***Original Research Article***

**SOIL PHYSICAL PROPERTIES UNDER DIFFERENT LAND USE SYSTEMS IN TARAI CONDITIONS OF UTTARAKHAND**

**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 system. 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 was studied. The land use systems taken for study were diversified cereal crop based systems with inclusion of legumes, an orchard based systems, a vegetable based system and an uncultivated system. The results showed that the bulk density for various land use systems ranged from 1.15 Mg/m3 to 1.44 Mg/m3; 1.29 Mg/m3 to 1.63 Mg/m3, particle density from 2.61 Mg/m3 to 2.69 Mg/m3; 2.61 Mg/m3 to 2.67 Mg/m3, porosity % from 45.85% to 56.04%; 38.98 % to 50.48%, 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 which 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 up better physical properties and health of the soil.

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

**ABBREVATIONS**

**BD** – bulk density

**CD**- critical difference

**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 atmosphere, lithosphere, hydrosphere and biosphere and is critical to food production and key to sustainability through its support to important societal and ecosystem services **(Brevik *et al.,* 2015; Lehmann *et al.,* 2020)**. The soil performs various functions such as supporting plant growth, regulating water movement and purifying water, decomposition of OM and recycle of nutrients, harboring organisms, and buffers environmental changes, provides provisions for food, fiber and fuel, detoxifies organic contaminants and sequester carbon as well.

Soil physical properties play an important role in determination of suitability of soils for many key processes pertaining to 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 provides information related to water and air movement through soil, as well as various conditions affecting germination, root growth and erosion processes. Land uses systems such as cereal based, legume based, horticulture based etc influence soil physical properties through tillage based operations, root growth patterns, organic matter addition, litter fall etc. In this regard the present study was conducted to study the effect of different land use systems on soil physical properties and soil health.

**2. MATERIAL 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. Borlaug Crop 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 the Himalayas. 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 Beni series of order Mollisols. The native vegetation is thick mainly because of prevalence of high moisture in *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 different land use systems comprising of field crops (cereals and legumes), horticultural crops, vegetable crops and uncultivated land of the same block during kharif, 2024. Soil samples from 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**

For assessing the effect of different land use systems on soil physical properties, bulk density of soil was determined by core sampler method of **Baver (1956),** particle density was determined using the procedure given by **Baver, (1956),** and porosity was calculated from the values of BD and PD.Soil water holding capacity was determined by Hilguard apparatus **(Piper, 1950).** The data from the observations for these parameters was analyzed statistically using ANOVA technique of **Panse and Sukhatme (1985)** and results were compared at 5% C.D. values.

**3. RESULTS AND DISCUSSION**

**3.1** **Bulk 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/m3 for 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 system 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 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) (1.39 Mg/m3,1.53 Mg/m3) at 0-15 cm depth but varied at 15-30 cm depth. BD values of Maize-Broccoli-Okra (1.42 Mg/m3, 1.54 Mg/m3) and Guava + Turmeric (1.45 Mg/m3, 1.59 Mg/m3) and Uncultivated (1.44 Mg/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 effect of legumes due to secretion of exudates, and addition of organic matter into the soil, which improves soil structure, and creates pore spaces which lowers 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 effect of legumes. The increase of 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 amongst 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 which mainly depends on soil mineralogy and 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 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%). 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 then non legumes. These findings corroborated with 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, and activity, 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 action of microorganisms improves particles binding, causing 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 Soybean-Lentil system (54.0%, 53.91%), for 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)**. 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 improves the water holding capacity **(Kumar*****et al.,* 2023)**. Further, the decrease in WHC with depth may also be correlated to decrease on organic matter content at subsurface level **(Gupta *et al.,* 2010).**

**4. CONCLUSION**

From the study it was concluded that different types of land use systems has varied effect of soil physical properties. The systems cultivating legumes were found to be better than non legume based. Rice-Wheat-Green manure which was at par with Soybean-Lentil system, and showed 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 inclusion of legumes improved soil physical health by improving porosity, water holding capacity, aggregation and bulk density with the effect more on surface then subsurface. It could be related to the diverse root architecture, adding more biomass to the soil and thus increasing organic material, exudates, binding agents, 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)**

Author(s) hereby declare that no generative AI technologies and text-to-image generators have been used during the writing or editing of this manuscript.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

**REFERENCES**

**Ahmed, H. (2002).** Assessment of spatial variability of some physicochemical properties of soils under different elevations and land use systems in the western slopes of Mount Chilalo, Arsi. M.Sc. Thesis Submitted to the School of Graduate Studies, Alemaya University, Ethiopia. 111p

**Alam, M.K., Islam, M.M., Salahin, N. and Hasanuzzaman, M., (2014).** Effect of tillage practices on soil properties and crop productivity in wheat‐mungbean‐rice cropping system under subtropical climatic conditions. *The scientific World Journal*, 1, p.437283.

**Alhameid, A., Singh, J., Sekaran, U., Ozlu, E., Kumar, S. and Singh, S. (2019)**. Crop rotational diversity impacts soil physical and hydrological properties under long-term no-and conventional-till soils. *Soil Research*, *58*(1):84-94.

**Bandyopadhyay, P.K., Saha, S. and Mallick, S. (2011).** Comparison of soil physical properties between a permanent fallow and a long-term rice–wheat cropping with inorganic and organic inputs in the humid subtropics of eastern India. *Communications in Soil Science and Plant Analysis*, 42(4):435-449.

**Baver, L.D. (1956)**. Practical values from physical analyses of soils. *Soil Science.* 68: 1-14.

**Brevik, E. C., Cerda, A., Mataix-Solera, J., Pereg, L., Quinton, J. N., Six, J. and Van Oost, K. (2015).** The interdisciplinary nature of soil. *Soil.* 1(1):117-129.

**Choudhary Deeksha, Naveen Datt, Sanjay K. Sharma, Pawan Pathania, Pardeep Kumar, Neha Chauhan, Kriti Gupta and Prakriti (2023).** Impact of Crop Diversification on Soil Physical properties and Maize Grain Equivalent Yield in a Typic Hapludalf of Himachal Pradesh. *Biological Forum – An International Journal,* 15(5): 1162-1167.

**Delgado, A., & Gómez, J. A. (2016).** The Soil. Physical, Chemical and Biological Properties. In: *Principles of Agronomy for Sustainable Agriculture*. pp 15–26. doi:10.1007/978-3-319-46116-8\_2.

**Dhaliwal, S.S., Naresh, R.K., Mandal, A., Walia, M.K., Gupta, R.K., Singh, R. and Dhaliwal, M.K. (2019)**. Effect of manures and fertilizers on soil physical properties, build-up of macro and micronutrients and uptake in soil under different cropping systems: a review. *Journal of Plant Nutrition*, 42(20), pp.2873-2900.

**Ekka, A.A., Kumar, D., Singh, A.P. and Singh, A. (2017)**. Variation in physico-chemical properties of soil under different agri-horti system in Vindhyan region. *Journal of Applied & Natural Science*, 9(2).

**Gupta, R.D., Arora, S., Gupta, G.D. and Sumberia, N.M. (2010)**. Soil physical variability in relation to soil erodibility under different land uses in foothills of Siwaliks in NW India. *Tropical Ecology*, 51(2), p.183.

**Iheshiulo, E.M.A., Larney, F.J., Hernandez-Ramirez, G., Luce, M.S., Liu, K. and Chau, H.W. (2023).** Do diversified crop rotations influence soil physical health? A meta-analysis. *Soil and Tillage research*, *233*, p.105781.

**Jain, P., Rai, H.K., Singh, V., Upadhyay, A.K., Sahu, R.K., Rawat, A. and Singh, R.B. (2023)**. Vertical Variability of Physical Properties under Different Land-Use Practices in Vertisols and Inceptisols of Central India. *International Journal of Environment and Climate Change*, *13*(7):528-537.

**Kumar, S., Gopinath, K.A., Sheoran, S., Meena, R.S., Srinivasarao, C., Bedwal, S., Jangir, C.K., Mrunalini, K., Jat, R. and Praharaj, C.S. (2023)**. Pulse-based cropping systems for soil health restoration, resources conservation, and nutritional and environmental security in rainfed agroecosystems. *Frontiers in Microbiology*, *13*, p.1041124.

**Kumar, V., Singh, S., Singh, P., Tiwari, S., Nand, M., Chiranjeeb, K. and Majhi, M. (2020).** Effects of cropping systems on soil properties and enzymatic activities in calcareous soil. *International Journal of Current Microbiology and Applied Sciences.* 9(4):1255-1262

**Lehmann, J., Bossio, D. A., Kögel-Knabner, I. and Rillig, M. C. (2020).** The concept and future prospects of soil health. Nature Reviews Earth & Environment. 1(10): 544-553.

**Maheswarappa, H. P., Hegda, M. B., Dhanapal, R. and Biddappa. C. (1998).** Mixed forming in coconut garden: Its impact on soil physical, chemical properties, coconut nutrition, and yield. *Journal of Plantation Crops*, 26 (2): 39–143

**Meena, S.N., Sharma, S.K., Singh, P., Ram, A., Meena, B.P., Jain, D., Singh, D., Debnath, S., Yadav, S., Dhakad, U. and Verma, P. (2023).** Tillage-based nutrient management practices for sustaining productivity and soil health in the soybean-wheat cropping system in Vertisols of the Indian semi-arid tropics. *Frontiers in Sustainable Food Systems*, *7*, p.1234344.

**Nouri, A., Lee, J., Yin, X., Saxton, A.M., Tyler, D.D., Sykes, V.R. and Arelli, P. (2019).** Crop species in no-tillage summer crop rotations affect soil quality and yield in an Alfisol. *Geoderma*, *345*:51-62.

**Pandey, V., Gautam, P. and Singh, A. P. (2018).** Assessment of physical properties of soil under different land use systems in a Mollisol. *Journal of*Pharmacognosy*and* Phytochemistry*.* 7(6): 2645-2648.

**Panse V.G. and Sukhatme P.V. (1985)**. Statistical Methods for Agricultural Workers. Indian Council of Agricultural Research Publication. 87-89

**Phogat, V. K., Tomar, V. S. and Dahiya, R. (2015)**. Soil physical properties. In: *Soil science: An introduction*, pp.135-171.

**Pikul Jr, J.L., Schwartz, R.C., Benjamin, J.G., Baumhardt, R.L. and Merrill, S. (2006)**. Cropping system influences on soil physical properties in the Great Plains. *Renewable Agriculture and Food Systems*, 21(1):15-25.

**Piper, C.S. (1950).** Soil and Plant Analysis, The University of Adelaide Press, Adelaide, Australia.p. 368.

**Puri, G.S. (1960).** Indian Forest Ecology, 1. Oxford Book and Stationery Co. New Delhi.

**Rajpoot, R. S., Bajpai, R. K., Shrivastava, L. K., Kumar, U., Tedia, K. and Mishra, V. N. (2021).** Evaluation of soil physical and chemical properties under rice-based cropping system in alfisols of Northern Hill Region of Chhattisgarh. *International Journal of Current Microbiology and Applied Sciences.* 10(1):2748-2761.

**Ram B, Singh AP, Singh V, Pareek N, Gautam P. (2022)**. Long term effect of different crop rotations on soil physical properties in a Mollisol. *Journal of Phytopharmacology* . 11(1):7-11. doi: 10.31254/phyto.2022.11102

**Weil, R. R. and Brady, N. C.  (2017).** *The Nature and Properties of Soils*; Prentice Hall: Upper Saddle River, NJ, USA. 15th  edition, Pearson, New York.

**Wilke, B. M. (2005).** Determination of Chemical and Physical Soil Properties. In: Monitoring and Assessing Soil Bioremediation. Soil Biology, vol 5. Springer, Berlin, Heidelberg. pp. 47-95. <https://doi.org/10.1007/3-540-28904-6_2>.

**Yolcubal, I., Brusseau, M. L., Artiola, J. F., Wierenga, P. and Wilson, L.G. (2004)**. Environmental physical properties and processes. *Environmental monitoring and characterization*. :207-239.