***Original Research Article***

**SOIL PHYSICAL PROPERTIES UNDER DIFFERENT LAND USE SYSTEMS IN TARAI REGION OF UTTARAKHAND, INDIA**

**ABSTRACT**

Soil physical properties play a key role in maintaining and improving soil health by influencing the structure of soil, porosity, water infiltration, aggregation, and various chemical and biological properties. The physical properties are influenced by the various cultivation and management practices, land use patterns and cropping systems. In the present study the effect of different types of land use systems on soil physical properties *viz.* BD, PD, porosity, and WHC at 0-15 cm and 15-30 cm depth were studied. The land use systems taken for the study were diversified cereal crop based systems with the inclusion of legumes, an orchard based system, a vegetable based system and an uncultivated system. A total of 66 soil samples from 0-15 cm and 15-30 cm depth were analysed for soils physical properties using F test of significance at 5% value of CD. The results showed that the bulk density for various land use systems ranged from 1.15 Mg/m3to 1.44 Mg/m3; 1.29 Mg/m3to 1.63 Mg/m3, particle density from 2.61 Mg/m3to 2.69 Mg/m3; 2.61 Mg/m3to 2.67 Mg/m3, porosity % from 45.85% to 56.04%; 38.98 % to50.48%, water holding capacity from 41.69% to 56.39%; 40.8% to 55.27%, at 0-15 cm and 15-30 cm soil depth, respectively. The results revealed that better soil physical properties were observed in those land use systems that included legumes as compared to those without legumes i.e. vegetable based and orchard based while the uncultivated system showed lowest values for all studied physical properties. From the study, it was concluded that the land use systems that followed legume inclusion along with diversification of crops showed better physical properties and health of the soil.

***Key words:*** *land use systems, physical properties, legumes, crop diversification, organic matter.*

**ABBREVATIONS**

**ANOVA-** analysis of variance

**BD** – bulk density

**CD**- critical difference

**CRD-** completely randomized design

**OM-** organic matter

**PD -** particle density

**SOC-** soil organic carbon

**WHC**- water holding capacity

**1. INTRODUCTION**

 One of the most important resources of nature, soil is a diverse ecosystem consisting of minerals, organic matter (OM), living organisms, water, and air. It maintains an unceasing flow of matter and energy within and with the surrounding environment via various physical, chemical, and biological processes **(Weil and Brady, 2017).** Soil is a complex system formed at the intersection of the atmosphere, lithosphere, hydrosphere and biosphere and is critical to food production and key to sustainability through its support of important societal and ecosystem services **(Brevik *et al.,* 2015; Lehmann *et al.,* 2020)**. The soil performs various functions such as supporting plant growth, purifying and regulating water movement, decomposition of OM and recycle of nutrients. It harbors organisms, buffers environmental changes and provides provisions for food, fiber and fuel, detoxifies organic contaminants and sequesters carbon as well.

Diversifying land use systems with inclusion of legumes along with cereals influence the soil organic carbon storage which causes quantitative and qualitative changes on SOM, and consequently on various physical, chemical and biological properties, on soil and environment health **(Cardoso *et al.,* 2013).** The diversification of land use systems not only optimize crop production but also balance soil biodiversity, enhance nutrient use efficiency, reduce soil borne pathogens, weed suppression and cause a break in the pest cycle **(Barbieri *et al.,* 2019; Gurr *et al.,* 2016).** It also influences soil structure, aggregation, porosity, reduces erosion hazard, improves carbon storage and carbon sequestration and reducing carbon foot-print. The inclusion of legumes for crop diversification reduces the need of synthetic fertilizers due to the symbiotic N2-fixation by the legume plants from the atmosphere, thus, reducing the carbon footprint of agricultural products and overall leading to improvement in soil health **(Tian *et al.,* 2021; Plaza-Bonilla *et al*., 2018; Liu *et al*., 2022).**The goal of soil health maintenance is to ensure maximum productivity and environmental sustainability under five essential evaluation standards *viz*. nutrient cycling, water relations, biodiversity and habitat filtering, buffering and physical stability and support **(Hatfield *et al.,* 2017).**

Soil physical properties play an important role in the determination of suitability of soils for many key processes about agricultural and environmental uses. The supporting capability, movement, retention and availability of water and nutrients to plants, ease in root penetration and flow of heat and air are directly influenced by soil physical properties. The physical properties of soil also influence the chemical, biological properties and agronomic potential. **(Phogat *et al.,* 2015; Delgado and Gomez, 2016).** Soil physical properties provide information related to water and air movement through soil, as well as various conditions affecting germination, root growth and erosion processes. Land use systems such as cereal based, legume based, and horticulture based etc influence soil physical properties through tillage based operations, root growth patterns, organic matter addition, litter fall etc. Increasing crop diversity influences soil physical health due to diverse root system that increases the network and continuity of soil pores, aggregation and SOC **(Liu *et al.,* 2022).** **Patra *et al.* (2023)** found that a diversified maize-wheat-green gram system showed improved soil physical properties. **Nath *et al.* (2023)** also reported increased in soil porosity, WHC and improved soil physical conditions in a pigeon pea-wheat and maize-wheat-mungbean systems over the non legume maize-wheat system. Several other similar studies have reported the effect of different land uses on soil physical properties **(Kumar *et al.,* 2020; Maitra *et al.,* 2021; Padwal *et al.,* 2023)**, however limited studies have been done to study the long term effect of the diversified land use systems on soil physical properties in *Tarai* region of Uttarakhand*.* In this regard the present study was conducted to study the influence of different types of land use systems being followed for a period of seven years (2017-2024) on soil physical properties and soil health.

**2. MATERIAL AND METHODS**

**2.1 Field site and sampling**

The present study was conducted in the year 2024 from the ongoing experiment on different land use systems, setup in the year 2017 at the Integrated Farming System Unit block, located at Norman E. BorlaugCrop Research Centre, of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar (Udhamsingh Nagar), Uttarakhand, India, which lies in the foothills of the Shivalik range of theHimalayas. It is a sub-humid, sub-tropical climate zone, locally called as *Tarai* region. It is located at 290 N latitude and 730 3’ E longitudes with an altitude of 243.84m above mean sea level. The climate in Pantnagar is sub-humid and sub-tropical, with hot, dry summers and cool winters. The *Tarai* region experiences a dry season from early October to mid June and a wet season from mid-June to early October. The average annual rainfall is between 1300 and 1500 mm, with roughly 85 to 90% of that amount occurring between June and September. The soils belong to the Beni series of order Mollisols. The native vegetation is thick mainly because of the prevalence of high moisture in the *Tarai* belt and the forest area is classified as low alluvial savannah **(Puri, 1960).**

Three composite soil samples from 0-15 cm and 15-30 cm depth representing the whole area were collected randomly from eleven different land use systems comprising field crops (cereals and legumes), horticultural crops, vegetable crops and uncultivated land of the same block during kharif 2024. Soil samples from the following land use systems were analyzed:

1. Rice- Wheat- Green Manure
2. Sorghum-Berseem+ Mustard+ Oat-Maize+Cowpea
3. Basmati Rice-Oat-Bajra+ Cowpea (Fodder)
4. Maize-Broccoli-Okra
5. Basmati Rice-Potato-Maize(Green Cobs)
6. Maize-Yellow Sarson- Moong
7. Black Gram-Wheat-Maize Fodder+ Cowpea
8. Soybean- Lentil
9. Guava+Turmeric
10. Soybean-Wheat
11. Uncultivated

Design- CRD

Replications -3

**2.2 Methodology**

The physical properties were measured in the laboratory using the following procedures-

**2.2.1 Bulk density-** the bulk density was determined by using core sampler method given by **Baver (1956)**. For this, the core sampler was pushed into the soil to a depth of 0-15 cm and 15-30 cm and the collected soil core samples were transferred into a pre -weighed moisture box, weighed and dried in oven at 105˚C for 48 hrs. Bulk density was calculated using the following formula:

 Bulk density (Mg/m3**) =** $\frac{Oven dry weight of soil (Mg)}{Total volume of soil (m3)}$

**2.2.2 Particle density-** Particle density was determined by using the procedure given by **Baver (1956).** For this 50 mL of water was filled in a 100 mL of graduated cylinder and 20 g of oven dry soil was added in it. The content in cylinder was stirred, slowly tapped and allowed to stand for 10 minutes. Then the difference between initial volume of water and the volume of soil plus water mixture was recorded which represents the volume of water displaced or the volume occupied by the soil particles.

Particle density (Mg/m3**) =**$\frac{weight of oven dry soil}{volume of soil solids}$

**2.2.3 Porosity-** Porosity was determined by the method given by **Baver (1956)** by using the following formula.

$$Porosity \left(\%\right)=1-\frac{Bulk density of soil}{Particle density of soil }×100$$

**2.2.4 Water holding capacity-** For determination of water holding capacity (WHC) of the soil samples Hilguard apparatus was used **(Piper, 1950).** For this first the empty cups of the hilguard apparatus along with filter paper disc were weighed and the sieved soil samples were then transferred into the hilguard apparatus with the help of a spatula, leveled smoothly on the surface and weighed again. The apparatus was then positioned in a petri dish filled with water to a depth of half its length and was left overnight for saturation. Next day the apparatus was removed, wiped from outside and weighed immediately. The water holding capacity was computed using the formula:-

$$MWHC \left(\%\right)=\frac{Moisture held by the soil}{Dry weight of soil }×100$$

$$ = \frac{\left(W3-W2\right)-W4 }{W2-W1}×100$$

Where, W1= weight of empty cup

 W2= weight of cup + soil

 W3= weight of cup + soil + water

 W4= weight of water absorbed by filter paper

**2.2.5 Statistical analysis-** The data from the observations for these parameters was analyzed statistically using the ANOVA technique of **Panse and Sukhatme (1985).** CRD design was used with three replications and F test of significance at 5% level of probability, was performed taking value of CD 5%.

**3. RESULTS AND DISCUSSION**

**3.1Bulk density**

Bulk density refers to the ratio of oven-dried particles to total soil volume, expressed in SI units, such as g/cm3, kg/m3, or Mg/m3. It indicates the soil's structural condition at a certain depth **(Wilke, 2005)**.The data on bulk density is shown in Table 1. The bulk density for the different land use systems ranged from 1.15 Mg/m3 to 1.44 Mg/m3for 0-15 cm depth and from 1.29 Mg/m3to 1.63 Mg/m3at 15-30 cm soil depth. Of all the studied land use systems it was observed that legume based systems showed lower values of bulk density while non legumes based systems had higher values of bulk density, with significantly lowest values of bulk density observed for the Rice-Wheat-Green manure system (1.15 Mg/m3, 1.29 Mg/m3), which was at par with Soybean-Lentil (1.24 Mg/m3, 1.37 Mg/m3) at 0-15 cm and 15-30 cm depth. BD of Black Gram-Wheat-Maize Fodder+ Cowpea (1.26 Mg/m3, 1.4 Mg/m3) was at par with Sorghum-Berseem+ Mustard+ Oat-Maize+Cowpea (1.3 Mg/m3, 1.45 Mg/m3), Maize-Yellow Sarson- Moong (1.3 Mg/m3, 1.48 Mg/m3), Soybean-Wheat (1.33 Mg/m3, 1.49 Mg/m3), Basmati Rice-Oat-Bajra+ Cowpea (Fodder) (1.37 Mg/m3, 1.52 Mg/m3), Basmati Rice-Potato-Maize(Green Cobs) (1.39Mg/m3,1.53 Mg/m3) at 0-15 cm depth but varied at 15-30 cm depth.BD values of Maize-Broccoli-Okra (1.42Mg/m3, 1.54 Mg/m3) and Guava + Turmeric (1.45Mg/m3, 1.59 Mg/m3) and Uncultivated (1.44Mg/m3, 1.63 Mg/m3),were at par with each other at 0-15 cm and 15-30 cm depth, respectively with highest value in uncultivated systems. The results also showed an increase of bulk density along with depth, which could be attributed to compaction at lower depth **(Gupta *et al.,* 2010)**. The lower values of bulk density in legume based system may be attributed to the effect of legumes due to secretion of exudates, and the addition of organic matter into the soil, which improves soil structure, and creates pore spaces which lower the bulk density **(Maheswarappa et al., 1998;Gupta *et al.,* 2010**). In various studies, **Ahmed (2002); Ekka *et al*. (2017); Pandey *et al.* (2018) and Kumar *et al.* (2020)** also reported a decrease in bulk density due to the effect of legumes. The increase bulk density with depth may be due to low organic matter content and decreased aggregation **(Kumar *et al.,* 2020)**.

**3.2. Particle density**

The density of all the soil solid particles together is referred to as the particle density of soils. It can be expressed as the ratio of the total mass of solid particles to the volume of solid particles, eliminating the pore spaces between them **(Blake and Hartage, 1986)**. In the study, the results showed that values of particle density ranged from 2.61-2.69 Mg/m3at 0-15 cm depth and 2.6-2.67 Mg/m3at 15-30 cm depth (table 1). The results showed no significant differences in particle density among the studied land use system. The results on particle density corroborated with the findings of **Alam *et al.***

**(2014); Meena *et al.* (2023).**Particle density is a relatively stable property that mainly depends on soil mineralogy and is less affected by crop types (**Alam *et al.,***

**2014; Meena *et al.,* 2023)**, Slight increase in particle density with depth may be due to decrease in organic matter content at lower depth **(Jain *et al.,* 2023).**

**Table 1. Effect of different land use systems on soil bulk density, particle density and porosity at 0-15 cm and 15-30 cm soil depth.**

|  |  |  |
| --- | --- | --- |
| **Land use systems**  | **Bulk density (Mg/m3)** | **Particle density (Mg/m3)** |
| **15 cm depth** | **30 cm depth**  | **15 cm depth** | **30 cm depth**  |
| 1. Rice- Wheat- Green Manure
 | 1.15 | 1.29 | 2.61 | 2.6 |
| 1. Sorghum-Berseem+ Mustard+ Oat-Maize+Cowpea
 | 1.3 | 1.45 | 2.63 | 2.61 |
| 1. Basmati Rice-Oat-Bajra+ Cowpea (Fodder)
 | 1.37 | 1.52 | 2.65 | 2.6 |
| 1. Maize-Broccoli-Okra
 | 1.42 | 1.54 | 2.66 | 2.63 |
| 1. Basmati Rice-Potato-Maize(Green Cobs)
 | 1.39 | 1.53 | 2.65 | 2.62 |
| 1. Maize-Yellow Sarson- Moong
 | 1.3 | 1.48 | 2.63 | 2.6 |
| 1. Black Gram-Wheat-Maize Fodder+ Cowpea
 | 1.26 | 1.4 | 2.61 | 2.61 |
| 1. Soybean- Lentil
 | 1.24 | 1.37 | 2.61 | 2.61 |
| 1. Guava+Turmeric
 | 1.45 | 1.59 | 2.67 | 2.66 |
| 10. Soybean-Wheat | 1.33 | 1.49 | 2.64 | 2.64 |
| 11.Uncultivated | 1.44 | 1.63 | 2.69 | 2.67 |
| C.D. at 5% | 0.130 | 0.109 | 0.105 | 0.069 |
| SE(m) | 0.044 | 0.037 | 0.035 | 0.024 |

**3.3. Porosity**

Porosity is defined as the ratio of pore space to the bulk volume of a soil sample **(Yolcubal*et al.* 2004).** Soil porosity is an important soil physical property influencing water infiltration and movement. The results for porosity (%) are shown in table 1. Significant differences in the values of porosity were observed in different land use systems ranging from 45.85% to 56.04% and from 38.98% to 50.48% for 0-15 cm and 15-30 cm, respectively. Rice-Wheat-Green manure showed significantly highest % porosity (56.04%, 50.48%), followed by Soybean-Lentil (52.34%, 47.13%) which was at par with Black Gram-Wheat-Maize Fodder+ Cowpea (51.81%, 46.41%). Porosity of Sorghum-Berseem+ Mustard+ Oat-Maize + Cowpea (50.72%, 44.26%), was significantly at par with Maize-Yellow Sarson- Moong (50.39%, 43.19%), Soybean-Wheat (49.54%, 43.64%), and Basmati Rice-Oat-Bajra+ Cowpea (Fodder) (48.17%, 41.42%) and Basmati Rice-Potato-Maize (Green Cobs) (47.71%, 41.65%). The porosity of Maize-Broccoli-Okra (46.64%, 41.55%) was at par with Guava + Turmeric (45.85%, 40.01%), and uncultivated (46.56%, 38.98%) at 0-15 cm and 15-30 cm depth, respectively which were lower in values from other systems. The results revealed inclusion of legumes showed higher values of porosity than non legumes. These findings corroborated with the findings of **Pandey *et al.* (2018); Ram *et al.,* 2022; Choudhary *et al.* (2023); Iheshiulo*et al* (2023).** The increase in porosity of these systems may also be attributed to their diversified nature which also adds more biomass which makes the soil more porous, increases microbial diversity, activity and aggregate stability which makes the soil more voluminous **( Bandhyopadhyay*et al.*, 2011; Dhaliwal  *et al.,* 2019).**Also the increase in binding agents and exudates by the action of microorganisms improves particle binding, causing a decrease in bulk density and thus increasing porosity **(Choudhary *et al.,* 2023).**

**Table2. Effect of different land use systems on soil porosity and WHC at 0-15 cm and 15-30 cm depth.**

|  |  |  |
| --- | --- | --- |
| **Land use systems**  | **Porosity (%)** | **Water holding capacity (%)** |
| **15 cm depth** | **15 cm depth** | **15 cm depth** | **30 cm depth** |
| 1. Rice- Wheat- Green Manure
 | 56.04 | 50.48 | 56.39 | 55.27 |
| 1. Sorghum-Berseem+ Mustard+ Oat-Maize+Cowpea
 | 50.72 | 44.26 | 50.72 | 48.72 |
| 1. Basmati Rice-Oat-Bajra+ Cowpea (Fodder)
 | 48.17 | 41.42 | 50.98 | 53.84 |
| 1. Maize-Broccoli-Okra
 | 46.64 | 41.55 | 46.05 | 45.21 |
| 1. Basmati Rice-Potato-Maize(Green Cobs)
 | 47.71 | 41.65 | 45.17 | 46.85 |
| 1. Maize-Yellow Sarson- Moong
 | 50.39 | 43.19 | 50.43 | 47.67 |
| 1. Black Gram-Wheat-Maize Fodder+ Cowpea
 | 51.81 | 46.41 | 53.05 | 50 |
| 1. Soybean- Lentil
 | 52.34 | 47.13 | 54 | 53.91 |
| 1. Guava+Turmeric
 | 45.85 | 40.01 | 45.51 | 43.63 |
| 1. 10. Soybean-Wheat
 | 49.54 | 43.64 | 49.56 | 46.65 |
| 1. Uncultivated
 | 46.56 | 38.98 | 41.69 | 40.8 |
| 1. C.D. at 5%
 | 3.432 | 3.422 | 2.836 | 4.172 |
| 1. SE(m)
 | 1.170 | 1.167 | 0.961 | 1.413 |

**3.4. Water holding capacity:**

Soil water holding capacity (WHC) refers to the amount of water stored by the soil for crop usage. The water holding capacity of soil is primarily determined by its texture and organic matter content **(Rajpoot *et al.,* 2021)**. The data on water holding capacity is presented on Table 2. The results showed that of all the treatments significantly highest water holding capacity (WHC) was recorded for Rice-Wheat-Green manure (56.39%, 55.27%) which was at par with the Soybean-Lentil system (54.0%, 53.91%), for the 0-15 cm and 15-30 cm. WHC of Black Gram-Wheat-Maize Fodder+ Cowpea (53.05%, 50.0%), Maize-Yellow Sarson- Moong (50.43%, 47.67%), Sorghum-Berseem+ Mustard+ Oat-Maize+Cowpea (50.72%, 48.72%), Basmati Rice-Oat-Bajra+ Cowpea (Fodder) (50.98%, 53.84%) were at par with each other. Further, WHC of Soybean-Wheat was significantly higher at 0-15 cm depth than Basmati Rice-Potato-Maize (Green Cobs), Guava + Turmeric, Maize-Broccoli-Okra and uncultivated, which had the lowest WHC at 0-15 cm and 15-30 cm depth, respectively. Similar results have been reported by **Gupta *et al.* (2010); Pandey *et al*. (2018); Ram *et al.* (2022) Alhameid*et al*. 2020; Nouri *et al.* 2019; Pikul *et al.* 2006)**. The incorporation of legumes adds organic matter to the soil which on decomposition produces polysaccharides, binding agents which promote aggregation and thus, helps in retaining more water and improve the water holding capacity **(Kumar*et al.,* 2023)**. Further, the decrease in WHC with depth may also be correlated to decrease in organic matter content at the subsurface level **(Gupta *et al.,* 2010).**

**4. CONCLUSION**

From the study it was concluded that different types of land use systems has varied effects on soil physical properties. The systems cultivating legumes were found to be better than non legume based. Rice-Wheat-Green manure was at par with the Soybean-Lentil system, andshowed better soil physical properties and soil health followed by other legume based and diversified systems. Uncultivated systems showed the lowest values for all the measured physical properties. Crop diversification with the inclusion of legumes improved soil physical health by improving porosity, water holding capacity, aggregation and bulk density with the effect more on the surface than subsurface. It could be related to the diverse root architecture, adding more biomass to the soil and thus increasing organic material, exudates, binding agents and nutrients which also facilitate microbial biodiversity, activity which influences soil physical properties. The study thus, highlighted the beneficial effect of legume based crop diversification on soil physical properties, and thus soil health.

**Disclaimer (Artificial intelligence)**

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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