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Soil Quality And Health Management Through Farming Practices: To Ensure Agricultural Sustainability.

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ABSTRACT

The challenge in agro-ecosystem of soil instability is mainly accelerated by population pressure, poor soil management practices and natural climate change. Proper soil management practices are considered as a better way to enhance agriculture production in sustainable healthy soil without forgetting environmental quality, human and animal health. Change in soil health is estimated by using physical, chemical and biological indicators. This review emphasis on timely monitoring of soil health by soil health indicators and soil management practices that may be used to improve the soil quality to sustain agriculture in longer run. Several research papers and books revealed and confirmed that the following soil management practices improve soil health through their influence on soil aggregation and soil micro flora and fauna: conservation tillage, crop rotations, intercropping, cover cropping, agroforestry, organic manure amendment, soil liming and inoculation of different effective microorganisms. These practices have positive influences on nutrient availability to the crops through soil microbial and fauna activities and the increase of soil microbial population, diversity and functions. Protection and improvement of all valuable soil resources is critical in sustainable agriculture.

Keywords: soil health, soil quality, soil indicators, farming practices; sustainable agriculture

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INTRODUCTION

Agriculture has been intensified to meet the food demand of continuously increasing world population. However food grain production is not proportional to world population due to many factors which also includes soil fertility decline. Unbalance and faulty fertilizer application in long term resulted in poor soil health and nutrient deficient which negatively impact soil microbial and biological functions [1,2]. Studies show that soil test based integrated nutrient management holds the key to reserve the current situation and in turn will help in boosting crop production and productivity [3]. Though this approach seems promising, but the major problem lies in ignoring soil biological component and testing in developing countries like India. It is well known fact that farmers, scientist as well as decision makers in agriculture till date relied on physical and chemical properties of soil to determine the capacity of land to produce; however the important regulatory biological component is generally ignored [4]. Soil analysis is the crucial factor in determining the impact of management practices on soil particles and to maintain productive sustainability. There is a need of agricultural biological research to develop the concept of soil quality in terms of soil health as an indicator of sustainability. The predictions to soil health changes always depend on our capacity to clearly define what are soil health properties and their relationship with specific soil functions. Soil health indicators should not only quantify the soil function but also indicate the impact of global change drivers like carbon dioxide (CO_2) levels rise, rainfall altered precipitation and nitrogen fixation on soil physical, chemical and biological functions [5]. Our knowledge in relating soil properties and their interaction with soil micro flora is limited and need to study urgently to quantify the soil biological loss during agricultural practices.

Nowadays specially in developing countries soil quality and soil health under intensive land use agriculture and fast economic development is a big challenge on soil health.(Doran et al., 1996). The concept of soil health and quality was descripted early by Karlen et al. [6] and these two terms soil quality and soil health are usually used interchangeably but with a slight difference [7]. Soil health definition gives more emphasis on finite non-renewable dynamic and living resource whereas soil quality relies on soil function. Ideal soil health support most life processes such as nutrient and water regulation, maintain microbial diversity and activities, sequester heavy metal and play role in bio-remediation [8]. Based on several different use of soil resources the meaning of soil health and soil quality is variable and can be defined according to the purpose of land use [9] in agriculture , plants and animals productivity is taken as the most important in cultivated soil which should be totally different from urban soil [10]. This review preferably concerned on soil health concept and different improved farming practices which have been shown to maintain or improve soil health and quality since both contribute to sustainable agriculture and soil productivity.

Soil

Soil is a fundamental resource for inhabitant living organisms and main medium for plant growth and performance. Soil generally composed of four unique components namely mineral solids, air, water and organic matter which comprise living biota [11]. Soil texture is inherent characteristics and consequent from soil forming process which may subject to change due to management practices. Soil water facilitates nutrient transport and regulate plant nutrient uptake, while air provides oxygen required for microbial and plant cell functioning. Both water and air lodges the pore space and creates soil aggregates. Organic matter is derivatives of living organisms may be divided into three major fractions, the living, the dead (active fraction for microbial regulation) and very dead (stable fraction). Primarily dead fraction consists of fresh crop residue, recently dead microbial cells and insects, leaf litters and manure, however this fraction is considered active as it regulate the soil microbial functions. The carbohydrates, proteins and other compounds are broken down and degraded by active microbial pool which fuels soil microbial population. Interestingly the microbial exudates help to muddle the mineral particles together to form soil aggregates. Virtuous soil aggregation is vital for maintaining good soil structure which enables sufficient air exchange and water drainage. Organic matter which are resistant to further degradation are termed as very dead organic matter fraction or humus.

Soil Health Indicators

The soil physical properties are estimated from soil texture, bulk density as measure of compaction, porosity, soil water holding capacity, water infiltration rate [12]. All these properties have mainly influenced and can be improved in positive way through additions of organic matter to the soil. Therefore capacity of soil to sustain plant growth and biological activities is a function of its physical properties.

The high crop yield is only obtained if the soil is able to provide nutrient to the crops, for that reason the smallholder farmers apply soil nutrient in large quantity [13] because it is possible to increase the availability of plant nutrients in the soil by adding inorganic fertilizers; incorporation of cover crops or using other organic material in form of manure or composts [14]. Results of soil chemical nutrient analysis may be taken as chemical indicators of soil health which provide information of capacity of that soil to provide and supply nutrients to the crops which is depend on the soil pH, high pH value is not desirable and can be corrected by adding lime in the soil with the base cations Ca and/or Mg to bring the soil to neutral.

The importance of biological indicators identification was described by several authors, soil health and quality is influenced by process of microbiological mediation such as nutrient recycling and capacity, stability of aggregate [15, 16]. As mentioned in Fig 1, biological indicators that are commonly used to measure soil heath and quality include soil organic matter, microbial biomass, mineralizable nitrogen, soil organic matter, respiration rate etc. [17]. Soil organic matter plays a key role in soil quality and soil function because it determine water holding capacity of soil, susceptibility and resistance of soil aggregation [18]. Carbon content in the soil is strongly influenced by organic matter as indicated by microbial biomass and respiration rate [19]. Others nutrients such as Nitrogen in some tropical soil can be in considerable amount of mineral N in the top 2m depth [20].

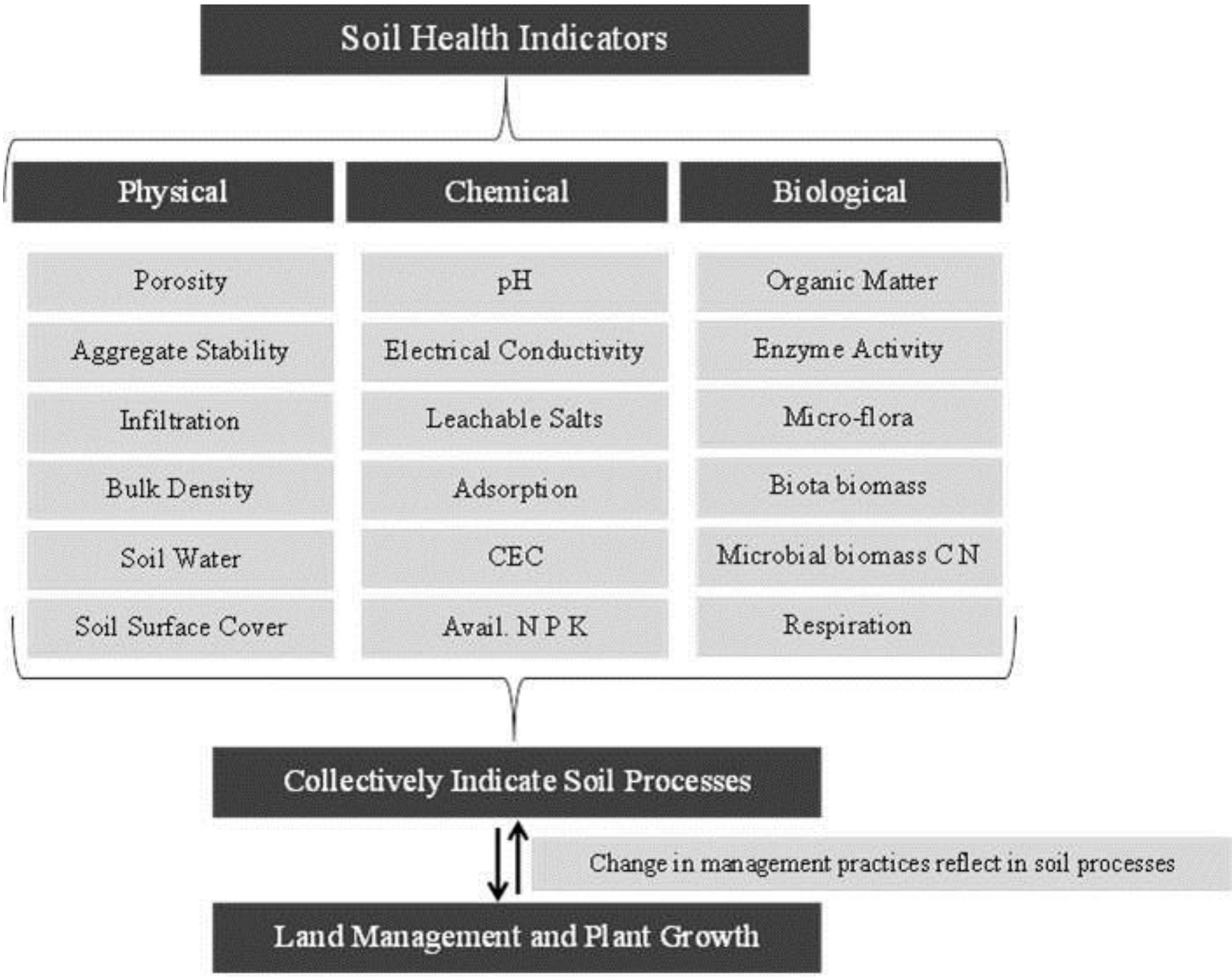

Figure 1: Some of the basic soil properties as soil health indicators and their interaction to management practices.

Soil health or Soil quality

Soil health and soil quality are frequently used as interchangeable terms to define the soil capacity to function to support productivity within precise ecosystem which maintain environmental quality. The National Resource and Conservation Service (USDA-NRCS) define soil quality and soil health similarly, however amended inherent and dynamic soil quality to the definition. The aspects of soil quality which relates soil natural composition and properties impacted by environmental factors and soil formation process in absence of human impact. On the other hand dynamic soil quality infers the soil properties that change due to management practices. Soil health indicators should quantify the difference between inherent and dynamic soil health which will be important to compare one soil health parameter with other. Soil depth, nutrient supply, beneficial microbial population, less chemical stress, microbial resilience etc are desired soil characteristics anticipated in healthy soil. At present soil health are infers by determination of certain soil heath indicators. While selecting soil health and soil quality indicators to use for testing the soil, there are several criteria to consider. The ideal and appropriate soil health indicator should be easy to assess, quantify changes in soil function, sensitive to agro-ecological zone variation, represent physical, chemical and biological soil properties and can predict the both qualitative and quantitative changes in time to make management decisions.

Soil health management and agriculture practices

Soil health disturbance is majorly done by farming activities like intensive cultivation, irrigation, overuse and faulty use of fertilizer, limited crop rotations, lack of organic matter amendment etc. Soil physical degradation in form of erosion, textural loss, aggregate instability which further leads to chemical and biological property loss subsequently results in compaction and reduced crop productivity. Soil quality assessment report survey in vegetable farms showed that soil degradation is common happening in all field [21]. However the intensity of different soil degradation is linked with increased compaction, reduced field capacity, reduced organic matter, drought like condition and excessive runoff.

Soil health depends on both inherent and dynamic soil quality (fig 2) and former relies on group of different factors which may be natural soil characteristics like texture as result of soil formation, however later is affected by change in land use pattern and management practices and generally correlated with soil biological function. In addition the dynamic component is of most interest to farmers because good management allows the soil to come more productive in sustainable manner. The inherent and dynamic soil quality components do interact; however, as some soil types are much more susceptible to degradation and poor management than others.

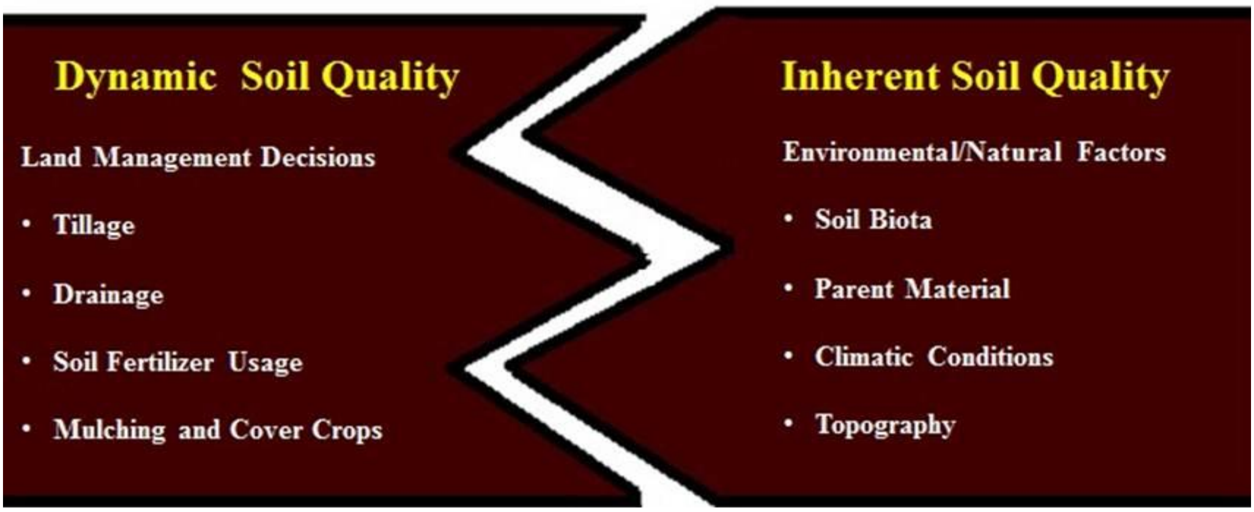

Figure 2: Various factors affecting dynamic and inherent soil quality

Conservation Agriculture Practices for Soil Health

Soil itself work for us as well as we work for it by using management farming practices that improve and sustain soil health subsequently increase productivity and profitability in sustainable manner. Conservation agriculture is one of the strategies that help to improve and sustain the fertility status of the soil. Soil conservation is integral component of farming systems which should aim to manage and regulate agro-ecosystems for productive sustainability and food security. Conservation tillage, efficient soil cover, crop rotation and diversified crop plantation are some examples which if implemented properly can aid in managing minimum soil disturbance and loss [22]. A fully functioning soil produces the maximum amount of products at the least cost. Maximizing soil health is essential to maximizing profitability in sustainable agriculture. Agriculture intensification is considered as the major impact of soil quality and generally environment health. Soil health deterioration have negative impact on plants as well as on other living organism, however efficient agricultural practices may reverse the trend and improve soil and plant health [23].

Soil tillage management (Reduced tillage or conservation tillage)

With different tillage techniques the soil should be disturbed as less as possible to manage the even distribution and amount of plant residue on the ground surface of the soil (NRCS, 2014). Degradation of agricultural soils found as result of excessive tillage and has spurred interest in no-till cropping systems. These farming systems improve directly soil physical properties throughout reducing sheet rill and wind erosion, increase and sustain soil health and organic matter content, increase infiltration rate and moisture conservation in soil, reduce energy required also prove food and shelter for wildlife [24]. No till systems have been compared to excessive tillage practices under several range of condition. Studies on how the practices affect physical soil properties had mixed results. Overall, no-tillage systems tend to increase macrospore connectivity while generating inconsistent responses in total porosity and soil bulk density as compared to conventional tillage systems [24]. The impact of an NT system on physical soil properties varies and dependent on the soil temperature and moisture regime, length of time the system has been in place, amount of disturbance resulting from the system, diversity and intensity of the crop rotation, limitations of the soil and site, removal of residue after harvest, and use of other practices, Use of a no-till system and these other practices is effective in improving physical soil properties. This is especially important for soils that have inherent limitations, such as those that are sandy, have a very high content of clay, have a claypan or fragipan, or have other physical limitations that affect the amount of water available for plants, plant growth and vigor, and plant yield [25, 26, 27]. In general, long-term use of a no-till system along with use of high-residue crops during the growing season will enhance physical soil properties through the development and maintenance of water-stable aggregates, which increase the infiltration rate and the available water capacity [28]. Soil physical properties that are influenced by tillage management are discussed below:

Bulk density

Bulk density is an indicator of soil health and its compaction , it affect also plant rooting depth or restrictions, soil water capacity, plant nutrient availability, soil porosity , soil microorganism activity, nutrient availability which influence soil productivity [29]. Many studies showed that the bulk density will increase slightly in the early stages of implementation of a no-till system after conventional tillage (CT) has been used [30]. Some studies also show that bulk density may increase more with long-term use of NT systems than with CT [31, 32, 33].

The amount of biomass and organic material left on the soil surface and returned to the soil has a major effect on the decrease or increase of BD when comparing NT to CT. Soils that have a higher amount of soil organic matter and improved porosity naturally have lower BD than soils that have similar textures but have less organic matter content. Long-term NT studies by Kahlon et al [34] show a decrease in bulk density when additional practices, such as double cropping or applying mulch, are used in different climatic settings. Under ideal conditions, bulk density can be decreased even with short-term NT if additional practices, such as growing cover crops, are also used [35].

Available Water Capacity/Total Soil Water (Soil Water availability)

Several studies show that available water capacity improves when other physical soil properties, such as soil organic matter, the infiltration rate, bulk density, soil structure, and penetration resistance, are improved [35, 36]. No-till systems, as compared to conventional tillage, resulted in higher levels of soil moisture in virtually every study in which soil moisture was measured. Maintaining soil moisture is important for achieving high yields of biomass in rain-fed environments during the dry periods of the growing season. NT systems along with using high-residue crops in the crop rotation, using cover crops that provide high levels of biomass, maintaining crop residue with a high content of carbon, and avoiding excessive removal of residue, as well as climate, are key to increasing and maintain water content and availability in soil.

Soil Organic Matter

The extent that soil organic matter (SOM) is improved or maintained is not solely dependent on use of no-till systems but also on additional practices such as mulching, rotating crops, harvesting forage or biomass and using cover crops. In some long-term studies, SOM does not improve but losses were minimized, for instance, in a 24-year study, NT plots on eroded soils in Southern Illinois that have a fragipan and are under a corn and soybeans rotation stored which retained 7.8 megagrams of carbon per hectare more than conventional tillage CT plots [27] Although erosion was minimized and the SOM content was higher in the NT plots, the SOM content did not increase over the 24 years. This was due to erosion, a fragipan in the soil, and the use of low-residue crops (soybeans). Even in thermic temperature regimes in the Southeast, SOM levels under mid- and long-term NT systems were higher than those under CT systems, but SOM levels are not likely to increase unless additional measures are used [33]. Using high-residue crops and including perennial legumes, small grain, and/or high-carbon cover crops (such as cereal rye) provide the additional carbon and root mass needed to increase or maintain SOM levels. Aziz et al. [37] demonstrated that SOM could be significantly increased with no restrictions in silt loam by adding crop diversity to traditional corn/soybeans rotations or to other rotations that include low-residue crops. Studies of long-term use of no-till systems that included additional measures, such as mulching, growing cover crops, and using diverse rotations in thermic soil temperature regimes, showed increases in SOM [33, 34, 37].

Infiltration rate

Brock [28] analyzes soil compaction, soil sealing/crusting, penetration resistance and water soil infiltration from south-eastern part of USA. The study reported that long term no-till field resulted in reduced crusting/sealing and increased infiltration with significantly reduced runoff. Infiltration, penetration resistance, crusting/sealing improved more under all NT systems studied as compared to conventional tillage (CT) systems, in all areas where these properties were analyzed [35, 38].

Aggregate Size and Stability and Soil Structure

Studies comparing CT and NT system prove that aggregate stability and soil structure significantly increase in NT systems. For instance NT system on sandy piedmont soils in Georgia under thermic and humid climatic conditions which cause rapid breakdown of organic matter improve aggregate stability within 3 years of operation [32]. Brock [28] reported that water-stable aggregates cannot be sustained with CT since the residue cover is not sufficient to protect against surface crusting and that long-term NT is needed to increase aggregate stability. This emphasizes the importance of limiting soil disturbance, especially for soils with inherent limitations, such as a claypan or sandy texture [39]. Aggregate stability and size are very crucial in maintaining soil structure and minimizing erosion which further regulate most of the soil functions.

Cover Crop

Cover crop are defined as any living ground cover that is planted into or after agriculture crops mainly cash crops and turned into the soil before planting next crop plants. Hartwig and Ammon [40] stated that first benefit of cover crops is reduction of runoff and soil erosion subsequently resulting in improvement of soil health and sustainable soil productivity. Planting crops, including grasses, legumes, and forbs, for seasonal cover and other conservation purposes. The use of hairy vetch increased soil organic matter content, water aggregate stability, porosity, and available water for plants and reduced bulk density and penetration resistance [35]. The research done by Kladivko [41] showed that both cereal and legumes improve soil aggregation, decrease soil bulk density, control weeds and provide siol moisture for the cash crops during stress of summer period. Some of the benefits of cover crops include; increased availability of nitrogen if the cover crop is a legume and addition of organic matter to the soil through the leaf litter and other crop residues. Cover crops also keep the soil moist, which is a good condition for microbial activity. cover crops also shown to affect soil microbial biomass C and N of long term field (Moore et al., 2000). Dupont et al [42] in a study reported that cover crop managed with low to mid C: N ratio increases the richness of beneficial nematodes which aid in increasing soil NH_4-N levels consequently nitrogen mineralization. Similarly Griffiths [43] also reported that increase in soil fauna significantly contribute to N mineralization, liberating up to 30% of mineralized N.

Mulching

Mulch generally placed on soil surface as cover aiming to reduce evaporation as wells as controlling weeds. Mulches restrict the movement of soil moisture [34] and generally are natural like peat, straw etc. and artificial like opaque plastic sheets. Depends upon the mulch type, mulching influence soil temperature and consequently soil functions. Mulching has significant and positive impact on soil physical properties. Studies showed that mulching improves bulk density of soil [44] saturated hydraulic conductivity (Ksat) and mean aggregate size in the surface layer increased under ridge-till, no-till, and plow-till systems [34]. Blanco-Canqui and Lal [45] also reported soil mulching in Ohio soils resulted in higher Ksat, porosity and water content. The aggregate stability of soils in Wisconsin was positively impacted by residue treatment [46]. Similar results were reported by Zhang et al. [47] reported that soils under straw cover had increased macro-aggregate stability and Ksat.

Many studies reported improvement in biological activities by proper mulching. Zhang et al (2008) reported abundance of earthworms under wheat straw mulch field as compared to non-mulch field. Karlon et al [46] found that ergostol (biochemical measure of fungal biomass), earthworm populations, and total carbon content increased with increased mulching. In addition, mulching increased the total carbon in bulk soil and macro-aggregates. Generally, it was also reported that mulching enhanced the effects of no-till management systems and support and helps to conserve moisture, reduce energy use associated with irrigation, control surface erosion, and reduce airborne particulates [34, 47]

Nutrient Management

Application of compost and Farm Yard Manure has been found to be associated with increased microbial abundance and their activities [48]. Graham et al. [49] concluded that the increase in enzyme activities in response to farm yard manure is even higher than increases of microbial biomass and soil community structure, despite all these being affected positively. Increase in microbial biomass carbon with organic fertilizer application in comparison the control and these increases can be attributed to the substrates carbon for energy and various nutrient elements provided to the microorganisms from manure and compost as compared to inorganic fertilizers that does not contain C and usually contain specific nutrient types [50]. In a well-functioning healthy soil system, nutrients are also conserved, recycled, and made available for plant uptake. Microbial functions include decomposition, nutrient cycling, detoxification and suppression of pathogenic organism and importantly biogeochemical cycle regulation are vital in soil ecosystem functioning [51].

Good soil health (SH) includes the proper amount of nutrients for plant growth. Deficient amounts result in insufficient plant cover and excessive erosion, and excessive amounts result in runoff of surface water and leaching of contaminants into ground water. Salts, sodium, pH, and excessive trace elements are also important to soil health and need to be managed for optimum soil function [50]. This conservation practice plays important roles in sustainable agriculture such as nutrient conservation, minimizing agricultural nonpoint source pollution of surface water and ground water resources, judicious use of organic manure and its by-products as plant nutrients and maintaining physical, chemical and biological properties of soil.

Intercropping and Crop Rotation

Different Cropping practices like intercropping and crop rotations are used both in conservation agriculture and conventional agriculture systems. They have shown evidence of promoting Microbial multiplication and activities. Intercropping or polyculture is defined as the cultivation of two or more crops on the same piece of land to the extent that crops interact biologically [52]. Intercropping practices that include legumes promote Rhizobial-legume symbiotic relationships that lead to biological nitrogen fixation [53]. Biological nitrogen fixation improves the fertility of the soil and both the soil health and quality as the availability of nitrogen positively affects the C: N ratios by increasing the N value [20, 54, 55]. This in turn improves the general microbial ecology of the soil by allowing proliferation of diverse and increased numbers ofsoil biota. Growing crops in a planned sequence on the same field is known as crop rotaion (NRCS, 2014) . In the long term, the production of organic matter may affect some physical soil properties, such as aggregate stability. The effects, if any, vary according to the crop and type of rotation. For some soils, the rotation may not affect aggregation [56]. The rotation does not affect the stability of the aggregates, despite a high content of organic matter and the effect of the rotation on physical soil properties may depend on the individual crop grown. For example, soils under corn had lower Ksat and slightly higher bulk density than soils under soybeans [57]. Intercropping and crop rotation practices mainly help the soil to:

- Reduce rill and inter-rill erosion and also wind erosion
- Improve soil quality
- Manage Plant nutrient balance
- Supply nitrogen through biological nitrogen fixation and reduce energy that should used
- Improve water conservation
- Manage saline seeps
- Manage plant pests such as weeds, insects and diseases
- Provide feed for domestic livestock
- Provide annual crops for bioenergy feedstock
- Provide food and shelter cover for wildlife, including pollinator forage, cover and nesting

AGROFORESTRY

Agroforestry is an integrated system technique of land resource management in which trees are combined with crops or pastures simultaneously or in phases with the objective of sustained optimization of total production per unit area. The bacterial and fungal colonies in agroforestly systems are stimulated by arthropods such as collembola roles in micro-fragmentation of litter and nutrient cycling and maintain soil health [58]. Quantity and quality of litter, species diversity, deep and perennial root systems associated with agroforestry create a more suitable occasion of soil faunal (including earthworms) activities [59]. The activities of earthworms especially the burrowing provides good aeration and nutrient rich substrates respectively for microflora [60]. Agroforestry is also reported to enhance arbuscular mycorrhizal fungi abundance as compared to mono-cropped systems [61]. This in turn improves phosphorus availability to plants.

CONCLUSION

For developing nation like India where agriculture is basic need for food security and economy, the importance of soil should not be ignored. It's an urgent need for the developing nations to make farmer aware about the impact of cultivation and other soil uses on soil health. Farmers should be conscious to use indicators or quantifiable values which relate to chemical, physical and biological health indicators. The present review explains different agriculture management practices like conservation tillage (less tillage to zero tillage), adequate and judicious fertilizer usage, manure amendment, crop rotation, fallow techniques, crop residue cover etc. can improve soil functioning and stability as well as increase soil productivity with the least cost in sustainable manner. Studies on long term conservation tillage showed its capacity to increase soil health when coupled with intensive cropping system. Considering beneficial functions of soil biota, it is therefore noted that thorough exploitation of these soil management practices or farming systems will have a substantial contribution to improving low input ecological friendly farming methods and soil health in general. In this international year of soil, sensible use of soil health indicator broadly across the nation and accordingly agricultural management changes will enhance soil sustainability and productivity.

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