were in reference to (Kumar *et al.*, 2018), (Shiva *et al.*, 2017), (Kumar *et al.*, 2021), (Mishra *et al.*, 2012), (Sharma *et al.*, 2010) and (Lindsay and Norvell, 1978).

Table 7 : Soil Available Nutrient Status of NSP-6 Farm Under Different Cropping Systems.

Cropping System	Plot	Depth (cm)	Soluble anions (me L^{-1})			Available Sulphur (mg kg^{-1})	Available Zinc (mg kg^{-1})
			Nitrogen	Phosphorus	Potassium		
Paddy–Oat	A1	0-15	186.35	15.01	253.45	8.54	0.37
		15-30	181.33	13.67	250.32	7.91	0.36
	A2	0-15	194.46	14.21	254.61	9.02	0.34
		15-30	192.76	13.67	251.34	8.83	0.33
	A3	0-15	188.42	15.65	255.76	9.79	0.36
		15-30	184.71	14.71	253.47	8.54	0.35
	A4	0-15	184.62	14.73	252.23	8.15	0.37
		15-30	179.17	13.51	250.46	8.02	0.36
	A5	0-15	182.73	13.21	249.56	7.92	0.37
		15-30	176.24	12.64	248.40	7.63	0.35
Paddy-Wheat	A6	0-15	194.58	14.32	254.26	8.13	0.35
		15-30	191.41	12.51	251.43	8.03	0.32
Paddy-Berseem	B1	0-15	230.59	15.85	258.87	10.67	0.37
		15-30	228.35	14.61	252.52	10.92	0.36
	B2	0-15	228.56	15.22	256.81	10.35	0.38
		15-30	226.28	14.37	255.43	10.57	0.37
	B3	0-15	223.82	15.41	252.73	10.15	0.37
		15-30	221.65	15.33	251.42	9.67	0.36

	B4	0-15	215.82	14.57	248.64	9.49	0.38
		15-30	213.47	13.83	247.22	9.38	0.37
	B5	0-15	210.73	14.38	246.82	9.34	0.37
		15-30	209.81	13.86	244.53	9.26	0.36
Paddy + Wheat + Maize	**C1**	0-15	237.41	16.85	263.51	11.36	0.39
		15-30	235.98	15.67	261.32	11.19	0.38
Paddy-Vegetables	**C2**	0-15	222.64	14.21	252.47	9.87	0.38
		15-30	220.84	13.09	250.39	9.66	0.37
Max			**237.41**	**16.85**	**263.51**	**11.36**	**0.39**
Min			**176.24**	**12.51**	**244.53**	**7.63**	**0.32**
Total Mean			**206.83**	**14.54**	**253.42**	**9.40**	**0.36**
S.D.			**20.87**	**1.07**	**4.27**	**1.15**	**0.02**

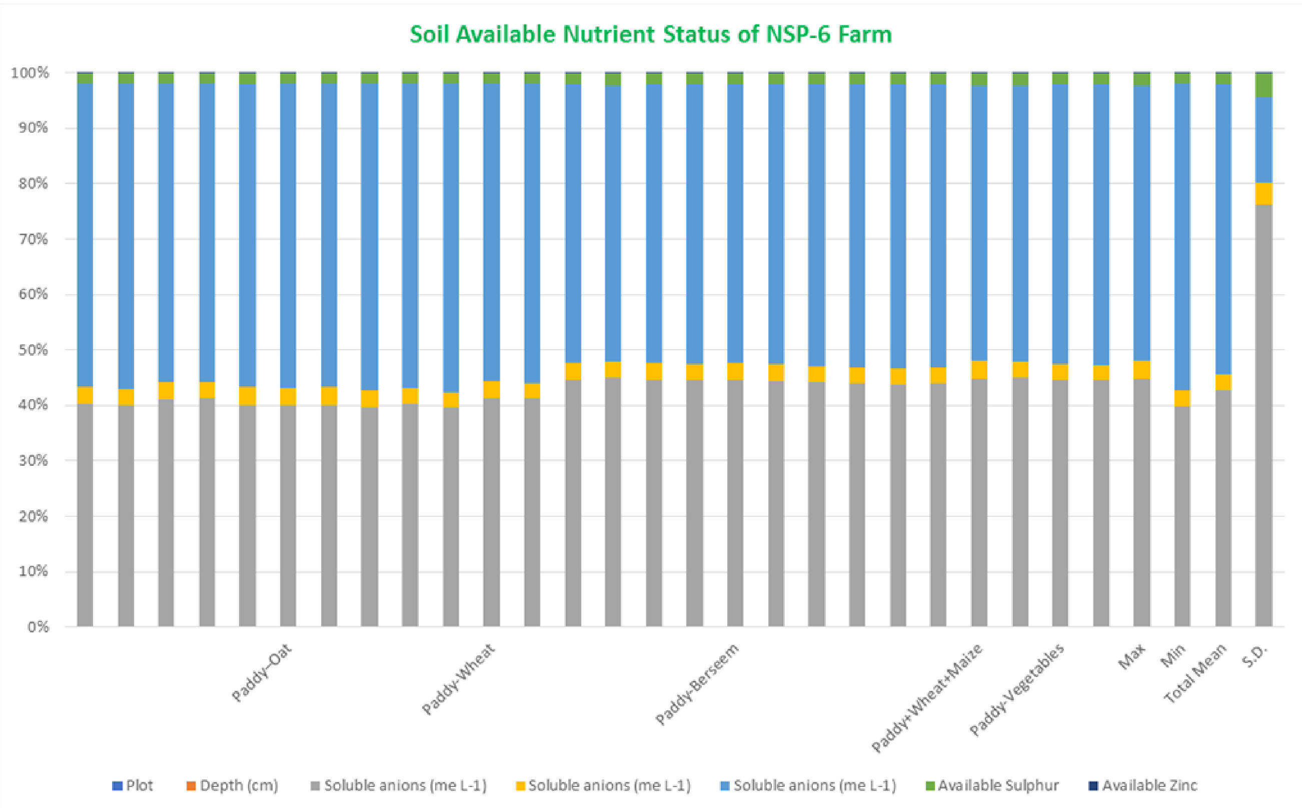

Fig. 4 : Soil Available Nutrient Status of NSP-6 Farm Under Different Cropping Systems.

Correlation study of soil properties:

The correlation studies among different physico-chemical properties of soil and availability of different nutrients Viz. Nitrogen, Phosphorus, Potassium and Sulphur and Zinc were correlated and calculated at 1% and 5% Degree of freedom to observe the relation among different properties of soils and availability of nutrients.

Correlation between physical, physico-chemical and chemical properties of soils.

The correlation between physical and physico-chemical properties of soils are presented in table 8. The results reveals that the SAR vs. ESP, CEC, pH; ESP vs. CEC, pH; CEC vs. pH; pH vs. Sand; Porosity vs. B.D; SAR. vs. CEC; ESP vs. Sand; $CaCO_3$ vs. pH; O.C. vs. Clay showed significantly and positive correlation at 1% and 5%, respectively. whereas SAR vs. Clay; ESP vs. Clay; pH vs. Clay; Porosity vs. B.D.; P.D. vs B.D.; Clay vs. Sand; Silt vs. Sand resulted significantly and negative correlation at 1% level. The similar results were found by (Sharma and Kumar, 2003) and (Raghubanshi *et al.,* 2008).

Table 8 : Correlation between physical and physic-chemical and chemical properties.

Parameter	Sand (%)	Silt (%)	Clay (%)	BD	PD	POROSITY	pH	EC	OC	CaCO3	CEC	ESP (%)	SAR
Sand (%)	1.000	-0.773**	-0.836**	0.161	0.060	-0.084	0.719**	0.342	-0.548	0.120	0.431	0.669*	0.714**
Silt (%)		1.000	0.297	-0.067	-0.190	-0.030	-0.314	-0.554	0.168	0.242	0.010	-0.239	-0.295
Clay (%)			1.000	-0.184	0.075	0.152	-0.810**	-0.035	0.680*	-0.391	-0.657*	-0.800**	-0.818**
BD				1.000	-0.788**	-0.971**	0.111	-0.037	-0.251	0.064	0.157	0.305	0.264
PD					1.000	0.913**	-0.070	0.215	0.040	-0.230	-0.199	-0.250	-0.197
POROSITY						1.000	-0.102	0.107	0.182	-0.133	-0.182	-0.301	-0.253
pH							1.000	-0.047	-0.666*	0.614*	0.802**	0.895**	0.898**
EC								1.000	0.086	-0.233	-0.198	-0.112	-0.075
OC									1.000	-0.625*	-0.692*	-0.665*	-0.640*
CaCO3										1.000	0.724**	0.550	0.494
CEC											1.000	0.709**	0.680*
ESP (%)												1.000	0.989**
SAR													1.000

Note: * = Significant at 5% level, ** = Significant at 1% level

Correlation between soil properties and availability of nutrients.

The correlation between soil properties and soil available nutrients are presented in table 9. The results reveal that Organic Carbons vs. Nitrogen, Sulphur; pH vs. $CaCO_3$ had positive correlation at 1% and 5%, respectively. While B.D. vs. Porosity; pH vs. available N, S and Zn had negative correlation (Singh *et al.*, 2013) and (Sharma and Kumar, 2003).

Table 9 : Correlation between physical, physico-chemical properties and availability of nutrients.

Parameter	BD	PD	POROSITY	pH	EC	OC	$CaCO_3$	CEC	Nitrogen	Phosphorus	Potassium	Sulphur	Zinc
BD	1.000	-0.788**	-0.971**	0.111	-0.037	-0.251	0.064	0.157	-0.272	-0.134	0.038	-0.230	-0.165
PD		1.000	0.913**	-0.070	0.215	0.040	-0.230	-0.199	-0.044	0.016	-0.118	-0.075	0.085
POROSITY			1.000	-0.102	0.107	0.182	-0.133	-0.182	0.164	0.095	-0.072	0.123	0.142
pH				1.000	-0.047	-0.666*	0.614*	0.802**	-0.765**	-0.462	-0.434	-0.654*	-0.619*
EC					1.000	0.086	-0.233	-0.198	-0.046	0.236	0.125	0.077	-0.084
OC						1.000	-0.625*	-0.692*	0.831**	0.668*	0.561	0.827**	0.440
$CaCO_3$							1.000	0.724**	-0.379	-0.442	-0.267	-0.338	-0.296
CEC								1.000	-0.638*	-0.711**	-0.520	-0.641*	-0.757**
Nitrogen									1.000	0.574	0.436	0.927**	0.573
Phosphorus										1.000	0.703*	0.717**	0.571
Potassium											1.000	0.594*	0.270
Sulphur												1.000	0.555
Zinc													1.000

Note: * = Significant at 5% level, ** = Significant at 1% level

Statistical Analysis

The recorded survey data were statistically analysed using appropriate techniques to assess the effects of cropping systems on productivity and soil health indicators. Descriptive statistics were computed and suitable inferential statistical tests such as t-test and chi-square test were applied wherever required. The significance of variation among different parameters was tested at the 5 per cent level of probability. Correlation coefficients among various soil parameters were worked out and regression equations were developed following the standard procedures described by (Chandel,1984).

Conclusion

The present study demonstrates that cropping systems significantly influence soil fertility dynamics and depth-wise physico-chemical properties under sodic and alkaline conditions of the NSP-6 Experimental Farm, ANDUA&T, Ayodhya. Soil texture remained unchanged (silty loam) across all treatments, indicating that it is an inherent property and not affected by cropping systems and soil depth.

Bulk density (1.52-1.58 Mg m^{-3}), particle density (2.62-2.68 Mg m^{-3}) and porosity (39.79-43.30%) showed relatively narrow variation, suggesting that short term cropping interventions had limited impact on soil physical structure. However, a consistent increase in bulk density and decline in porosity with depth was observed primarily due to reduced organic matter and compaction in sub-surface layers.

Soil chemical properties revealed that the soils were moderately to strongly alkaline with pH ranging from 8.25 to 8.91 and mean EC of 0.34 dS m^{-1}, indicating non saline but sodicity prone conditions. Exchangeable sodium percentage (14.46-28.57) and Sodium Adsorption Ratio (12.14-26.19) further confirmed the sodic nature of soils, particularly under continuous cereal-based systems such as Paddy-Oat, which recorded the highest values of pH (8.91), ESP (28.57%) and SAR (26.19).

In contrast, diversified cropping systems significantly improved soil chemical environment and nutrient availability. The Paddy-Wheat-Maize system recorded the lowest pH (8.25), higher organic carbon (4.45 g kg^{-1}) and superior nutrient status including available nitrogen (237.41 kg ha^{-1}), phosphorus (16.85 kg ha^{-1}), potassium (263.51 kg ha^{-1}), sulphur (11.36 mg kg^{-1}) and zinc (0.39 mg kg^{-1}).

Similarly, the Paddy-Berseem system showed higher organic carbon content (up to 4.42 g kg^{-1}) along with relatively lower ESP and SAR values. A consistent depth-wise variation was observed, with higher organic carbon and nutrient availability in surface soils (0-15 cm) compared to subsurface soils (15-30 cm), highlighting the role of surface organic matter accumulation in nutrient dynamics.

Overall, the findings indicate that diversified cropping systems, particularly Paddy-Wheat-Maize and Paddy-Berseem are more effective in maintaining soil fertility and improving soil chemical properties under sodic conditions.

Acknowledgement

The author extends heartfelt gratitude to the professors and the Head of the Department, Department of Soil Science and Agricultural Chemistry at Acharya Narendra Deva University of Agriculture and Technology for their invaluable support and guidance.

Conflicts of Interest: None

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