Chemical Science Review and Letters ISSN 2278-6783

Review Article

Physico-Chemical Properties of Soil and Its Relationship with Soil Health

Alok Singh Jayara*, Sharad Pandey and B.K. Ambasta

Himgiri Zee University, PO Sherpur, Chakrata Road, Dehradun 248197

Abstract

Agriculture is the backbone of Indian economy. The progress of technology in form of high yielding varieties, fertilizers, pesticides etc has made the country self sufficient in food grain. However, the excess use of chemicals shows bad impact on environment. It has also led to either reduction or stagnation in the yields of crops. On the other hand, the increasing population, especially in the developing nations likes India has led to the reduction of per capita availability of land year after year. The rising urbanization has also reduced the opportunity of expanding agricultural lands. Thus the food grain production can only be increased by increasing the yields from existing agricultural land. The yield from a unit area largely depends on soil health. The soil health depends on the physical, chemical and biological properties of soil. The review paper focuses on the importance of the mentioned aspect of soil.

Keywords: Economy, Technology, high yielding varieties, stagnation, per capita availability, physico-chemical properties

***Correspondence**

Author: Alok Singh Jayara

Email: aloksingh.jayara@gmail.com

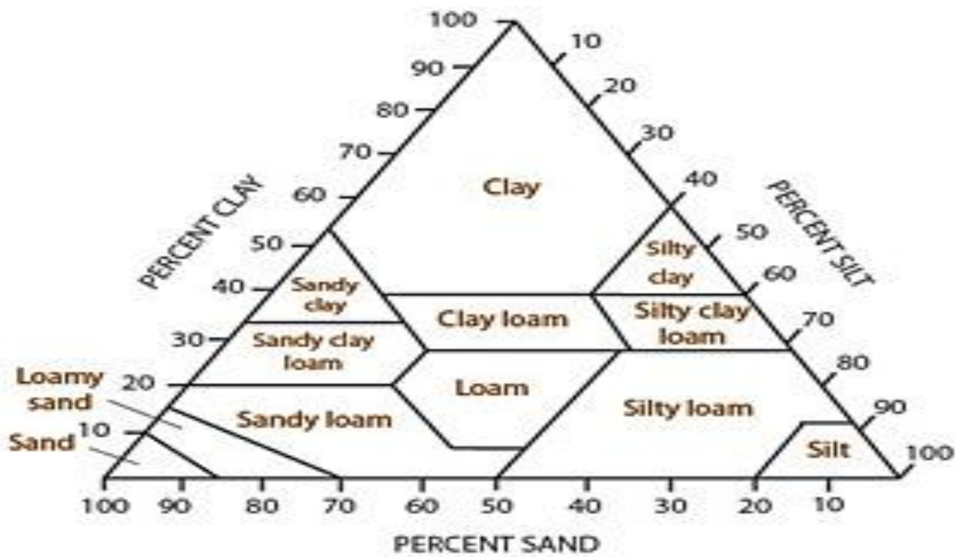
Introduction

Indian agriculture is known since ancient times. It is an integral component for our survival and largely depends upon soil and water. Soil is one of the major components of agriculture. The soil acts as store house of nutrients and provides anchorage to the roots of crop, movement of moisture and its availability to the plants. The study of soil is carried out in two perspectives i.e. pedology and edaphology. Pedology refers to the study of soil alone and edaphology is study of soil in relation with agriculture. Soil is a natural body to produce and sustain crops. The scientific study of soil probably started in the mid nineteenth century and was dominated by the geologists, chemists and plant physiologist. Justus Von Liebig in his famous publication “Chemistry applied to Agriculture and physiology” put forward the theory that plants assimilate mineral nutrients from soil which varied in their capacity of nutrient supply. The fundamental principles of soil science were first laid down by Dukochaev et al. in U S S R in 1879. It is very difficult when we have described the soil as a natural three dimensional body of landscape and attempt to adequately describe its characteristics. Joffe (1949) defined it as “The soil is a natural body of mineral and organic constituents, differentiated in horizons of variable depth, which differ from material below in morphology, physical make-up, chemical properties and composition, and biological characteristics.” [1] Generally there is a difference between soil and a soil. Soil is considered as a dynamic entity whose all the properties (including physical, chemical, mineralogical and biological) are considered with respect to plant growth whereas, a soil is physical entity which is studied from view point of pedology. Thus concept of soil is rather a living concept in relation to agriculture. This living system capacity of soil emanates from the physico-chemical properties i.e. soil texture, structure, porosity, soil moisture, pH, electrical conductivity, soil organic matter content and the status of the nutrients in the soil. The term soil quality and soil health are used interchangeably in the scientific literature. The term‘soil quality’ is preferable from viewpoint of researcher whereas, producers prefer ‘soil health’ [2]. Soil health is considered as the state of soil at a particular time equivalent to the dynamic soil properties that change in the short term while soil quality may be considered as soil usefulness for a particular purpose over a long time scale, equivalent to intrinstic or static soil quality [3]. The important determinants of soil quality includes nutrient cycling in soil, filtering and buffering of soil, nutrient cycling, structural support, biodiversity present in it, production capacity and water and solute flow in the soil [4].

In the past decades, the use of resources has increased at a rapid pace. The utilization of resources has been replaced with their exploitation. This has been more severe with the increasing population and reduction in the resource base. With the commercialization of agriculture and the increased pace of industrialization, soil has been a victim of the deterioration in terms of soil health. Soil health is basically its capacity to supply optimum conditions for the growth of organisms, sustaining agriculture and other primary needs of human. It depends on the prevailing physico-chemical properties of the soil. In the subsequent paragraphs, we present discussion on the individual property and its relationship with the soil health.

Soil Texture

The relative proportion of the sand, silt and clay particles in the soil is termed as the soil texture. The influence of each component depends on its relative percentage, e.g. the soil is categorized as clayey when it contains 30 per cent clay of the total whereas, it is sandy soil when sand constitutes more than 80 per cent of soil. The soil texture is related to the soil health through its influence on soil aeration, soil moisture and cation exchange capacity. The soil having higher percentage of the sand have good aeration, however, it is not able to hold moisture at lower potential. On the other hand, the clayey soils is having good moisture holding capacity and higher cation exchange capacity, however, they are prone to water logging under excess moisture. Among all, the loam soils are considered to be good for agriculture as it is having both good aeration and water holding capacity (Sand 52 per cent; silt 28-50 per cent; clay 7-27 per cent). The soil textural triangle is presented as below:



Textural triangle

Different methods exist for the determination of the soil texture at farmer’s field. The easiest method for determination of soil texture at farmer’s field is the “feel method”. One can determine the texture of the soil e.g. sand feel gritty i.e. the particles can be sensed as differentiated when pressed between the fingers; silt feels sticky when it is wet and like talcum powder when it is dry and clay feels wet and sticky when wet and hard under dry conditions.

It was reported that simulated yields of maize and wheat were higher in silt loam than sandy loam and loamy sand soil due to higher water retention in silt loam [5]. It was reported that rice yields were 46 per cent higher in clay soils than in sandy loam soils averaged across cultivars and water regimes [6]. It was reported that grain and forage yield of the summer crops decreased with increasing gravel concentration. The dilution of the soil mass with increasing gravel concentration and corresponding decrease in the nutrients and water holding capacity of the soil appears to have depressed crop yields [7].

Soil Structure

The arrangement of primary particles of soil i.e. sand, silt and clay in the secondary structures is termed as soil structure. Soil structure is of four types i.e. granular or crumb; columnar or prismatic; blocky or sub-angular blocky and platy type. Most suitable soil structure for agriculture is granular/ crumby as it is good for aeration and permits free drainage. The others are mostly found in the sub-soil structure except platy, which is also present in the surface of the newly formed soils. Columnar and prismatic are found in the sub-surface of the arid and semi arid regions and sodic soils. The angular and sub-angular blocky are found in the clay rich sub-soil of the black soil regions. This property of the soil is also impacted by the presence of the other constituents e.g. the soil rich in organic matter is having good structure whereas the alkali soils are having the dispersed structure and has the columnar structure.

The soil texture is generally not amenable to change whereas the soil structure can be improved through addition of organic matter, vermi-compost, crop rotation and addition of green manure. The soil structure plays important role for good aeration, water movements, root growth, better growth of soil microflora and fauna.

Porosity

The porosity of soil depends largely on the texture and structure of the soil. Generally two types of pores are present in soils i.e. micro pores (< 0.6 mm) and macro pores (> 0.6 mm). The macropores are those which are easily drained off and thus useful in the maintaining the aeration of the soil and micro pores are useful for the water holding capacity of the soil. Better aeration of soil is required for the root respiration and its growth whereas the micro-pores are important for the water movement in the soil. The porosity of the soil is indirectly influenced by the texture and structure of the soil. Too much of the macropores lead to the rapid drying of soils and thus the plants suffer the moisture stress at the earliest whereas larger fraction of micropores lead to the waterlogging and poor aeration of the soil. Good density of macropores leads to the better infiltration capacity and reduces the loss of soil and water in form of runoff. Thus, a balance of the micro and macro-pores is essential requirement of the good root growth and vegetation. Ideally, it is considered that 50 per cent of the total soil volume should be occupied with pores having 25 per cent macro-pores and 25 per cent micro-pores.

It was reported that as the total air filled porosity decreases to 10 per cent or less, the oxygen diffusion rate in the soil is inhibited causing injury to roots and their inability to function [8]. Pore size distribution and pore continuity play an important role in root growth by directly determining the soil volume filled with air and water, and indirectly the soil resistance. Furthermore, pore size distribution and pore continuity determine the ability to transport oxygen throughout the soil to the roots [9].

pH

pH represents the potency of hydrogen. It is the negative logarithm of the hydrogen ion or hydronium ion concentration. Mathematically, it is expressed as pH= - log $[H^+]$

pH is measured on Sorenson scale and is also known as pH scale. The pH less than 7.0 is considered to be acidic whereas the pH greater than 7.0 is known as the alkaline. The medium/solution having pH 7 is considered ‘Neutral’. Though pH influences very much the soil health, the major impact is on the availability of the nutrients, growth of micro-flora and micro-fauna and growth of different crops. Generally neutral pH is considered suitable for the nutrient availability, acidic pH favors availability of the micro-nutrients such as iron, manganese, copper, zinc. However, at very low pH there is toxicity of these micro-nutrients. There are nutrients such as molybdenum which are available at alkaline pH, however, most of the nutrients i.e. nitrogen, phosphorus, potassium, sulphur etc are available in the neutral pH. pH influence the growth of different micro-flora in the soil e.g. Fungi dominates at lower pH(<5) i.e. in acidic medium whereas, actinomycetes are dominant at alkaline pH. The different crops have preference for different pH range. *e.g.* millets and tea can thrive in acidic soils, whereas, the crop such as maize, wheat, pulses are not able to survive at low pH. Similarly, cotton and rapeseed are able to tolerate the saline soils. Lowland rice on account of submerged conditions, have pH stabilization near neutral, is suitable for soils having both acidic and alkaline pH. The high pH (>8.5) is associated with the sodic soils. In these soils there is the higher concentration of the sodium ions leads to the de-flocculation of the clay colloids leading to poor aeration and water movement in the soil.

Some soil borne diseases are closely associated with soil pH. For example, clubroot disease of cabbage and other crucifers a major epidemic disease caused by *Plasmodiophora brassicacea* occurs when soil pH is lower than 5.7 but is dramatically reduced in a pH range from 5.7 to 6.2. This disease is virtually eliminated when the soil pH is greater than 7.3. Similarly, common scab of potato is favored when the pH is greater than 5.2 but significantly reduced at pH less than 5.2 [10].

Extremely and strongly acidic soils (pH4.0-5.0) can have high concentration of soluble aluminum (Al^{3+}) ion and manganese, which may be toxic to the growth of some plants, A pH range of approximately 6-7 promotes the most readily available plant nutrients, while a pH above 7 (alkaline) reduces the ability of plants to absorb elements such as iron, manganese, boron and other trace elements [11-14].

There is relationship between soil pH and plant diseases because many diseases are caused by extreme pH which makes essential nutrient unavailable to the crops, because the soil itself is unhealthy. For example, Chlorosis of leafy vegetables and potato scab occurs in alkaline condition and acidic soils can cause club root [11, 12].

Soil Temperature

Soil temperature plays an important role for soil health in agricultural system. The soil temperature regimes on the basis of Mean Annual Soil Temperature (MAST) and varies from pergelic (< 0ºC) to megathermic (> 22ºC). Optimum soil temperature is required for the decomposition of organic matter and thus availability of nutrients. Optimum temperature for nitrification is 30-35 ºC for good root growth and better uptake of water and nutrients.

However, temperature greater than optimum leads to the decay of roots, loss of organic matter and inhibit some specific process, such as tuber growth stop at a soil temperature greater than 25 ºC. On the basis of temperature requirement, there are three classes of organisms i.e. psychrophiles (<10ºC); mesophiles (20-35ºC) and thermophiles (>45ºC).

The effects of soil temperature (12°C vs. 25°C) were demonstrated on the growth and development of carrot cultivars. A soil temperature of 12°C resulted in a higher fibrous root (involved in the uptake of water and nutrients)-shoot ratio i.e. (root:shoot), thicker and smaller leaves, and a higher taproot (stores carbohydrates and other compounds): shoot ratio [15].

Electrical Conductivity

The electrical conductivity is the measurement of salts present in the soil. These substances build the osmotic potential in the soil. The presence of the cations and anions increases the osmotic potential and thus, influence the water uptake capacity of the plant adversely. It leads to the physiological drought in the plants *i.e.* wilting of plants even when there is sufficient moisture is present in the soil. In addition, excess of these cations and anions have antagonistic relationship with nutrient present in the soil *e.g.* excess of sodium leads to reduction in potassium uptake by plants. When concentration of soluble salts increases in the soil, the excess salt is normally leached down beyond the root zone. In case the leaching of salts doesn't take place, the soluble cations and anions are precipitated and the carbonates and bicarbonates of sodium remain in the soil. This excess of carbonates and bicarbonates of sodium leads to the deflocculation of soil, leading to barren soils. However, in such cases the electrical conductivity of soil is less than 4 dSm^{-1} due to lesser solubility of carbonates and bicarbonates of sodium.

It was reported that there is positive significant correlation of EC with pH, OC, potassium and phosphorus [16]. It was reported that there is higher order correlation between electrical conductivity and physical parameters of Indian soils [17].

Organic Matter Content

Organic matter provides life to the soil. It act as source of carbohydrate to the soil organisms (provided C:N is in the optimum range). It is source of various nutrients in the soil e.g. more than 95 per cent of nitrogen and sulphur to plants is provided by the soil organic matter. The chromic acid oxidation method is utilized for the determination of the organic carbon in soil. It is an indirect measure of organic matter and also serves as an index of the available N content (C:N assumed to be 10:1 in soil). Organic matter is also source of phosphorous, micronutrients such as zinc, boron, iron etc. Organic matter enhances the availability of the soil nutrients through its chelating action. Organic matter enhances the availability of the least mobile nutrients such as phosphates in soil. Organic matter positively influences the soil structure and water holding capacity of the soil. Organic matter has the cation exchange capacity in range of 250-400 c mol kg^{-1}, thus, acts as a storehouse of nutrients in soil. Soils rich in organic matter are indicator of good soil health.

It was reported that yields of many crops was larger on soil with extra organic matter both on the sandy loam at Woburn and the silty clay loam at Rothamsted [18]. Soil Organic Matter (SOM) is the central indicator of soil quality and health, which is strongly affected by agricultural management [19, 20]. SOM is a major terrestrial pool for C, N, P, and S, and the cycling and availability of these elements are constantly changed by microbial immobilization and mineralization [21, 22]. The importance of increased SOM or soil organic carbon (SOC) is its effect on improving soil physical properties, conserving water, and increasing available nutrients. These improvements should ultimately lead to greater biomass and crop yield [23-25]. There is considerable concern that if SOM or SOC concentrations in soils are allowed to decrease too much, the productive capacity of agriculture will be then compromised by deterioration in soil physical properties and by impairment of soil nutrient cycling mechanisms [23, 26].

Long Term Fertilizer Experiments (LTFE) continuing for the last 40-50 years in different agroecoregions of the country have proved beyond doubt that application of organics like FYM to the extent of 10-15 t/ha to a single crop (preferably kharif crop) in the cropping sequence along with recommended dose of NPK not only produced but also maintained the highest grain yields over the years in both crops at all centers in the country. Application of N alone over the years degraded soil health to the extent that it produced grain yields even lower than the control having no addition of NPK. Inclusion of P and K showed incremental increase in crop yields and improvement in different attributes of soil health thereby highlights the significance of balanced fertilization. Further, treatment having addition of FYM with recommended dose of NPK not only showed built-up of soil organic carbon but also improvement in all parameters of soil physical, chemical and biological attributes of soil health.

Nutrient Content

Nitrogen is among the three primary nutrients required by the plant. Its concentration varies from 1- 5 per cent in plants. The major role of nitrogen in plants is formation of chlorophyll, proteins, nucleic acids, leaf growth etc. The main source of nitrogen in soils is organic matter. Nitrogen loss in soil mainly occurs through the process of leaching, volatilization and denitrification. These depend on the pH and moisture status of the soil, as the higher moisture promotes losses through leaching and denitrification and higher pH of soil is responsible for volatilization losses. The nitrogen content is indirectly influenced by the temperature as higher temperature leads to the decomposition of the organic matter and thus the nitrogen content will be lower.

Phosphorus varies from 0.1 -0.4 per cent in the plants. Phosphorous is required for the root growth, carbohydrate metabolism, ATP formation, nucleic acids, membrane formation (phospholipids provide the selectivity to membrane). Phosphorous is present in the soil in organic as well as inorganic forms. The apatites are the major source of phosphorous in soil; however, it is also present in the fixed forms namely aluminum, iron and calcium phosphates. The organic forms of phosphorous in soils are phytates, inositol phosphorus and phospholipids.

Potassium is required in amount equal to that of nitrogen in plants. It is required for the stomatal control, maintaining the pH and osmotic potential, imparting disease resistance and activation for various enzymes e.g. starch synthetase. It is also termed as quality nutrient. The main sources of potassium in soils are micas and feldspar. Potassium in soil solution is in equilibrium with the exchangeable form which is in equilibrium is in with the non exchangeable and ultimately with the fixed form of potassium in soil.

The secondary nutrients are calcium, magnesium and sulphur in soils. Calcium is required for the cell wall formation, it maintains cellular pH; Magnesium is required for the chlorophyll formation and ribosome formation; Sulphur is required for nitrogen metabolism and protein formation.

The micro nutrients are required in small quantities; however, they are also essential for the plant growth. Micronutrients act as electron carrier in electron transport system, help in redox reaction, act as enzyme activators, pollen germination, lignin synthesis etc. Micronutrients are the latest area of interest for soil scientists. This has become more important when there is cultivation of the soil exhaustive crops and the farmers are still unaware of the localized micronutrient deficiencies in India.

Addition of the nutrients is done mostly by the addition of the chemical fertilizers. If these nutrients are supplied by the organic sources e.g. farmyard manure or vermicompost, there will be balance in nutrition of both macro and micro-nutrients. Biofertilisers can also be applied e.g. seed treatment of legumes with the Rhizobium boost the N fixation in the crop and soil. Similarly, if the phosphate solubilizing bacteria are added they can lead to the release of fixed phosphorous in the soil and aid in plant growth.

The current alarming rate of decline of earth's natural resources, particularly of the reserves of rock phosphate and fossil fuel, is of great concern for the future of agriculture, particularly in developing countries [27]. Our modern society would not exist without the invention of technical creation of reactive N, used to fertilize agricultural land in order to ensure food security for the growing global population [28]. It was reported that crop yields were increased by 19–41% (rice) and 61–76% (rapeseed) during the two years of rice-rapeseed rotation under NPK fertilization compared to PK fertilization across the study sites. Yield responses to fertilization were ranked NPK > NP > NK > PK, illustrating that N deficiency was the most limiting condition in a rice-rapeseed rotation, followed by P and K deficiencies [29]. Increasing level of P application (0 to 90 kg P_2O_5 ha^{-1}) and inoculation with *A. awamori* and *A. niger* significantly increased uptake of N, P, and K in wheat at all stages of crop growth [30].

An adequate K nutrition is also of great importance for the composition of harvested products and the quality of diet. In addition, impaired nutrient management and related nutrient input-output imbalances, especially with K, may represent a serious issue in forest nutrition and wood production [31]. Significant yield increase was observed of 12% to potassium in rice at Pantnagar [32]. In a 5-year field study on a sandy loam soil (ammonium acetate extractable potassium-123 kg ha^{-1}), application of 25 kg ha^{-1} resulted in a mean increase in yield of rice and wheat by 280 and 160 kg grain ha^{-1}, respectively [33].

The post–Green Revolution scenario of Indian agriculture has been associated with second generation problems including emerging deficiencies of micronutrients one after another [34].

Soil Biology

Soil biology refers to the study of the living organisms in the soils. The soil biota mainly consists of flora and fauna. The soil flora constitutes the macro and micro flora. The macroflora includes the roots of the higher plants and trees whereas, microflora consist of fungi, bacteria, actinomycetes etc. Similarly, the soil macrofauna consist of the various organisms such as earthworms, rats, moles, ants etc and microfauna consists of the protozoa, nematodes etc. The soil biota has important role in the recycling of the plant nutrients through nutrient fixation and decomposition, nutrient availability to the plants, maintaining the soil structure, maintaining the balance in the soil biota e.g. protozoa feeds on some bacteria in the soil. The soil biota also acts as the natural predators and parasites of the various plant diseases causing organisms. The soil biota has an important role for ecosystem services and maintaining a favorable balance of various life forms. The activity of fungi and bacteria, growing roots and their exudation in soil and activtiy earthworms in soil promotes the macroaggregate (size > 250 μm) formation which are converted into microaggregates (size < 250 μm) with reduction in the biotic activity or any physical disturbance e.g. tillage [35].

Soil Degradation

Soil degradation doesn't form the part of any type of the properties of the soil. However, it is imperative to discuss the various aspects of soil degradation to understand the soil health. Soil degradation encompasses all the processes which impact the fertility and productivity of the soil e.g. erosion, nutrient loss, waterlogging, desertification, acidification, loss of organic matter, salinization and toxicant accumulation.

In India, soil degradation extends upto 45 per cent of the total geographical area due to different agents, out of which more than 65 per cent of the land degradation is due to the water and wind erosion (NBSSLUP, 2004). Water erosion is the major problem causing loss of top soil and/ or terrain deformation in about 148 mha and wind erosion is dominant in western regions covering 13.5 mha. The water erosion up to the stage of sheet and rill erosion can be averted with agronomic practices; however, if the erosion is not checked can lead to the formation of ravines and badland topography. The excess of wind erosion has also led to the expansion of desert in the western regions of country. The practice of conventional clean cultivation has not only increased the susceptibility of soils toward the erosion but has also led to the reduction of organic matter content of the soil.

Waterlogging and salinization form the cause and effect relationship. The waterlogging near the channel area, lowland topography or the resultant of excess irrigation leads to the accumulation of the salts. Use of excessive fertilizers is also responsible for the saline and acidic soils.

Toxic accumulation is current topic to be dealt in details on account of commercialization of agriculture and rapid urbanization. The addition of various fertilizers has led to the pollution of not only the soil but also of the water bodies and ground water. E.g. Atrazine has revolutionized the weed management in maize and millets but it is also a long residual herbicide in soil.

The application of untreated sewage to soil though increases the organic carbon, N, P and K, however, it also leads to the accumulation of the micronutrients such as zinc, copper, iron and manganese and the potentially toxic elements such as cadmium. This become more severe when the soil is utilized for the cultivation of leafy vegetables such as spinach than any cereal crop as the cadmium is accumulated more in the green leafy vegetables. In the long time, the regular addition of sewage water leads to the loss of soil aeration and condition is known as soil sickness.

The industrial effluents such as distillery and paper mill effluents are characterized by the low pH, higher biological oxygen demand and contain considerable amount of N , P , K ,Ca and S. The irrigation with the pulp and paper effluents increases pH, organic carbon and N, P and K content of the soil. The effluents from the tanneries and textiles have high biological oxygen demand and have higher value of sodium content leading to the structural breakdown of the soil.

Conclusion

In 2025, the food grain requirement for India's 1.4 billion people will be about 300 million tonnes (M t). This production level will require about 30 M t of nitrogen (N), phosphorus (P), and potassium (K), including 8.6 M t of P_2O_5. In addition, another 14 to 15 M t of NPK would be needed for vegetable, plantation, sugar cane, cotton, oilseed, potato, and other crops. Thus, about 40 to 45 M t of NPK, containing 11 to 13 M t of P_2O_5, will be required just to maintain a broad average $N:P_2O_5:K_2O$ ratio of 4:2:1. [36]. Looking to the requirement of foodgrains and consequent nutrient requirement, the importance of the soil health can't be neglected. Better soil health is important for the nutrient supply to the plants, root growth, survival of beneficial microflora and fauna and the sustainability of the crop production system. This importance need to be taken out from the academic domain to the policy making. In recent the various initiatives of Government of India e.g. nutrient based subsidy, soil health card will definitely influence the soil health positively. The farmer awareness at the field level is needed through extension agents. Better soil health will definitely ensure the food, nutritional and environment security to the future generations.

References

[1] T. D. Biswas, S. K. Mukherjee, Textbook of Soil Science, Tata McGraw- Hill Publishing Company Limited, New Delhi, 2006, p5.

[2] R. F. Harris, D. F. Bezdicek, Descriptive aspects of soil quality/ health. In: Defining soil quality for sustainable environment (J. W. Doran, D.C. Coleman, D. F. Bezdicek and B. A. Stewart, Eds). Soil Science Society of America, Special Publication No. 35, Madison, Wisconsin, 1994, 35: 23-35.

[3] N. N. Goswami, Soil and its quality vis-à-vis sustainability and society- Some random thoughts. In: Proceedings if the International conference on Soil, Water and Environment Quality, Indian Society of Soil Science, New Delhi, 2006 Pp 43-58.

[4] C. A. Seybold, M. J. Mausbach, D. L. Karlen, H. H. Rogers. Quantification of soil quality. In; Soil Processes and Carbon Cycle (R. Lal and J. M. Kimble, R. F. Follet and B. A. Stewart, Eds), CRC press, Boca Raton, FL. 1998,387-404.

[5] S. K. Jalota, Sukhvinder Singh,G. B. S. Chahal, S. S. Ray, S. Panigraghy, Soil texture, climate and management effects on plant growth, grain yield and water use by rainfed maize-wheat cropping system: Field and simulation studies. Agriculture Water Management, 2010 97: 83-90.

[6] F. Dou, J. Sorian, R. E. Tabien, K. Chen. Soil Texture and Cultivar Effects on Rice (*Oryza sativa*, L.) Grain Yield, Yield Components and Water Productivity in Three Water Regimes. PLoS ONE, 2016, 11(3): e0150549. https://doi.org/10.1371/journal.pone.0150549

[7] S. S. Grewal, K. Singh, S. Dyal, Soil profile gravel concentration and its effect on rainfed crop yields. Plant Soil 1984, 81: 75–83 https://doi.org/10.1007/BF02206896

[8] W.M.H.G. ENGELAAR, T. YONEYAMA, Combined effects of soil waterlogging and compaction on rice (Oryza sativa L.) growth, soil aeration, soil N transformations and N discrimination. Biology and Fertility of Soils, 2000, 32: 484-493.

[9] J. LIPIEC, R. HATANO. Quantification of compaction effects on soil physical properties and crop growth. Geoderma, 2003, 116, p.107-136.

[10] S. Kioke, K. V. Subbarao, R. M. David, T. A. Turini, Vegetable Diseases Caused by Soil borne Pathogens. Publication 8099. Davis: University of California Division of Agriculture and Natural Resources, 2003 http://ucanr.org/freepubs/docs/ 8099.pdf.

[11] W. R. Miller, R. L. Donachue, Soils: An introduction to soils and plant growth. Prentice Hall India, New Delhi-11001, 1992, pp 226-420.

[12] S. L. Tisdale, W. L. Nelson, J. D. Beaton, J. L. Halin. Soil fertility and fertilizers. 5th edition Prentice Hall inc. Upper Saddle River, New Jersey 07458, USA. 1993, Pp45-561.

[13] D. J. Green Land,Characterization of soils, Oxford University Press, New York, 1981, pp5.

[14] R. E. White, Introduction to the principles and practices of soil science. Blackwell Scientific publications Oxford London, 1979, Pp417.

[15] M. V. González, V. O. Sadras, M. A. Equiza, J. A. Tognetti, Suboptimal temperature favors reserve formation in biennial carrot (*Daucus carota*) plants. physiol Plant. 2009, 137:10–21. [PubMed].

[16] Atul Kumar H. Patel, Electrical conductivity as soil quality indicator for different agricultural sites of Kheda district in Gujarat. International Journal of Innovative Research in Science, Engineering and Technology, 2015, 4: 8.

[17] R. Pravin Chaudhary, V. Dodha Ahive, Manav Chakarbarty, Saroj Maity. Electrical Conductivity as a Tool for Determining the Physical Properties of Indian Soils. International Journal of Scientific and Research Publications, 2014, 4.

[18] A. E. Johnston, Soil organic matter, effect on soil and crops. Soil Use and Management , 2007, 2(3):97 – 105.

[19] R. Lal, J. Kimble, E. Levine, C. Whitman. World soils and greenhouse effect: An overview. In: Lal R. et al. (eds.): Soils and Global Change. Lewis Publ., Boca Raton, FL 1995: 1–8.

[20] R. J. Farquharson, G. D. Schwenke, J. D. Mullen, Should we manage soil organic carbon in Vertisols in the northern grains region of Australia? Aust. J. Exp. Ag.,2003, 43: 261–270.

[21] D. J. Hillel, Out of the earth-civilization and the life of the soil. The Free Press, New York, NY 1999.

[22] F. Feichtinger, E. Erhart, W. Hartl, Net N-mineralisation related to soil organic matter pools. Plant Soil Environ., 2004, 50: 273–276.

[23] A. Bauer, A. L. Black. Quantification of the effect of soil organic matter content on soil productivity. Soil Sci. Soc. Am. J, 1994, 58: 185–193.

[24] Z. Berzsenyi, B. Gyorffy, D. Lap. Effect of crop rotation and fertilization on maize and wheat yields and yield stability in a long-term experiment. Eur. J. Agron, 2000, 13: 225–244.

[25] F. Onemli, The effects of soil organic matter on seedling emergence in sunflower (Helianthus annuus L.). Plant Soil Environ., 2004,50: 494–499.

[26] P. Loveland, J. Webb. Is there a critical level of organic matter in the agricultural soils of temperate regions: a review. Soil Till. Res., 2003,70: 1–18.

[27] S. B. St.Clair, J. P. Lynch. The opening of Pandora's Box: climate change impacts on soil fertility and crop nutrition in developing countries. Plant Soil 2010, 335: 101–115. doi: 10.1007/s11104-010-0328-z
[28] J. W. Erisman, M. A. Sutton, J. N. Galloway, Z. Klimont, W. Winiwarter, How a century of ammonia synthesis changed the world. Nat Geosci, 2008 1:636–639.
[29] M. Yousaf, Li, J., Lu, J. et al. Effects of fertilization on crop production and nutrient-supplying capacity under rice-oilseed rape rotation system. Sci Rep, 2017,7: 1270. https://doi.org/10.1038/s41598-017-01412-0
[30] Amita Sharma, U. S. Rawat, B. K. Yadav. Influence of Phosphorus Levels and Phosphorus Solubilizing Fungi on Yield and Nutrient Uptake by Wheat under Sub-Humid Region of Rajasthan, India. International Scholarly Research Network ISRN Agronomy, 2012, 1-10. Article ID 234656, doi:10.5402/2012/234656
[31] P. Ache, J. Fromm, R. Hedrich. Potassium-dependent wood formation in poplar: seasonal aspects and environmental limitations. Plant Biol, 2010, 12:259–267.
[32] A. Dobermann, P.C. Sta. Cruz, K. G. Cassman. Potassium balance and soil potassium supplying power in intensive, irrigated rice ecosystems, In Potassium in Asia- Balanced Fertilization to Increase and Sustain Agricultural Production. IPI, Basel, Switzerland, 1995, 199-234.
[33] O. P. Meelu, Yadvinder Singh, Bijay Singh, A. L. Bhandari. Response of potassium application in rice-wheat rotation. 1995. 94-98. In Dev, G. and Sidhu, P.S. (eds.) Use of Potassium in Punjab Agriculture, Potash and Phosphate Institute of Canada- India Programme Gurgaon, India.
[34] R. K. Rattan, N. Saharan, S. P. Datta. Micronutrient depletion in Indian soils - Extent, causes and remedies. Fertiliser News, 1999,44(2): 35-50.
[35] J. Six, E. T. Elliot, K. Paustian. Soil macro aggregate turnover and micro aggregate formation: a mechanism for C sequestration under no tillage agriculture. Soil Biology and Biochemsitry, 2000, 32: 2099-2103.
[36] K. N. Tiwari, Phosphorous needs of Indian soils and crops. Better Crops International.2001, 15. No 2: 6-10.

Publication History

Received	27.11.2020
Revised	05.12.2020
Accepted	06.01.2021
Online	30.01.2021