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Soil quality management through conservation agriculture and other practices for higher productivity in rainfed agriculture amidst climate change

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ABSTRACT

The soils in the rainfed region are at the verge of degradation by virtue of several regions. The major reasons which degrade soil quality and deteriorate its productive capacity could be: i) washing away of topsoil and organic matter associated with clay size fractions due to water erosion, ii) intensive deep tillage and inversion tillage with moldboard and disc plough resulting in a) fast decomposition of remnants of crop residues which is catalyzed by high temperature, b) breaking of stable soil aggregates and aggravating the process of oxidation of entrapped organic C and c) disturbance to the habitat of soil microflora and fauna and loss in microbial diversity, iii) less use of fertilizers and widening of plant nutrients removal-use gap , iv) mining and other commercial activities such as use of top soil for other than agricultural purpose, v) mono cropping without following any suitable rotation, vi) nutrient imbalance caused due to disproportionate use of primary, secondary and micronutrients, vii) no or low use of organic manures and poor recycling of farm based crop residues viii) no or low green manuring ix) poor nutrient use efficiency x) indiscriminate use of other agricultural inputs such as herbicides, pesticides, fungicides, etc., , xi) water logging, salinity and alkalinity and acid soils.As a result of several above-mentioned reasons, soils encounter diversity of constraints broadly on account of physical, chemical and biological soil health and ultimately low productivity. Amidst climatic variation and climatic change, there are likelihoods of occurring more degradation of soil resource. Under such situation, conservation agriculture and other resource conservation practices have proved quite effectivein protecting thesoil fromfurther degradation andin restoration of soil quality. This review paper deals withdifferent aspectsof soil quality management through conservation agriculture and other resource conservation techniques.

Key words: Soil degradation, causes of soil degradation, climate change risks, conservation agriculture, soil quality indicators, steps to promote conservation agriculture

INTRODUCTION

India is primarily an agrarian economy. Of the total geographical area of 329 million ha, 142 million ha is devoted to agriculture (FAI, 1990). Out of an estimated net cultivated area of 142.2 m ha about 73 m ha.Area is under rainfed agriculture and depends on the rain God, while 69 m ha area is irrigated. The irrigated area produces about 56% of total food requirement of India. The remaining 44% of the total food production comesfrom rainfed agriculture. Most of the essential commodities such as coarse cereals (90%), pulses (87%), and oil seeds (74%) are produced from the rainfed agriculture. These statistics emphasise the role that rainfed regions play in ensuring food for the ever-rising population. Owing to the diversity in rainfall pattern, temperature, parent material, vegetation and relief or topography, this country is bestowed with different soil types predominantly alluvial soils, black soil, red soils, laterites, desert soils, mountainous soils etc. Taxonomically, soils in India fall under Entisols (80.1 m ha), Inceptisols (95.8 m ha), Vertisols (26.3 m ha), Aridisols (14.6), Mollisols (8.0 m ha), Ultisols (0.8 m ha), Alfisols (79.7 m ha), Oxisols (0.3 m ha) and non-classified soil (23.1 m ha). Rainfall wise, 15 m ha area falls in a rainfall zone of <500mm, 15 m ha under 500 to 750 mm, 42 m ha under 750 to 1150 mm and 25 m ha under > 1150 mm rainfall. Predominant soil orders which represent semi-arid tropical region are Alfisols, Entisols, Vertisols and associated soils. Other soil orders such as Oxisols, Inceptisols and Aridisols also form a considerable part of rainfed agriculture. Most of the soils in rainfed regions are at the verge of degradation with low cropping intensity, relatively low organic matter status, poor soil physical health, low fertility, etc.

Land degradation and deterioration of soil and water quality are the major threats to national food security and environmental safety. It has been estimated that out of the 329 million

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hectare of geographical area in the country, the total degraded area accounts for 120.7 m ha, of which 73.3 m ha is affected by water erosion, 12.4 m ha by wind erosion , 6.73 m ha by salinity and alkanity and 25 m ha by soil acidity. Moisture stress accompanied by other soil related constraints result in low productivity of majority of the crops (Sharma et al 1999). Besides natural causes, agricultural use of land is causing serious soil losses in many places across the world including in Indian subcontinent. It is probable that human race will not be able to feed the growing population, if this loss of fertile soils continues at the existing rate. In many developing countries, hunger is compelling the community to cultivate land that is unsuitable for agriculture and which can only be converted to agricultural use through enormous efforts and costs, such as those involved in the construction of terraces and other surface treatments.

Indian sub-continent predominantly represents wide spectrum of climate ranging from arid to semi arid, sub humid and humid with wider variation in rainfall amount and pattern. Seasonal temperature fluctuations are also vast. Soils representing rainfed regions are marginally low in organic matter status. The first predominant cause of soil degradation in rainfed regions undoubtedly is water erosion. The process of erosion sweeps away the topsoil along with organic matter and exposes the subsurface horizons. The second major indirect cause of degradation is loss of organic matter by virtue of temperature mediated fast decomposition of organic matter and robbing away of its fertility. Above all, the several other farming practices such as reckless tillage methods, harvest of every small component of biological produce and virtually no return of any plant residue back to the soil, burning of the existing residue in the field itself for preparation of clean seed bed, open grazing etc aggravate the process of soil degradation.

MAJOR CAUSES OF SOIL DEGRADATION

The major reasons which degrade soil quality and deteriorate its productive capacity could be enumerated as: i) washing away of topsoil and organic matter associated with clay size fractions due to water erosion resulting in a 'big robbery in soil fertility', ii) intensive deep tillage and inversion tillage with moldboard and disc plough resulting in a) fast decomposition of remnants of crop residues which is catalyzed by high temperature, b) breaking of stable soil aggregates and aggravating the process of oxidation of entrapped organic C and c) disturbance to the habitat of soil microflora and fauna and loss in microbial diversity, iii) dismally low levels of fertilizer application and widening of removal-use gap in plant nutrients, iv) mining and other commercial activities such as use of top soil for other than agricultural purpose, v) mono cropping without following any suitable rotation, vi) nutrient imbalance caused due to disproportionate use of primary, secondary and micronutrients, vii) no or low use of organic manures such as FYM, compost, vermi-compost and poor recycling of farm based crop residues because of competing demand for animal fodder and domestic fuel, viii) no or low green manuring as it competes with the regular crop for date of sowing and other resources, ix) poor nutrient use efficiency attributing to nutrient losses due to leaching, volatilization and denitrification, x) indiscriminate use of other agricultural inputs such as herbicides, pesticides, fungicides, etc., resulting in poor soil and water quality, xi) water logging, salinity and alkalinity and acid soils.As a result of several above-mentioned reasons, soils encounter diversity of constraints broadly on account of physical, chemical and biological soil health and ultimately end up with poor functional capacity (Sharma *et al.,* 2007). In order to restore the quality of degraded soils and to prevent them from some further degradation, it is of paramount importance to follow resource conservation andconservation agriculture practices on long-term basis.

There is no doubt that, agricultural management practices such as crop rotations, inclusion of legumes in cropping systems, addition of animal based manures, adoption of soil water conservation practices, various permutations and combinations of deep and shallow tillage, mulching of soils with in-situ grown and externally brought plant and leafy materials always remained the part and parcel of agriculture in India. Despite all these efforts, the concept of conservation farming could not be followed in an integrated manner to expect greater impact in terms of protecting the soil resource from degrading processes.

CLIMATE RELATED POTENTIAL RISKS IN AGRICULTURE IN INDIA

As comprehensively reviewed by Rao *et al.* (2010), the major weather related risks in Agriculture could be as follows:Monsoons in India exhibits substantial inter-seasonal variations, associated with a variety of phenomena such as passage of monsoon disturbances associated with active phase and break monsoon periods whose periodicities vary from 3-5 and 10-15 days respectively. It is well noticed that summer monsoon rainfall in India varied from 604 to 1020 mm. The inter-seasonal variations in rainfall cause floods and droughts, which are the major climate risk factors in Indian Agriculture. The main unprecedented floods in India are mainly due to movement of cyclonic disturbances from Bay of Bengal and Arabian Sea on to the land masses during monsoon and post-monsoon seasons – and during break monsoon conditions in some parts of Uttar Pradesh and Bihar. The thunderstorms due to local weather conditions also damages agricultural crops in the form of flash floods. Beside floods, drought is a normal, repetitive feature of climate associated with deficiency of rainfall over extended period of time to different dryness levels describing its severity. During the period from 1871 to 2009, there were 24 major drought years, defined as years with less than one standard deviation below the mean. Another important adverse effect of climate change could be unprecedented heat waves. Heat waves generally occur during summer season where the cropped land is mostly fallow, and therefore, their impact on agricultural crops is limited. However, these heat waves adversely affect orchards, livestock, poultry and rice nursery beds. The heat wave conditions during May 2003 in Andhra Pradesh and 2006 in Orissa are some examples that have affected the economy to a greater extent. Also occurrence of heat waves in the northern parts during summer is common every year resulting in quite a good number of human deaths. Further, the water requirements of summer crops grown under irrigated conditions increase to a greater extent. Another adverse effect of climate change is cold waves which mostly occur in northern states. The Northern states of Punjab, Haryana, U.P., Bihar and Rajasthan experience cold wave and ground frost like conditions during winter months of December and January almost every year. The occurrence of these waves has significantly increased in the recent past due to reported climatic changes at local, regional and global scales. Site-specific short-term fluctuations in lower temperatures and the associated phenomena of chilling, frost, fogginess and impaired sunshine may sometimes play havoc in an otherwise fairly stable cropping/farming system of a region.

a) Impact of climate change on soil quality

Climate change is likely to have a variety of impacts on soil quality. Soils vary depending on the climate and show a strong geographical correlation with climate. The key components of climate in soil formation are moisture and temperature. The variation in temperature and moisture causes different patterns of weathering and leaching. Wind redistributes sand and other particles especially in arid regions. The amount, intensity, timing, and kind of precipitation influence soil formation. Seasonal and daily changes in temperature affect moisture effectiveness, biological activity, rates of chemical reactions, and kinds of vegetation. Soils and climate are intimately linked. Climate change scenarios indicate increased rainfall intensity in winter and hotter, drier summers. Changing climate with prolonged periods of dry weather followed by intense rainfall could be a severe threat to soil resource. Climate has a direct influence on soil formation and cool, wet conditions and acidic parent material have resulted in the accumulation of organic matter. A changing climate could also impact the workability of mineral soils and susceptibility to poaching, erosion, compaction and water holding capacity. In areas where winter rainfall becomes heavier, some soils may become more susceptible to erosion. Other changes include the washing away of organic matter and leaching of nutrients and in some areas, particularly those facing an increase in drought conditions, saltier soils, etc.

Not only does climate influence soil properties, but also regulates climate via the uptake and release of greenhouse gases such as carbon dioxide, methane and nitrous oxide. Soil can act as a source and sink for carbon, depending on land use and climatic conditions. Land use change can trigger organic matter decomposition, primarily via land drainage and cultivation. Restoration and recreation of peat lands can result in increased methane emissions initially as soils become anaerobic, whereas in the longer term they become a sink for carbon as organic matter accumulates. Climatic factors have an important role in peat formation and it is thus highly likely that a changing climate will have significant impacts on this resource.

b) Carbon build up and rising temperatures

In India, over two-thirds of the increase in atmospheric CO_2 during the past 20 years is due to fossil fuel burning. The rest is due to land-use change, especially deforestation, and to a lesser extent, cement production. Global average surface temperature increased 0.6 (0.2) ^oC in the 20th century and will increase by 1.4 to 5.8 ^oC by 2100. Estimates indicate that India's climate could become warmer under conditions of increased atmospheric carbon dioxide. The average temperature change is predicted to be in the range of 2.33^{o}C to 4.78^{o}C with a doubling in CO_2 concentrations. Over the past 100 years, mean surface temperatures have increased by 0.3-0.8^{o}C across the region. The 1990s have been the hottest decade for a thousand years. The time taken for CO_2 to pass through the atmosphere varies widely, with a significant impact. It can take from 5 to 200 years to pass through the atmosphere, with an average of 100 years. This means that CO_2 emission produced 50 years ago still linger in atmosphere today. It also means that current emissions won't lose their deleterious effect until year 2104. Even though drastic measures to reduce climate emissions have been taken in recent years, climate change is impossible to prevent. As a result of increasing pressure from climate change on current key areas of food production, there might be a rising need for increased food production. The production of food more locally is also being promoted in an attempt to reduce food miles. To meet food production and security objectives, there might be the need to afford prime agricultural land more protection. The rise in temperatures will influence crop yields by shifting optimal crop growing seasons, changing patterns of precipitation and potential evapo-transpiration, reducing winter storage of moisture in snow and glacier areas, shifting the habitat's of crops pests and diseases, affecting crop yields through the effects of carbon dioxide and temperature and reducing cropland through sea-level rise and vulnerability to flooding

c) Climatic change effect on soil fertility and erosion

No comprehensive study has yet been made of the impact of possible climatic changes on soils. Higher temperatures could increase the rate of microbial decomposition of organic matter, adversely affecting soil fertility in the long run. But increases in root biomass resulting from higher rates of photosynthesis could offset these effects. Higher temperatures could accelerate the cycling of nutrients in the soil, and more rapid root formation could promote more nitrogen fixation. But these benefits could be minor compared to the deleterious effects of changes in rainfall. For example, increased rainfall in regions that are already moist could lead to increased leaching of minerals, especially nitrates. In the Leningrad region of the USSR a one-third increase in rainfall (which is consistent with the GISS 2 x CO2 scenario) is estimated to lead to falls in soil productivity of more than 20 per cent. Large increases in fertilizer applications would be necessary to restore productivity levels. Decreases in rainfall, particularly during summer, could have a more dramatic effect, through the increased frequency of dry spells leading to increased proneness to wind erosion. Susceptibility to wind erosion depends in part on cohesiveness of the soil (which is affected by precipitation effectiveness) and wind velocity.

Nitrogen availability is important to soil fertility and N cycling is altered by human activity. Increasing atmospheric CO_2 concentrations, global warming and changes in precipitation patterns are likely to affect N processes and N pools in forest ecosystems. Temperature, precipitation, and inherent soil properties such as parent material may have caused differences in N pool size through interaction with biota. Keller *et al.,* 2004 reported that climate change will directly affect carbon and nitrogen mineralization through changes in temperature and soil moisture, but it may also indirectly affect mineralization rates through changes in soil quality.

d) Impact on biodiversity

Climate change is having a major impact on biodiversity and in turn biodiversity loss (in the form of carbon sequestration trees and plants) is a major driver of climate change. Land degradation such as soil erosion, deteriorating soil quality and desertification are driven by climate variability such as changes in rainfall, drought and floods. Degraded land releases more carbon and greenhouse gases back into the atmosphere and slowly kills off forests and other biodiversity that can sequester carbon, creating a feedback loop that intensifies climate change.

Soil management techniques to mitigate ill effects of climate change:

In order to mitigate the ill effects of climate change on soil quality and to protect the soil and land resource, it is important to give more focus on conservation agriculture practices including conservation tillage, crop residue retention and recycling, effective crop rotations by way of including legumes in the cropping systems, addition of animal based manures, adoption of soil water conservation practices, land cover management and mulching of soils with in-situ grown and externally brought plant and leafy materials etc. Some of these issues have been discussed in length in this lecture notes.

CONSERVATION AGRICULTURE – concepts and approaches

Conservation agriculture is a practice that reduces soil erosion, sustains soil fertility, improves water management and reduces production costs, making inputs and services affordable to small-scale farmers. Conservation agriculture is defined as a set of practices aimed at achieving the following three principles simultaneously: i) maintaining adequate soil cover, ii) disturbing the soil minimally, and iii) ensuring crop rotation and intercropping. Conservation agriculture as defined by Food and Agricultural Organizations (FAO) of the United Nations is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. It is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt the biological processes (Philip *et al.,* 2007). Conservation agriculture, in broader sense includes all those practices of agriculture, which help in conserving the land and environment while achieving desirably sustainable yield levels. Tillage is one of the important pillars of conservation agriculture which disrupts inter dependent natural cycles of water, carbon and nitrogen. Conservation tillage is a generic term encompassing many different soil management practices. It is generally defined as ‘any tillage system that reduces loss of soil or water relative to conventional tillage; mostly a form of non-inversion tillage allows protective amount of residue mulch on the surface (Mannering and Fenster, 1983).

Lal (1989) reported that the tillage system can be labeled as conservation tillage if it i) allows crop residues as surface mulch, ii) is effective in conserving soil and water, iii) maintains good soil structure and organic matter contents, iv) maintains desirably high and economic level of productivity, v) reduces the need for chemical amendments and pesticides, vi) preserves ecological stability and vii) minimizes the pollution of natural waters and environments. In order to ensure the above criteria in agriculture, there is a need to follow a range of cultural practices such as i) using crop residue as mulch, ii) adoption of non-inversions or no-tillage systems, iii) promotion of crop rotations by including cover crops, buffer strips, agroforestry, etc., iv) enhancement of infiltration capacity of soil through rotation with deep rooted perennials and modification of the root zone; v) enhancement in surface roughness of soil without jumping into fine tilth, vi) improvement in biological activity of soil fauna through soil surface management and vii) reducing cropping intensity to conserve soil and water resources and building up of soil fertility. The effects of conservation tillage on various soil properties, organic matter status, soil nutrient status and environmental quality have comprehensively reviewed by Blevins and Frye (1993), Lal (1989), Unger and McCalla (1980) and Unger (1990). From the various reviews, it is understood that no single tillage system is suitable for all soils and climatic conditions. The predominant advantages of the conservation tillage have been found in terms of soil erosion control, water conservation, less use of fossil fuels specifically for preparation of seed bed, reduced labour requirements, more timeliness of operations or greater flexibility in planting and harvesting operations that may facilitate double cropping, more intensive use of slopping lands and minimized risk of environmental pollution. Some of the discouraging and undesirable effects of conservation tillage has been reported as: (1) Increase in use of herbicides and consequently increased cost, (2) problems and difficulties in controlling of some of the infested weeds, (3) difficulty in managing poorly drained soils, (3) slower warming of temperate soils due to surface residue layer during winter and springs which delays germination and early growth. However, in tropics this negative aspect can become an asset in helping in maintaining relatively lower temperature and thereby enhancing germination. It also helps in preserving soil and water resources.

Importance and scope of conservation agricultural practices with reference to rainfed areas

As discussed in the foregoing section, soil quality degradation is more prominent in rainfed agro-eco-regions because of natural and human induced crop husbandry practices, which call for the adherence to the conservation agriculture management as top priority. Conservation agriculture has the main aim of protecting the soil from erosion and maintaining, restoring and improving soil organic carbon status in the various production systems, hence more suited and required in rainfed agriculture. Predominantly, this goal can be achieved by way of minimizing the soil tillage, inclusion of crop rotation or cover crops (mostly legumes) and maintaining continuous residue cover on soil surface. The former is governed by the amount of draft, a farmer is using and the latter by the produce amount, harvesting index and fodder requirements including open grazing. The crop rotations are induced by crop diversification, which has wider scopes in the rainfed agriculture than in irrigated agriculture. Diversification will help not only in minimizing the risk occurred due to failure of crops, improving total farm income but also in carbon sequestration.

Tillage, which is one of the predominant pillars of conservation agriculture, disrupts the inter-dependent natural cycles of water carbon and nitrogen. Tillage unlocks the potential microbial activity by creating more reactive surface area for gas exchange on soil aggregates that are exposed to higher ambient oxygen concentration (21%). Tillage also breaks the aggregate to expose fresh surfaces for enhanced gas exchange and perhaps, may lead to more carbon loss from the interior that may have higher carbon-dioxide concentration. Thus, an intensive tillage creates negative conditions for carbon sequestration and microbial activity. However, the main question is whether the intensity of tillage or length of cultivation of land which is an environment enemy in production agriculture in terms of loss of carbon-dioxide, soil moisture through evaporation and biota dwindling is a major production constraint to agriculture or not. The developed countries suffer from heavy-duty mechanization, while India is suffering from long use of plough without caring much about the maintenance of land cover. The major toll of organic C in slopping lands has been taken by water erosion due to faulty methods of up and down cultivation.

CONSERVATION AGRICULTURE VIS-À-VIS SOIL QUALITY

Various research reports have emphasized that conservation agricultural practices play an important role in preventing the soils from further degradation and in restoring back the dynamic attributes of soil quality. According to Doran and Parkin (1994) and Karlen *et al.,* (1997), soil quality is defined as the functional capacity of the soil. Seybold *et al.,* (1998) defined the soil quality as 'the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitation.' Quality with respect to soil can be viewed in two ways: (1) as inherent properties of a soil; and (2) as the dynamic nature of soils as influenced by climate, and human use and management. This view of soil quality requires a reference condition for each kind of soil with which changes in soil condition are compared and is currently the focal point for the term 'soil quality'. The soil quality as influenced by management practices can be measured quantitatively using physical, chemical and biological properties of soils as these properties interact in a complex way to give a soil its quality or capacity to function. Thus, soil quality cannot be measured directly, but must be inferred from measuring changes in its attributes or attributes of the ecosystem, referred to as 'indicators'. Indicators of soil quality should give some measure of the capacity of the soil to function with respect to plant and biological productivity, environmental quality and human and animal health. Indicators are measurable properties of soil or plants that provide clues about how well the soil can function. They provide signal about desirable or undesirable changes in land and vegetation management that have occurred or may occur in the future. Some of the important indicators which are given below can be influenced by appropriate soil management practices which in turn can help in moderating the ill effects of climate change (Table1).

Table 1: Predominant soil quality indicators and related processes and functions which can moderate the ill effects of climate change

Soil quality indicators	Soil processes and functions
i) Physical indicators	
A. Mechanical	
Texture	Crusting, gaseous diffusion, infiltration
Bulk density	Compaction, root growth, infiltration
Aggregation	Erosion, crusting, infiltration, gaseous diffusion
Pore size distribution and continuity	Water retention and transmission, root growth, and gaseous exchange
B. Hydrological	
Available water capacity	Drought stress, biomass production, soil organic matter content
Non-limiting water range	Drought, water imbalance, soil structure
Infiltration rate	Runoff, erosion, leaching
C. Rooting zone	
Effective rooting depth	Root growth, nutrient and water use efficiencies
Soil temperature	Heat flux, soil warming activity and species diversity of soil fauna
ii) Chemical indictors	
pH	Acidification and soil reaction, nutrient availability
Base saturation	Absorption and desorption, solubilization
Cation exchange capacity	Ion exchange, leaching
Total and plant available nutrients	Soil fertility, nutrient reserves
iii) Biological indicators	
Soil organic matter	Structural formation, mineralization, biomass carbon, nutrient retention
Earthworm population and other soil macro fauna and activity	Nutrient cycling, organic matter decomposition, formation of soil structure
Soil biomass carbon	Microbial transformations and respiration, formation of soil structure and organo-mineral complexes
Total soil organic carbon	Soil nutrient source and sink, biomass carbon, soil respiration and gaseous fluxes

Source: Lal (1994)

Role of conservation Agriculture (reduced tillage and residue management) in mitigating the adverse effect of climate change

Conservation tillage and residue management help in the following ways in influencing some of the soil properties and mitigating the adverse effects of climate change.

- **Soil Temperature**: Surface residues significantly affect soil temperature by balancing radiant energy and insulation action. Radiant energy is balanced by reflection, heating of soil and air and evaporation of soil water. Reflection is more from bright residue.

- **Soil aggregation:** It refers to binding together of soil particles into secondary units. Water stable aggregates help in maintaining good infiltration rate, good structure, protection from wind and water erosion. Aggregates binding substances are mineral substances and organic substances. Organic substances are derived from fungi, bacteria, actinomycetes, earthworms and other forms through their feeding and other actions. Plants themselves may directly affect aggregation through exudates from roots, leaves and stems, leachates from weathering and decaying plant materials, canopies and surface residues that protect aggregates against breakdown with raindrop impact, abrasion by wind borne soil and dispersion by flowing water and root action. Aggregates with. 0.84 mm in diameter is non-erodable by wind and water action. Well-aggregated soil has greater water entry at the surface, better aeration, and more water-holding capacity than poorly aggregated soil.
- Aggregation is closely associated with biological activity and the level of organic matter in the soil. The gluey substances that bind components into aggregates are created largely by the various living organisms present in healthy soil. Therefore, aggregation is increased by practices that favor soil biota. Because the binding substances are themselves susceptible to microbial degradation, organic matter needs to be replenished to maintain aggregation. To conserve aggregates once they are formed, minimize the factors that degrade and destroy them.
- Well-aggregated soil also resists surface crusting. The impact of raindrops causes crusting on poorly aggregated soil by disbursing clay particles on the soil surface, clogging the pores immediately beneath, sealing them as the soil dries. Subsequent rainfall is much more likely to run off than to flow into the soil. In contrast, a well-aggregated soil resists crusting because the water-stable aggregates are less likely to break apart when a raindrop hits them. Any management practice that protects the soil from raindrop impact will decrease crusting and increase water flow into the soil. Mulches and cover crops serve this purpose well, as do no-till practices which allow the accumulation of surface residue.
- **Soil density and porosity:** Soil bulk density and porosity are inversely related. Tillage layer density is lower in ploughed than in unploughed (area under grass, low tillage area etc). When residues are involved, tilled soils will reflect lower density. Mechanization with heavy machinery results in soil compaction, which is undesirable and is associated with increased bulk density and decreased porosity. Natural compaction occurs in soils, which are low in organic matter and requires loosening. But, practicing conservation tillage to offset the compaction will be effective only when there is adequate residue, while intensive tillage may adversely influence the soil fauna, which indirectly influence the soil bulk density and porosity.
- **Effects on other physical properties:** Tillage also influences crusting, hydraulic conductivity and water storage capacity. It has been understood that the textural influences and changes in proportion of sand, silt and clay occur due to inversion and mixing caused by different tillage instruments, tillage depth, mode of operation and effect of soil erosion. Soil crusting which severely affects germination and emergence of seedling is caused due to aggregate dispersion and soil particles resorting and rearrangement during rainstorm followed by drying. Conservation tillage and surface residue help in protecting the dispersion of soil aggregates and helps in increasing saturated hydraulic conductivity. Increased HC in conjunction with increased infiltration resulting from conservation tillage allows soil profile to be more readily filled with water. Further, less evaporation is also supported by conservation tillage, and profile can retain more water.
- **Effect on soil organic matter and soil fertility:** Conservation agricultural practices help in improving soil organic matter by way of i)regular addition of

organic wastes and residues, use of green manures, legumes in the rotation, reduced tillage, use of fertilizers, and supplemental irrigation ii) drilling the seed without disturbance to soil and adding fertilizer through drill following chemical weed control and iii) maintaining surface residue, practicing reduced tillage, recycling of residues, inclusion of legumes in crop rotation. These practices provide great opportunity in maintaining and restoring soil quality in terms of soil organic matter (SOM) and N in semi-arid tropical (SAT) regions. It is absolutely necessary to spare some residue for soil application, which will help in improving soil tilth, fertility and productivity.

Some research experiences on the effect of conservation agriculture and other resource conservation practices on soil quality improvement

There are several reports on the influence of conservation agricultural management practices comprising of tillage, residue recycling, application of organic manures, green manuring and integrated use of organic and inorganic sources of nutrients, soil water conservation treatments, integrated pest management, organic farming, etc., on soil quality. Improved soil quality parameters create additional muscle power to soil to combat the ill effects of climate change. Some of the results pertaining to the effect of conservation agricultural practices on soil quality are given below:

The studies conducted over a 9 year period in Alfisols at Bangalore with finger millet, revealed that the yields were similar with optimum N, P, K application and with 50% NPK applied through combined use of fertilizers + FYM applied @ 10 t ha^{-1}. Application of vermicompost in combination with inorganic fertilizer in 1:1 ratio in terms of N equivalence was found very effective in case of sunflower grown in Alfisol at Hyderabad (Neelaveni, 1998). Combined use of crop residues and inorganic fertilizer showed better performance than sole application of residue. Use of crop residue in soil poor in nitrogen (Bangalore) showed significant improvement in the fertility status and soil physical properties. Continuous addition of crop residues for five years enhanced maize grain yield by 25%. Organic matter status improved from 0.5% in the control plots to 0.9% in plots treated with maize residue at 4 t ha^{-1} year^{-1}. In Alfisols at Hyderabad, use of crop residues in pearl millet and cowpea not only enhanced the yields but also made appreciable improvements in stability of soil structure, soil aggregates and hydraulic conductivity.

Capitalisation of legume effect is one of the important strategies of tapping additional nitrogen through biological N fixation. There are many reports on this aspect (Singh and Das, 1984; Sharma and Das, 1992). The beneficial effect of preceding crops on the succeeding non-legume crops has been studied at many locations. When maize was grown after groundnut, a residual effect of equivalent to 15 kg N ha^{-1} was observed at ICRISAT (Reddy *et al.* 1982). Sole cowpea has been reported to exhibit a residual effect of the magnitude of 25-50 kg N ha^{-1} (Reddy *et al.* 1982). Based on a five year rotation of castor with sorghum + pigeon pea and green gram + pigeon pea in an Alfisol of Hyderabad, it was observed that green gram + pigeon pea intercrop (4:1) can leave a net positive balance of 97 kg ha^{-1} total N in soil (Das *et al.* 1990).

Results of a long-term study conducted on soil quality improvement revealed that the application of gliricidia loppings proved superior to sorghum stover and no residue treatments in maintaining higher soil quality index (SQI) values. Further, increasing N levels also helped in maintaining higher SQI. In another experiment , the highest soil quality index (SQI) was obtained in conventional tillage (CT) + gliricidia loppings (GL) + 90 kg N ha^{-1} ($CTGLN_{90}$) (1.27) followed by $CTGLN_{60}$ (1.19) and minimum tillage (MT) + sorghum stover (SS) + 90 kg N ha^{-1} ($MTSSN_{90}$) (1.18), while the lowest was under minimum tillage + no residue (NR) + 30 kg N ha^{-1} ($MTNRN_{30}$) (0.90) followed by $MTNRN_0$ (0.94), indicating relatively less aggrading effects. The application of 90 kg N ha^{-1} under minimum tillage even without applying any residue ($MTNRN_{90}$) proved quite effective in maintaining soil quality index as high as 1.10. The key indicators, which contributed considerably towards SQI were, available N, K, S, microbial biomass carbon (MBC) and hydraulic conductivity (HC). Among the various treatments, $CTGLN_{90}$ not only had the highest SQI, but was most promising from the viewpoint of sustainability, maintaining higher average yield levels under sorghum-castor rotation.From the view point of SYI, CT approach remained superior to MT. To maintain yield as well as soil quality in Alfisols, primary tillage along with organic residue and nitrogen application are needed (Sharma et al, 2005).

Another long-term experiment was conducted with two tillage (conventional (CT) and reduced (RT)) and five INM treatments (control, 40 kg N through urea, 4 t compost + 20 kg N, 2 t Gliricidia loppings + 20 kg N and 4 t compost + 2 t Gliricidia loppings) using sorghum and green gram as test crops. Tillage did not influence the soil quality index (SQI), while the conjunctive nutrient use treatments had a significant effect. The conjunctive nutrient use treatments aggraded the soil quality by 24.2 to 27.2 %, while the sole inorganic treatment could aggrade only to the extent of 18.2 % over the control. Statistically, the overall superiority of the treatments in aggrading the soil quality was: 4 Mg compost + 2 Mg gliricidia loppings (T5) > 2 Mg Gliricidia loppings + 20 kg N through urea (T4) = 4 Mg compost + 20 kg N through urea (T3) > 40 kg N through urea (T2). The extent of percent contribution of the key indicators towards soil quality index (SQI) was: microbial biomass carbon (MBC) (28.5%), available nitrogen (28.6%), DTPA- Zn (25.3%), DTPA- Cu (8.6%), hydraulic conductivity (HC) (6.1%) and mean weight diameter (MWD) (2.9%) (Sharma *et al.,*2008).

Based on some other studies, it has been established that the conservation agriculture and conjunctive nutrient-management practices significantly and positively improved various soil physico-chemical, chemical, physical and biological properties under different cropping systems viz. sorghum-mung bean (Sharma *et al.* 2015b; Sharma *et al.* 2016a), pearlmillet based system (Sharma *et al.* 2014a), maize-blackgram system (Sharma *et al.* 2019), rainfed maize–wheat system (Sharma *et al.* 2014b), maize-wheat (Sharma *et al.* 2015), fingermillet / groundnut - fingermillet system (Sharma et al 2016b), cotton / cotton + blackgram system (Sharma *et al.* 2011; Maruthi Sankar *et al.* 2012), rainfed pigeonpea + rice system (Behera *et al.* 2012) fingermillet based system (Sharma *et al.* 2018). In most of these studies, higher soil quality index was obtained with conjunctive nutrient-management practices.

Further, it has been reported that the addition of organic matter through farmyard manure and crop residues played a crucial role to determine the soil physical (Indoria *et al.* 2016) and chemical and biological functional capacity of soil (Sharma *et al.* 2017; Indoria *et al.* 2018). It has also been well proved that the soil organic carbon significantly improved the physical soil quality parameters by supplying the organic matter, carbon and energy to various microbes, which secrete various enzymes and enhance soil aggregation and in-turn resulted in positive effect on various soil physical properties. Indoria *et al.* (2017) have earlier brought out that increasing the SOM levels, reducing the extent of soil disturbance and minimizing the compaction and soil erosion enhance soil porosity and improved soil structure. Similarly, the enhanced microbial activity increased the nutrients transformation process including mineralisation and thus their availability to plants.

Based on the network tillage experiment being carried out since 1999 at various centers of All India Coordinated Research Project on Dryland Agriculture (AICRPDA), it was observed that in arid (< 500 mm rainfall) region, low tillage was almost comparable to conventional tillage and the weed management was not so difficult, whereas, in semi arid (500 – 1000 mm) region, conventional tillage was found superior. It is a well-established fact that infiltration of rainfall depends on soil loosening and its receptiveness and thus requires more surface disturbance. Success of crops depends on rainfall infiltration and soil moisture holding in the profile.

For improving the carbon content in soil, apart from crop residues, the agro-forestry also becomes important. However, nothing comes free. The agro-forestry system comprising of perennial components depends on the sub-soil components. It has been observed that grasslands and tree system play an important role in improving soil properties such as bulk density, mean weight diameter, water stable aggregates and organic carbon. Apart from the above, other soil properties such as infiltration rate and hydraulic conductivity were also influenced due to agro forestry systems compared to agricultural systems. Strategies to promote conservation agriculture and other resource conservation practices:

1. The following strategies are suggested to promote conservation agriculture and other resource conservation practices. There is a need to create awareness among the communities about the importance of soil resources, organic matter build up in soil. Traditional practices such as burning of residues, clean cultivation, intensive tillage and pulverization of soil up to finest tilth need to be discouraged.
2. Systems approach is essential for fitting conservation tillage in modern agriculture. In order to follow the principle of “grain is to man and a residue is to soil”, farming systems approach introducing alternative fodder crops is essential. Agroforestry systems with special emphasis on silvi-pastures systems need to be introduced. Unproductive livestock herds needs to be discouraged
3. For the adoption of conservation tillage, it is essential that complete package of practices may be identified based on intensive research for each agro ecological region.
4. The increased use of herbicides has become inevitable for adopting conservation tillage/conservation farming practices. The countries that use relatively higher amount of herbicides are already facing problem of non-point source pollution and environmental hazard. In order to reduce the herbicidal demand, there are scopes to study the allelopathic effects of cover crops and intercultural and biological method of weed control. In other words, due concentration is needed to do research on regenerative cropping systems to reduce dependence on inorganic chemicals.
5. Low tillage, crop rotation, cover crops, maintenance of residues on the surface, control of weeds through herbicides, are the key components of conservation farming. Therefore, it is essential that these themes must be studied in depth under diverse soil and climatic conditions across the country on long-term basis.
6. The other objective of conservation farming is to minimize the inputs originating from non-renewable energy sources. Eg.Fertilizers and pesticides. Hence, research focus is required on enhancing fertilizer use efficiency and reduction in use of pesticides. This aspect can be strengthened by following integrated nutrient management and integrated pest management approach.
7. The past research experiences of conservation tillage reveal that the major toll of yield is taken by poor germination and poor crop stand because of poor microclimatic environment and hard setting tendencies of soil, excessive weed growth and less infiltration of water to the crop root zone. Therefore, the important aspects which need concentrated research focus include appropriate time of sowing, suitable seed rate, depth of seed placement and soil contact, row orientation, etc. Suitable cultivars having responsiveness to inputs also become important component of conservation farming.
8. The issues related to development of eco-friendly practices for tillage and residue recycling- appropriately for specific combination of soil-agro climatic cropping system-to alleviate physical constraints with higher water and nutrient use efficiency need to be addressed.
9. Inter-disciplinary research efforts are required to develop appropriate implements for seeding in zero tillage, residue incorporation and inter-cultural operations.

Research focus is needed on modeling of tillage dynamics and root growth, incorporation of soil-physical properties in crop-growth simulation models and relating it to crop yields under major cropping sequences.

Research and management strategies to improve soil resilience towards climatic change

The following research, developmental and policy strategies are suggested to restore and maintain soil quality on long-term basis.

- **Checking soil resource through effective soil and water conservation (SWC) measures**: It is well accepted connotation that ‘Prevention is better than cure'. In order to protect the top soil, organic matter content contained in it and associated essential nutrients, it is of prime importance that there should be no migration of soil and water out of a given field. If this is controlled, the biggest robbery of clay-organic matter -nutrients is checked. This can be easily achieved, if the existing technology on soil and water conservation is appropriately applied on an extensive scale. The cost for in-situ and ex-situ practices of SWC has been the biggest concern in the past. There is a need to launch 'soil resource awareness program' among the farming community. Suitable incentives / support need to be given to the farming community by way of employment / food for work program, etc.

- **Rejuvenation and reorientation of soil testing program in the country:** About more than 600 Soil testing labs situated in the country need to be reoriented, restructured and need to be given fresh mandate of assessing the soil quality in its totality including chemical, physical, biological soil quality indicators and water quality. The testing needs to be on intensive scale and recommendations are required to be made on individual farm history basis. Special focus is required on site specific nutrient management (SSNM). Soil Health Card system needs to be introduced. Soil fertility maps of intensive scale need to be prepared. District soil testing labs need to be renamed as 'District Soil Care Labs' and required to be well equipped with good equipments and qualified manpower for assessing important soil quality indicators including micronutrients. Fertilizer application needs to be based on soil tests and nutrient removal pattern of the cropping system in a site specific manner. This will help in correcting the deficiency of limiting nutrients. Keeping in mind the sluggish and inefficient activities of regional soil testing labs of the states, private sector can also be encouraged to take up Soil Care Programs with a reasonable costs using a principle of 'Soil Clinics, Diagnosis and Recommendation'.
- **Promotion of management practices which enhance soil organic matter**: Management practices such as application of organic manures (composts, FYM, vermi-composts), legume-crop based green manuring, tree-leaf green manuring, residue recycling, sheep-goat penning, organic farming, conservation tillage, inclusion of legumes in crop rotation need to be encouraged (Sharma *et al.,* 2002, 2004). Similar to inorganic fertilizer, subsidy provisions for organic manures can also be made so that growers should be motivated to take up these practices as components of integrated nutrient management (INM). As is being done in some of the countries such as USA, conservation tillage and land cover need to be promoted in India too for better carbon sequestration.
- **Development and promotion of other bio-resources for enhancing microbial diversity and ensuring their availability**: In addition to organic manures, there is a huge potential to develop and promote bio-fertilizers and bio-pesticides in large scale. These can play an important role in enhancement of soil fertility and soil biological health. Use of toxic plant protection chemical can also be reduced. In addition to this, there is a need to focus on advance research for enhancing microbial diversity by identifying suitable gene pools.
- **Ensuring availability of balanced multi-nutrient fertilizers:** Fertilizer companies need to produce multi-nutrient fertilizers containing nutrients in a balanced proportion so that illiterate farmers can use these fertilizers without much hassle.
- **Enhancing the input use efficiency through precision farming:** The present level of use efficiency of fertilizer nutrients, chemicals, water and other inputs is not very satisfactory. Hence, costly inputs go waste to a greater extent and result in monetary loss and environmental (soil and water) pollution. More focus is required to improve input use efficiency. The components required to be focused could be suitable machinery and other precision tools for placement of fertilizers, seeds and other chemical in appropriate soil moisture zone so that losses could be minimized and efficiency could be increased. This

aspect has a great scope in rainfed agriculture. This will also help in increasing water use efficiency (WUE) too.

- **Amelioration of problematic soils using suitable amendments and improving their quality to a desired level:** History has a record that poor soil quality or degraded soils have taken toll of even great civilizations. No country can afford to let its soils be remaining degraded by virtue of water logging, salinisation, alkalinity, erosion etc. Lots of efforts have already gone into the research process. There is a need to ameliorate the soils at an extensive scale on regular basis. No matter, how much it costs.
- **Land cover management:** Promotion of land cover management is must to protect the soil and to enhance organic matter in soil.
- **Mass awareness about the importance of soil resource and its maintenance:** There is need to introduce the importance of soil resource and its care in the text books at school and college levels. The subject is dealt at present apparently along with geography. Farming communities too need to be made aware about soil, its erosion, degradation, benefits and losses occurred due to poor soil quality. This can be done through various action learning tools which explain the processes of soil degradation in a simple and understandable manner.
- **Need to constitute a high power body such as National Authority on Land and Soil Resource Health or National Commission on Soil Resource Health:** State Soil and Water conservation departments restrict their activities only up to construction of small check dams, plugging of gullies etc in common lands. State Soil testing labs are almost sluggish in action, poorly equipped and are with under-qualified manpower. Mostly, no tests are done except for Organic C, P and K. State Agricultural Universities (SAU) only adopt few villages, and consequently, no extensive testing of soil health is done. ICAR institutions also take up few watersheds. Then, there will be no one to work for Soil Health Care program at extensive scale. Hence, a Central High Power Authority / Commission on soil Resource Health is needed to coordinate the program with States. It is beyond the capacity of research organizations to take up such giant and extensive task in addition to their regular research mandates.

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