Challenges and Emerging Opportunities in Indian Agriculture

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Frontier Soil Technologies for Sustainable Development Goals (SDGs) in India

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Abstract

Achieving the United Nations Sustainable Development Goals (UN-SDGs) targets won't be conceivable without a solid and manageable agriculture. Beyond its direct effect on hunger and lack of healthy sustenance, our food production system is additionally connected to other development challenges being included to in the SDGs. A healthy soil biosphere is needed to reduce the world hunger. Soil is a highly valuable non-renewable resource that fits well as a key to meet the SDGs. Climate change mitigation can't be complete without focus on soil health. Many established technologies are being used by the farmers to increase the productivity of crop and soil. However, certain frontier technologies such as nanotechnology, remote sensing, precision agriculture, etc. are being applied in improving soil health. These technologies are complementing the existing technologies in increasing the nutrient use efficiency of the fertilizers, reduce soil degradation, improve soil quality and thereby, reducing risks to environmental pollution. The problem lies in the widespread adoption of these technologies by the farmers as they are bound to the socio-economic constraints. Therefore, proper actions must be taken up to encourage them to adopt these technologies without affecting their farm income and resources.

Keywords

Sustainable Development Goals (SDGs); Soil Organic Carbon (SOC); Integrated Nutrient Management (INM); Precision Farming; and Conservation Agriculture.

Frontier Soil Technologies for Sustainable Development Goals (SDGs) in India

1. Introduction

1.1. Relevance of Agriculture to UN- Sustainable Development Goals

Among the 17 measurable Sustainable Development Goals (SDGs) set by the UN General Assembly in 2015 to tackle modern global challenges by 2030, almost all of the goals are relevant to agriculture directly or indirectly, giving agriculture a multidimensional importance. The goals cover a wide span of area from policy to global hunger and climate resilience. As agriculture acts as a crucial bridge between the people and the environment, it should be regarded as an integral part of the SDGs. With the alarming rate of human population growth, among all the issues, food crisis remains the most unsolvable problem around the globe till date. In developing countries, it is estimated that 780 million people were undernourished (FAO, 2017). On the other hand, 640 million people are overweight and obese, due to unhealthy life style, especially in developed countries and some parts of developing countries. However, even though it is required to reduce food waste and obesity, we still need more production of food in the same piece of land without jeopardizing natural resources and environment. Not only in food production, agriculture also accounts for the release of greenhouse gases. According to FAO (2017) data, greenhouse gas emission from sectors including agriculture, forestry and fisheries has nearly doubled in the past fifty years which might be expected to increase 30 per cent more in the coming twenty years, if no proper measures are taken up immediately.

Although agriculture is in the prime pedestal in achieving the SDGs, it also stands in the center of many daunting challenges around that requires the interplay of science, business, policy, *etc*. While several achievements have been made in the last three decades to reduce poverty, still the biggest challenge is to eradicate extreme poverty or to reduce the world poverty by half, therefore, the first and foremost SDG is termed as “No poverty”. According to World Bank (2016), 767 million people falls under the category of extreme poverty, almost two-thirds of these people resides in rural areas. In addition to this, in areas such as Sub-Saharan Africa and South Asian countries where majority of the extremely poor people are concentrated, private as well as public investments in agriculture and rural areas have been unchanged or decreased (FAO, 2017). Therefore, in order to achieve the Sustainable Development Goal 1 (No poverty) and 8 (Decent work and Economic growth), it is a must to make a significant increase in both the quality and quantity of the investments made in agriculture and rural areas. To further boost the rural development, specific policies and actions must be taken up by countries that reaches to the poor directly. Policies must be formulated that can address the challenges of the poor people and allow them to earn a living and make their livelihood. SDG 2 implies no/zero hunger and attaining food security, which can be linked to agriculture directly.

The biggest obstacle to sustainable development is extreme level of global hunger and malnutrition that results in unproductive individual and thereby, affecting their livelihood. When 800 million people in the world are suffering from hunger, being the developing countries mostly affected, an improved change of the global food and agriculture system is required if we have to nourish these large sections of hungry people and even the expected 2 billion more people which might add to the undernourished by 2050 (FAO, 2017). Investments in agriculture are the need of the hour to enhance agricultural productivity and sustainable food production in order to help in reducing the dangers of hunger. Around 80 per cent of the food supplied to developing countries is provided by 500 million small-scale farmers who follow rainfed agriculture system. Therefore, investing in these small-scale farmers is also a crucial way to improve food security and also the nutrition security for the poor people. Lack of proper harvesting practice and food wastage have also contributed to food scarcity. To procure the benefits of agricultural development to the rural poor section, equitable distribution of land and access to the available natural resources must be made.

Agricultural research funded by public sectors must focus on the practical problems that are faced by poor and small-scale farmers. There should not be any kind of discrimination against agriculture and family famers (Rosegrant and Hazell, 2001). Ensuring good health and promoting well-being is the third goal of SDGs. Good health always begins with proper nutrition which is through the products of the agriculture sector. Nutrition is not only the availability of food but also includes access to food at every household level and healthy environment. While climate change is bringing tolls on food production, a loud call must be made on climate-smart agriculture with better nutritional outcomes and thereby, constructing a stronger and more sustainable food value chains in the environment. The gap between agriculture and nutrition can be bridged by creating a nutrition sensitive food production system. In 2014, 19 per cent of the agriculture projects funded by the World Bank included nutrient sensitive parameters (World Bank, 2016).

In terms of gender equality (SDG 5), women constitute about half of the total agricultural labour force available in the developing countries. Rural women often face the discrimination in accessing land, economic opportunities, markets, technologies, *etc*. than men. If this access is provided equally to all the gender, significant improvement in agricultural productivity could be achieved with long term gains. Therefore, the need for full participation of all gender in rural communities in decision-making process is important. In addition to this, water scarcity is another hurdle that all farmers need to face in agriculture (SDG 6: clean water and sanitation). Crops along with livestock withdraw 70 per cent of all water, and it may go up to 90 per cent in few developing countries. In this era where wars begin with water, more food production with less water is the only agenda to build a resilient farming community. By the end of 2030, energy demand will rise to the peak especially in developing countries (World Energy Council, 2016). Therefore, cultivation of biofuels may increase in order to meet the energy demand in future years (SDG 7: Affordable, reliable and clean energy). SDG 12 focuses on sustainable consumption and production. With the growing population and increasing urbanization, it's difficult to feed all of them with same resources that calls for to a shift to more sustainable production and consumption approaches. Agriculture is one of the victims that is threatened by the climate change, and the only solution is a climate smart agriculture with a sustainable approach (SDG 13: Climate Action). Without immediate actions, the change in climate will severely affect the food production system, resulting in low availability of food, less productivity of crops, livestock and fisheries, and disturb the livelihoods of the largest section of agriculture dependent rural people.

2. Role of Soil Management in Addressing Multiple Challenges of Food Security and Poverty

Soil is the most valuable resource in agriculture and its degradation leads to decline in production and productivity, and sometimes loss in biological diversity. According to Wikipedia "soil management is the application of operations, practices and treatments to protect soil and enhanced its performance". Plants and most living organisms including microbes thrive on soil; they obtain their mineral nutrients and carbon from the soil. Proper management of soil ensures that there will be no deficiency or toxicity of mineral elements to plants, and desired amount of mineral elements will enter in the food chain. There are some direct and indirect benefits of soil management, with respect to crop production, environmental sustainability, and human health point of view. Management of soil in proper way will gain more importance in the coming years because of rapid increase in population, and increase in urbanization leads to decrease in agricultural land which shifts target for higher productivity and crop intensification. Food security in future is in question, sustainable soil management will be a challenging job through good conservation measures, reclamation strategies and proper nutrient management. Our future research should be focused on preventing soil from degradation, erosion and toxic metal contamination, and to assure food security *vis-à-vis* nutritional security by producing healthy and safe diet.

There are various soil management practices which enhance soil functions are tillage practices, residue management, intercropping, adoption of conservation agriculture (CA), soil conservation measures, application of soil amendments, and integrated nutrient management (INM). Tillage practices influences several physical, chemical and biological properties. In general, we assume that adoption of reduced tillage (RT) and minimum tillage (MT) are beneficial in the long run compared to conventional tillage (CT). Sharma et al., (2016) evaluated geometric mean of soil biological quality index (GMeanBSQI) under two different tillage systems (conventional tillage and minimum tillage) and three different residue systems, *viz.* sorghum stover, glyricidia loppings and no residue systems in subtropical Alfisol in Hyderabad, India. Higher geometric mean of soil biological quality was obtained in minimum tillage treatment (0.82) which is 19 per cent higher than conventional tillage (0.69). Both residue treatments recorded higher GMeanBSQI over no residue treatment (0.65), but glyricidia loppings (0.87) perform better than sorghum stover (0.75).

Adoption of conservation agriculture (CA) proved beneficial to address resource and productivity related constraints. CA is based on mainly three principles which are minimum disturbance of soil, maintaining residue cover and crop rotation (FAO, 2015).Various research conducted in developed countries reported that productivity and carbon content of soil improves in CA practices and while land degradation is minimized and thus, contributing to biodiversity and soil quality. CA enhances natural resources both below ground and above ground resources. Soil organic matter (SOM) content enhances in CA believed by many researchers (Srinivasa Rao *et al*., 2014). Combined effect of CA and balanced fertilization was evaluated by Kundu *et al*., (2013) in maize-horse gram sequence and SOC was recorded within 0.31 to 0.45 per cent in CA whereas in SOC in conventional system was lower that lies within 0.29 to 0.42 per cent. Enrichment of soil carbon in CA is associated with several benefits, which ultimately helps in enhancing productivity.

Soil degradation is another major problem in India; out of 328.7 Mha total geographical area, 264.5 Mha is under cultivation. According to the National Bureau of Soil Survey and Land Use Planning (NBSSLUP), 146.8 Mha land is degraded and the major agent is water erosion, which results in loss of top soil and terrain deformation. Deforestation and shifting cultivation in Northeastern India cause huge loss in top fertile soil and nutrients. Saha *et al*., (2012) reported combined effect deforestation and shifting cultivation results in huge losses of soil, nitrogen (N), phosphorus (P), potassium (K), manganese (Mn), zinc (Zn), calcium (Ca), and magnesium (Mg). They further reported that, adoption of agro forestry systems like agri-horti-silvi pastoral systems lower down soil loss by 99.3 per cent and improve soil carbon content by 44.8 per cent. Various soil conservation measures such as contour ploughing, strip cropping, hedgerow planting, vegetation cover, agro forestry (agronomic measures), and bunding, terracing, gully control structures can be advocated to control soil erosion.

Integrated nutrient management (INM) is combined use of organic and chemical fertilizers to supply plant nutrients in judicious amount. Addition of organic manures improves soil physical, chemical and biological properties leading to increase in productivity and nutritional value of crops grown. Crop residues added in the field decomposes and forms several organic acids, which improve phytoavailability of some microelements. Sometimes, organic manures act as soil amendments; apart from supplying plant nutrients, it helps to lower down phytotoxicity of heavy metals like Cd and Pb by forming stable complex. As organic manure like FYM and cow dung provides carbon for microbial food web, its addition improves microbial diversity of the soil. Inorganic fertilizers especially N, P, and K fertilizer application has increased crop production. Balanced fertilization improves in crop productivity and maintains soil functions in the long run. But imbalanced application of fertilizers leads to multinutrient deficiency, especially the deficiency of micronutrients (Zn, B and Fe) and nitrogen among the macronutrients. Combined use NPK + FYM showed increase in SOC content compared to NPK or FYM alone (Bhattachaya *et al*., 2011). Mandal *et al*., (2007) observed that NPK+FYM /Compost treatment accumulate 25-38 per cent more carbon than control in lower Indo-Gangetic plains under different cropping systems. The sequence of SOC accumulation under different cropping systems was rice-mustard-seasame > rice-fallow-rice > rice-wheat-fallow > rice-wheat-jute (Corchorus sp.) > rice-fallow-berseem (*Trifolium alexandrinum*), over the control. In subtropical Alfisol, INM (50% RDF and 4 t ground nut shell ha^{-1}) reported to enhance carbon accumulation rate up to 0.45 t ha^{-1} year^{-1} (Srinivasa Rao *et al*., 2009).

India has 2.4 per cent of world's arable land and 17.5 per cent of the global population. Every year, 1.19

per cent of population is increasing. Agricultural land is being converted into non-agricultural land. In order to assure food security and nutritional security, more crops have to produce from less land in a sustainable way. To achieve this, productivity of the existing agricultural land need to be improved by using scientific methods and technology. Main focus should be given to restoration of degraded soils (salt affected, polluted, contaminated soil), so that they may contribute to food production in future.

3. Soil Organic Carbon: An Important Aspect for Food Security, Soil Health and Climate Change Adaptation

Stabilizing or enhancing SOM is critical to minimizing risks of soil degradation and for ensuring sustainability of agriculture in the tropics. A severe depletion of SOM degrades soil physical quality, loss of favourable biology, and leads to the occurrence of multiple nutrient deficiencies. Soils of drylands are highly degraded and have low soil organic carbon (SOC) concentration because of a high rate of oxidation and accelerated erosion. The carbon balance of terrestrial ecosystems can be changed markedly by the impact of human activities - including deforestation, biomass burning and land use change, which results in the release of trace gases that enhance the 'greenhouse effect'. Routinely, soil surveys conducted for estimating soil organic carbon pool consider depth of about 1 m. However, the subsoil carbon sequestrating may be achieved directly by selecting plants/cultivars with deeper and thicker root systems that are high in chemical recalcitrant compounds like suberin and lignin (Srinivasarao *et al*., 2013). The low SOM concentration along with low inputs is among the principal reasons of low production and large yield gap. The severe depletion of SOC in the rainfed agro ecosystems in India has adversely impacted soil quality, crop productivity, and sustainability. Vertisols, Inceptisols, and Alfisols comprise a major share of SOC stocks in the top 30-cm-depth. Indeed, SOC stocks in the soil profiles across the country vary widely and follow the order
Vertisols>Inceptisols>Alfisols>Aridisols

Maintenance and improvement of soil productivity is critical in intensive cropping system. SOC attributes are reported from many long-term studies in rainfed India and has been selected as most prominent factor for net primary production (NPP) (Srinivasarao *et al.,* 2009). It has been reported that 1 per cent increase in SOM would increase total cereal productivity by 0.43 t ha^{-1}(Srinivasarao *et al.,* 2013). Increase in agronomic productivity was evaluated in major production systems through increase in SOC stock at the root zone. Result showed that the rate of increase (t C ha^{-1}year^{-1}) of the SOC stock at the root zone led to a significant increase in yield (kg ha^{-1}) in several rainfed crops. The increase were 13, 101, 90, 170, 145, 18 and 160 for groundnut, finger millet, groundnut-finger millet, sorghum, pearlmillet, soybean and rice, respectively (Srinivasarao *et al*., 2012a, b, c, d, e, f; Srinivasarao *et al.,* 2014a, b). This yield increases in the rainfed regions are much higher compared to irrigated systems of India and elsewhere in the world. As for example, an increase in SOC stock by 1 t ha^{-1}increased grain yield by 27 kg ha^{-1}in wheat (*Triticum aestivum*) in North Dakota, United States, 40 kg ha^{-1} in wheat in the semi-arid pampas of Argentina, 6 kg ha^{-1}in wheat and 3 kg ha^{-1} in maize in alluvial soils of northern India, 17 kg ha^{-1} in maize in Thailand, and 10 kg ha^{-1}in maize and 1 kg ha^{-1}in cowpea (*Vigna unguiculata*) in western Nigeria (Srinivasarao *et al*., 2017). Adoption of recommended management practices (RMPs) which could increase SOC stock by 1 t $ha^{-1}year^{-1}$ can increase food grain production by 32 mt/$year^{-1}$ in developing countries (Lal, 2006).

Soils hold the key for enhancing productivity and improving resilience against harsh climate in rainfed agriculture in India. Loss of fertile soil by erosion, depletion of SOM, emerging deficiencies of secondary and micronutrients, high soil compaction, surface crusting, and loss of soil biodiversity are among the strong limiting factors to productivity enhancement of rainfed agriculture in India. Soil quality can be restored through the adoption of recommended management practices (RMPs). Important among the RMPs for rainfed agriculture include: i) timely tillage at optimum moisture content to minimize formation of large clods and to improve soil tilth; ii) reduce secondary tillage and adopt no-till, or ridge tillage systems and leave crop residue mulch on the soil surface; iii) adopt crop rotations which include cereals and legumes; iv) include cover crops in the rotation cycle; v) use manure to enhance SOM concentration; and vi) use a strong hoe to break any surface crust for improving seedling emergence and increasing crop stand. Choice of RMPs differs among soil type and other site-specific factors. Through these resource conservation practices, one can reduce soil C losses by decreasing erosion, reducing oxidation of SOM and providing C inputs. Restoration of soil biota and their ecological processes breaks down organic matter into SOC fractions and stable organo-mineral complexes. In addition, such practices contribute to improve soil fertility and productivity. The global potential of SOC sequestration rate is estimated at 0.6 to 1.2 Gt C $year^{-1}$, comprising 0.4 to 0.8 Gt C $year^{-1}$ through adoption of recommended management practices on cropland soils, 0.01 to 0.03 Gt C $year^{-1}$ on irrigated soils and 0.01 to 0.3 Gt C $year^{-1}$ through improvement of rangelands and grasslands (Lal *et al.,* 2007). Long-term manure application increases the soil C pools and the effects may persist for longer periods. Although both organic and inorganic forms of C are found in soils, land use management typically has a larger impact on SOC (Srinivasarao *et al.,* 2013). The strategies for enhancement of soil C are discussed below.

4. Frontier Soil Technologies

4.1. Agronomic Practices

Agronomic practices are usually defined by those practices of cultivating crops on sloppy areas to act as cover crop and to control soil erosion. It acts as a shield of the soil surface from direct impact of sunlight and rain drops and reduces the physical impact and thereby, reducing soil erosion and run-off. There is an immense role of agronomic practices in soil and water conservation. Strip cropping allows the planting of crops in relatively narrow strips across the slope, arranged in such a way that strip crops are separated by another strip of erosion-resistance crops. This agronomic practice helps in concentration of rainwater in the land by checking surface run-off and increasing infiltration in soil (Morgan, 2005). In improved fallow systems (IFS), after cultivation of land with food crops for few years, it is kept as fallow land so as to rejuvenate the soil by itself. However, the fallow period can also be reduced by seeding leguminous trees (Meine and Bruno, 2000). This practice can be also referred as improved form of traditional shifting cultivation which is practiced in North-East India (Burgers *et al*., 2005). Another practice is contour tillage where all the mechanical treatments are operated nearly on the contour of the area applied across the slope. It consists of ploughing, planting crops and other practices along the contour which helps in soil conservation as it increases time of concentration of water (Deborah, 2003).

Mixed/Intercropping is a widely studied agronomic method where two or more crops are planted in the same field at the same time (Andersen, 2005). Mixed cropping allows the farmer to insure themselves against climate change. One of the most important agronomic practices is mulching. Mulching are ground covers that helps in preventing the soil from runoff and erosion, weed management, increase infiltration, *etc*. It may be used as organic materials or synthetic ones. Crop rotation is alternating cereal crops with legumes and other crops in the same field. It produces different amount and types of crop residues that can be managed easily and also helps in replenishing the soil health. Agronomic practices play a very important role in soil and water conservation due to its interception effect through plant canopy, mulching, *etc*.; although in many areas, the litter/mulching effect is higher in controlling soil erosion as compared to the canopy effect (Young, 1989). Inclusion of trees within agronomic practices adds value to it as it helps in increasing soil organic matter.

4.2. Conservation Agriculture

Conservation agriculture revolves around three practices of minimum tillage, incorporation of crop residue and crop rotation, promoted as a way to sustainable intensification in agriculture (Brouder and Gomez-Macpherson, 2014). In order to successfully implement these principles, several changes are required in the production system, equipment, weed control practices, fertilization method and residue management. Therefore, conservation agriculture can be regarded as a complex technology with crucial components and if it has to be introduced to small-scale farmers, intensive extension approaches is needed in order to solve the problems while shifting from the conventional agriculture to conservation agriculture. (Wall, 2007).

Not only providing the private benefits in increasing crop productivity and yield resilience, conservation agriculture carries along with it several positive environmental benefits such as increasing soil organic carbon. However, seeing the adoption rate of conservation agriculture by farmers, question arises of whether these promised benefits are being received by the farmers or not. Although initially conservation agriculture was regarded as a practice to regulate wind and water erosion, it is now adopted as a potential technology to mitigate global warming and soil carbon sequestration. Increase in soil carbon stock doesn't necessarily mean higher carbon sequestration of carbon in soil if there is no net transfer of carbon dioxide from atmosphere to soil. In conventional tillage, soil destruction occurs though physical breakdown of the soil structure rigorously (Duiker and Beegle, 2006). Despite of better structural distribution in plow tillage than the minimum tillage practices, soil structures are so weak that their resistance to water slacking is very low and thereby, resulting in soil deterioration (Verhulst *et al*., 2010). These problems can be prevented through conservation agriculture using permanent residue cover protecting the direct impact of rainfall, water and wind to soil. However, Swanepoel *et al*. (2018) demonstrated that yield improvements and increase in soil organic carbon under conservation agriculture were found to be slow and variable thereby, small-scale farmers were facing these problems in buffering themselves against the short-term loss economically. So, conservation agriculture cannot be blindly promoted as a panacea that it will definitely increase soil organic carbon content in soil and high yield. These benefits of conservation agriculture highly depend on several factors such as environmental factor especially climate and soil type. According to a meta-analysis conducted by Li *et al*. (2018) using a global dataset on conservation agriculture, this practice significantly increased microbial biomass carbon, nitrogen and mi microbial quotient (qMIC, soil microbial biomass carbon-to-soil organic carbon ratio).

Incorporation of crop residue in soil and no tillage practice in conservation agriculture came out as a promising practice in increasing the soil microbial health in different soil conditions, experiment duration and varying climatic conditions.

In addition to these benefits, conservation agriculture has been studied by several authors for its potential in mitigating climate change (Jat *et al*., 2012; Lal, 2015; UNEP, 2013) though it has already called for many controversies bringing up the "for" and "against" on this statement. Many conservation agriculture practices increase the soil organic carbon concentration in soil especially in surface layers which results in better soil quality. However, increased in soil organic carbon concentration doesn't follow necessarily the increase in soil organic carbon stock in soil which is an important parameter to mitigate the climate change. In conservation agriculture, certain crop diversification system enables an increased transfer of carbon from the atmosphere to soil through higher amount of photosynthate. This is found true in case of intercropping of maize with inclusion of legumes, especially in Sub-Saharan Africa where rainfall is found sufficient to enable the growth of the extra crop without harming the yield of the main crop or when an additional crop is introduced in the gap period between other crops, otherwise it will be kept as fallow. Replacement of one crop in an existing system with another can enhance carbon inputs in soil but it also highly depends on the root biomass of the new crop and its biomass (both above and ground biomass) that will be returned to soil and the chemical composition of the crop that affects its decomposition. Practices in conservation agriculture can also increase the use efficiency of nitrogen fertilizers that enables to create a synergy between conservation agriculture and N fertilizer resulting in decreasing greenhouse gas emissions (Aryal *et al*., 2015).

4.3. Integrated Nutrient Management

Although certain sources of nutrients (mineral and organic) are already present in soil, for better plant growth, supplementation of external supply of nutrients is a must. Fertilizers act as external sources of nutrients and can be available in organic form such as farmyard manure, compost, vermicompost, *etc*. or in inorganic fertilizers (Figure 1). In order to meet the raising food demand, balanced and optimal application of these nutrient sources is of prime importance. Use of mineral fertilizers in excessive amounts in intensive cultivation of crops has invited several challenges of environmental pollution, soil degradation and health risk (Bi *et al*., 2014; Ram *et al*., 2015; Bhattacharyya *et al*., 2016; Sharma *et al*., 2017; Mi *et al*., 2018). Therefore, taking these environmental and economic constraints into account, integrated nutrient management (INM) is promoted to efficiently integrate and utilize both the sources of nutrients in balanced manner so as to provide the required amount of nutrients to the soil and plants, as well as to reduce environmental pollution. The INM technology not only focuses on one crop but also optimal use of nutrient sources on different cropping systems and crop rotations, which is more appealing to farmers for long term planning. Moreover, INM practices incorporate methods such as deep placement of fertilizers and the utilization of nitrification inhibitors or urea coatings that have been created to increase nutrient use efficiency.

Many long-term fertilizer experiments have been set up in different parts of the world to evaluate the efficiency of INM and to comprehend the complex interaction between soil, plants and INM and their effects on productivity of crop and soil (Shahid *et al.,* 2016).. Meena *et al*. (2019) studied that integrated nutrient management through soil test crop response (STCR)-based fertilizers significantly improved the crop productivity and soil health in long term, while sole application of inorganic or organic sources could not sustain the yield and system productivity. In terms of soil parameters, changes in soil pH in INM is reported in many literature (Walker *et al*., 2004; Babu *et al*., 2007) and may be attributed to the inclusion of organic manures that releases organic acid during its microbial decomposition, oxidation of organic matter and release of CO_2 in the soil (Liang *et al*., 2012). In addition to this, optimum soil electrical conductivity is maintained through balanced fertilization that restricts increase in salt concentration in the soil (Badanur *et al*., 1990; Kumar *et al*., 1995). Addition of organic manure will certainly increase the carbon sequestration potential and soil organic carbon stock.

In the assessment of physical health of soil, bulk density (BD) is one of the critical parameters as it is closely related to soil strength and porosity, moisture content, *etc*. In soybean-wheat system, treatments with integrated use of NPK and farmyard manure could lower down the BD of the soil to 5.6 per cent than the treatments with NPK alone after the fourth cropping cycle (Bandyopadhyay *et al.,* 2010). Long-term experiments have also proved that incorporation of organic manures along with nutrient management such as cattle manure (Nymangara *et al*., 2001), poultry manure (Tejada and Gonzales, 2008), and farm yard manure (Haynes, 2005) has significantly reduced the soil bulk density. Lower bulk density could be due to higher organic matter in the soil (Hati *et al*., 2006), improved soil structure and aggregation, increased porosity, lower degree of compaction and subsequently, increased root growth (Leroy *et al*., 2008). Available nitrogen in soil is correlated with the soil organic carbon content.

Long-term use of farmyard manure for a period of seven years on Alfisol have shown significant increase in ammonical and nitrate nitrogen, while incorporation of green leaf manures could not produce any effect (Udayasoorian *et al*., 1989). However, Puranik *et al*. (1978) and Prasad and Rokima (1991) showed that the highest nitrogen content in soil was found in the treatments with integrated use of NPK and FYM. Secondary nutrients can also be enriched with integrated nutrient management. Especially in the case of sulphur, its deficiency in soil is emerging owing to inherent low sulphur content in soil, avoiding sulphur fertilization, and coarse textured soils leading to leaching losses. As organic sulphur fraction of the soil is strongly correlated to soil organic carbon content, integrated nutrient management can also correct the deficiency of sulphur in soil. Integrated nutrient management not only improves the soil quality but also increases the nutrient use efficiency of the fertilizers applied to soil.

Through integrated nutrient management, it is possible to adapt plant nutrition and soil fertility management in farming systems, to take good advantage of the integrated use of both the organic and inorganic sources of nutrients and to help in food production with environmental, economic and social benefits. It also boosts the farmers by improving their technical skills and decision-making ability. Integrated nutrient management should also utilize the untapped source of nutrients such as urban waste after the treatment of the waste so as to remove the unwanted elements from the waste such as heavy metals. Although the quality of these urban wastes cannot match the commercial fertilizers, utilization of these sources to supplement the nutrition can be an option. It also reduces the disposal problem of the urban waste which is costly, laborious and polluting the environment.

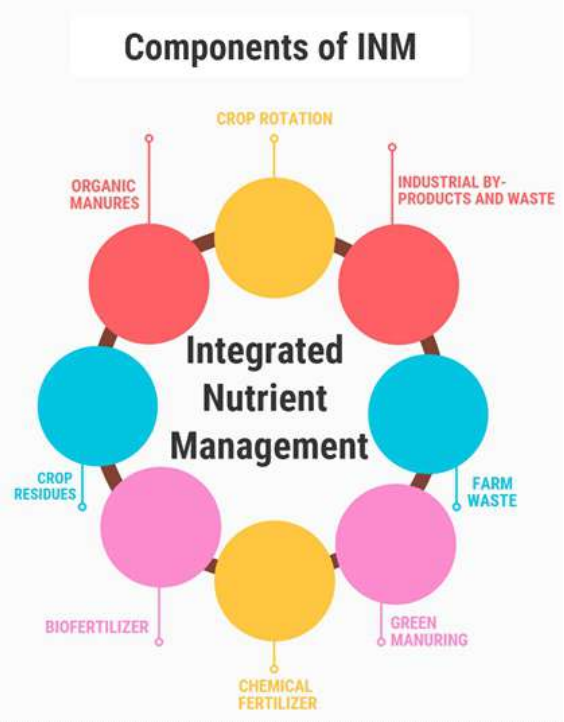


Figure 1: Components of Integrated Nutrient Management

4.4. Biochar and its Utility

According to Wikipedia, “Biochar is charcoal used as soil amendment. Biochar is a carbon rich solid product produced by pyrolysis”. Pyrolysis is thermal decomposition of organic matter in the absence of oxygen. Generally 400 to 700°C temperature is maintained in pyrolysis procedure. The stability of biochar depends on pyrolysis temperature, higher the pyrolysis temperature higher will be stability (Purakayastha *et al*., 2015). Biochar is made up of biologically recalcitrant carbon which is unutilized by microbes (Chan and Xu, 2009). Presence of aromatic form of carbon in biochar makes it stable against microbial attack, which helps in carbon sequestration. Field application of biochar provides several agricultural benefits. Biochar helps to ameliorate soil acidity, improves soil fertility, and minimize GHG production. Biochar is produced by several methods.

Lehman *et al*. (2007) reported that addition of biochar in soil is one of the strategies to mitigate negative climate change impact as CO_2 is sequestered in soils so that load of excess atmospheric CO_2 is lowered down. Plant fixes atmospheric CO_2 into biomass during photosynthesis, when we add the plant biomass into soil releases CO_2 at faster rate during decomposition. Conversion of the plant biomass into biochar instead of adding in soil will prevent emission of photosynthetically fixed CO_2 to atmosphere as decomposition rate of biochar is slower than plant biomass. During pyrolysis easily decomposable plant material is converted into biochar with higher stability, enhances scope for carbon sequestration. Carbon sequestration potential of biochar depends on how long carbon is held in soil. Conversion of plant biomass into biochar increases mean residence time of carbon as compared to direct addition of plant biomass into soil (Lehman, 2007).

Application of biochar along with chemical fertilizers can reduce N_2O emissions without affecting mineralization or nitrification processes. Nelissen *et al*. (2014) reported that application biochar with chemical fertilizer decreased cumulative N_2O emission by 52-84 per cent and NO emission by 47-67 per cent compared to mineral fertilizer application. Various factors such as soil type, soil water content, amount of fertilizer addition, biochar source, and pyrolysis temperature influence the effectiveness of biochar addition on N_2O emission (Nellisen *et al*., 2014). Martin *et al*. (2015) evaluated that effect of biochar application on greenhouse gas emissions from soil amended with anaerobic digestates. They reported that the highest N_2O emission obtained from maize anaerobe digestate treatment and biochar addition in all the treatments minimizes N_2O emission.

Biochar can be used for correction of soil acidity. Application of biochar in acid soil improves pH, CEC and minimizes Al^{3+} toxicity. In Indonesian Ultisol, Cornelissen *et al*. (2018) evaluated the impact of two different biochar (rice husk biochar and cocoa shell biochar) on soil parameters and yield of maize in five different seasons. Results showed that cocoa biochar performed better in correcting soil pH, CEC also high in cocoa biochar treated plot and recommended that cocoa shell biochar application at the rate of 15t ha^{-1} every third season for maintaining positive effects on maize yields. Similar study conducted in the moderately acidic Nepalese soil by Pandit *et al*. (2018), their study showed that application of biochar improves soil physicochemical properties like soil moisture percentage, nutrient supply (phosphorus, potassium and calcium) and Cation exchange capacity increased significantly. These beneficial effects contributed to higher maize yields in the biochar treated soil.

Biochar offers potential solutions not only for carbon sequestration and acidic soil reclamation but also helps to mitigate green house gas emissions. Currently, our country produces on an average 120-150 Mt/annum of surplus crop biomass, out of which 93Mt crop burned can be used as a feedstock of biochar (Srinivasarao *et al*., 2013). There are some practical problems associated with biochar production and application. They include availability of biochar, huge cost is involved in biochar production, once applied it remains in field surface if proper mixing is not done, and lack of policies regarding biochar production (Venkatesh *et al*., 2015).

4.5. Zeolites and their Utility

Zeolites are three-dimensional crystalline minerals mainly composed of aluminosilicates with rigid structure and are abundantly present in sedimentary rocks and volcanic soils. Pores and voids are the key characteristic of zeolites, mainly responsible for its high cation exchange capacity, molecular sieve as well as storage, capture, and release of nutrient molecules, cations, anions, and water. Application of zeolites have many beneficial effects on soil and ultimately crops grown in it. Zeolites are found to decrease urea hydrolysis in soil by adsorbing the involved urease enzymes on its surface, thereby reducing its activity. It traps ammonium ions in its pores such that the nitrifying bacteria are unable to reach those places, thus, reduces the ammonia volatilization and nitrate leaching losses resulting in the increase of nitrogen fertilizer use efficiency in soils. Zeolites increase the pH of acidic soils to the optimum value and improve physicochemical properties of soils. Zeolites are mainly effective in sandy or coarse-textured soils having low cation exchange capacity. Zeolites also specifically adsorb ammonium ions from organic manures like farmyard manure, compost, *etc*. as well as from ammonium-containing fertilizers which in turn, reduces its losses to the environment contributing to reduced pollution of air and groundwater.

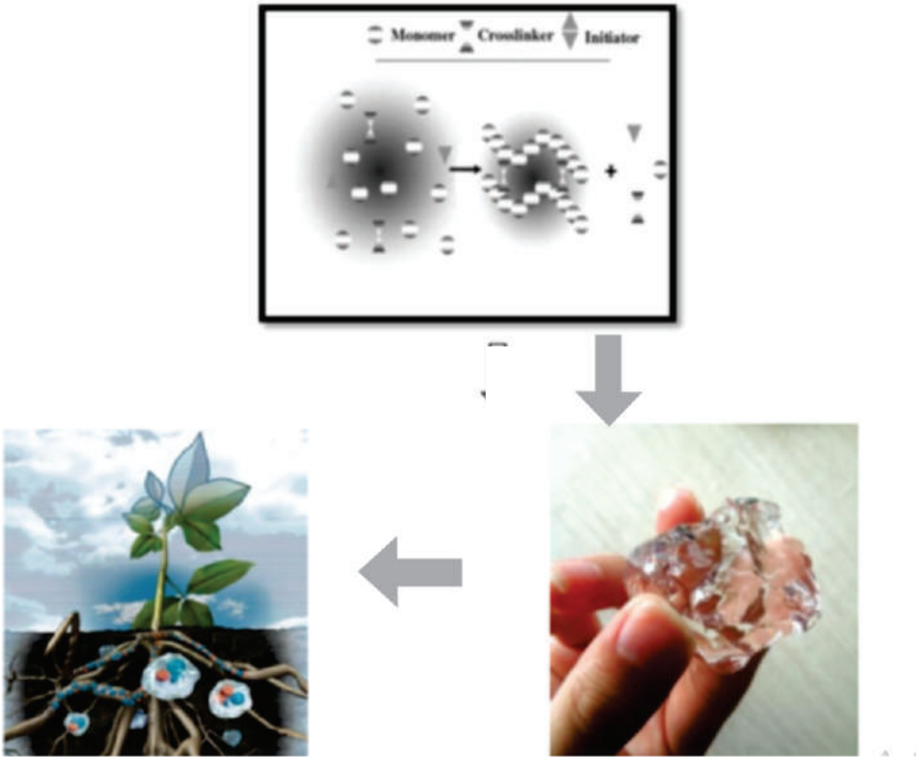
There are various products based on Zeolites, which are reported to act as slow-release fertilizers releasing nutrients corresponding to the demand of growing crops, like urea-impregnated zeolite chips, surfactant-modified zeolite (SMZ), zeolite-phosphate rock mixtures and potassium or ammonium saturated clinoptilolite. All these products are found to increase the nitrogen, phosphorus and organic manure use efficiency. Zeolites also improve water use efficiency by holding a large amount of water in its pores without influencing the air-filled pore space. It can also act as a controlled release carrier for herbicides and pesticides and thereby, reducing the contamination of soil and water. It is also found to remediate the soils contaminated with heavy metals due to their high cation exchange capacity which fixes the cationic heavy metals to non-available form. Therefore, it reduces the phytoavailability of many harmful heavy metals like lead, cadmium, chromium, *etc*. and hinders their entry in the food chain which ultimately provides quality food to the human beings and animals (Ramesh *et al*., 2011). Zeolites are also found to reduce the salinity stress of crops grown in coastal agricultural sandy soils by mitigating sodium ions risk (Ferretti, 2018). In this way, zeolites hold the great potential in paving the path towards conservation of resources like fertilizers and water, improving soil quality and reducing the environmental pollution, thereby leading us to the achievement of Sustainable Development Goals.

4.6. Hydrogels and their Utility

Hydrogels are polymeric substances having hydrophilic functional groups which get extensively swell when comes in contact with water along with retaining its structure and thereby, having excellent water absorbing capacity (Figure 2). Hydrogels have the ability to absorb water by hundred times its weight quickly and desorb that water under deficient condition. Hydrogels used in agriculture are mainly based on acrylamide (Ahmed, 2015). Hydrogels have capability to enhance water and nutrient use efficiencies in agriculture, which marks its potential use in the arid and semi-arid regions facing limited water availability. Hydrogels are applied in soils surrounding the root zone of the crops to retain water and nutrients in it, which in turn release them as per the requirement of plant and thus, increasing the water and nutrient use efficiency. Large volume and long duration retention of water by hydrogels also decreases irrigation frequency and thereby, decreasing irrigation costs and saving of irrigation water.

Characteristics of hydrogels like slow water retention and high swelling is beneficial for its use as soil conditioner and safer release of soluble fertilizers. It increases the water holding capacity of soil. Its use is mainly effective in sandy or coarse textured soils. It reduces the water loss by drainage and deep percolation. On releasing the water in soil by desorption, the volume of hydrogel decreases which creates pore space in soil. This increases porosity leading to increased air and water infiltration, storage and root growth. It could be very useful under drought conditions. It enhances nutrient use efficiency by decreasing leaching loss of soluble fertilizers, minimizing the dosages of fertilizers and supplying nutrients for the longer duration. It minimizes soil erosion by limiting water run-off. It also decreases compaction tendency of soil. It enhances the water productivity of crops. Overall, its role encompasses in water conservation, nutrient carrier and soil conditioner (Abobatta, 2018).

Hydrogels can be applied in the soil at the time of sowing of the crops with very minimal application rate *i.e.* 2.5 to 5 kg ha^{-1} (Kalhapure, 2016). Hydrogels are suitable for ensuring sustainability especially under water-stressed environment because it doesn't harm the environment as it degrades completely and doesn't leave its residues in soil and plant products. Apart from using hydrogels in water and nutrient retention and release, they can also be used for the controlled or slow release of pesticides. Hydrogel-based formulations for controlled release of active ingredients has several benefits like longer application duration, reduced dosage, reduced harmful impacts on environment, animals and human beings, reduced evaporation and leaching loss of active ingredient, increased effectiveness on target organism, and ease of handling (Rudzinski, 2002).



Hydrogel in action at plant roots

Hydrogel

Source: Neethu et al. (2018)

Figure 2: Schematic Diagram of Hydrogel

4.7. Fertigation and Foliar Spray

4.7.1. Fertigation

There are 4 R's in soil fertility: application of *right* source of fertilizer/manure, *right* time, *right* dose, and *right* place. Fertilizers are golden molecule; proper care should be taken in their use. We generally practice surface broadcasting or band placement of fertilizer application. But the availability of plant nutrients from fertilizer application depend upon several factors like soil reaction, fixation by clay minerals (specially P fertilizers), soil moisture content, presence of $CaCO_3$, leaching, soil temperature and denitrification *etc.* which reduces it use efficiency. To improve the efficiency of added fertilizers, various methods advised by researchers like use SRFs/CRFs, apply fertilizers along with irrigation water (fertigation) and foliar spray.

In simple language, supplying fertilizers in field with irrigation water is called fertigation. This system cut down labour cost for fertilizer application, saves time and improves the use efficiency of applied fertilizers. Fertigation allows application of plant nutrients at desired site where high concentration of active roots are present. During fertigation, fertilizers are mixed with water uniformly which helps to overcome chance of fixation by soil constituents and thereby, increases use efficiency. Fertigation reported to save 40-60 per cent of applied fertilizer, due to higher fertilizer use efficiency (Kumar and Singh, 2002). Drip irrigation is most preferred over other methods of irrigation because of its high water application efficiency, low amount of water required, low evaporation and percolation loss. Fertigation is reported to be beneficial over other systems of fertilizer and water application especially for vegetable production. Fertigation in broccoli reported to increase yield by 115.37 and 17.32 per cent over drip irrigation and check basin method, respectively (Singh *et al*., 2002).

High initial cost, clogging of drippers due to precipitation of salts like bicarbonates and carbonates, corrosion of metal pipelines, and in arid region salt injury to crops due to evaporation and salinity build up are some hindrance of fertigation. Furthermore, the availability of water soluble compatible fertilizers restricts the use of micronutrients and phosphatic fertilizers along with irrigation water.

4.7.2. Foliar Spray

Foliar spray refers to application of plant nutrients, hormones, herbicides and other beneficial substances directly to plant canopy by sprayer tool. In drought condition, non availability of soil moisture hinders the absorption of soil applied fertilizers as plant uptake nutrient through water. In this scenario, foliar application overcomes these limits and plant can easily uptake nutrient in moisture deficient conditions. Foliar spray proves to be highly beneficial in severe nutrient deficiency conditions, as it allows rapid absorption of plant nutrients through aerial parts and cope up deficiency impact. Various soil factors such as soil reaction, fixation by clay minerals, soil moisture availability, and soil area explored by plant roots play key role in nutrient use efficiency of soil applied fertilizers. These factors are not come into picture in foliar spray, and very small quantities of fertilizers are required for foliar spray. Foliar spray in combination with soil application reported to enhance micronutrient use efficiency than soil application alone. Saha *et al*. (2015) evaluated the mode of zinc application on zinc use efficiency of 26 rice genotypes in BCKV, West Bengal. They applied 20 kg Zn ha^{-1} as $ZnSO_4$, $7H_2O$ soil application as basal and soil + foliar application as basal and two foliar sprays. Results obtained in their study showed that grain yield increases on an average 29 per cent and 22 per cent in soil + foliar application and soil application only compared to control. Higher average zinc use efficiency recorded in soil + foliar application with mean value 2.74 per cent, whereas in soil application mean value is 0.90 per cent.

Some precautions are to be taken in foliar spray such as use of high dose fertilizer may cause burning of plant leaves, compatibility of fertilizers with other agrochemicals like herbicides, bad weather conditions (foliar spray is not recommended in rainy day), and use of optimum amount of water. Use of compatible water soluble fertilizers and conditioners like little amount of lime in order to correct residual acidity may be successfully utilized to increase use efficiency of nutrients specially micronutrients and thereby, contributing towards nutritional security.

4.8. Agroforestry

After recognizing agroforestry as a scientific discipline, its potential in enhancing soil health and quality has been studied widely (Nair, 2011). Agroforestry serves as an important practice with several ecosystem services that couldn't be possible without its benefits in improving the productivity of soil (Jose, 2009). Soil organic matter content was found to increase when trees are included in agroforestry through addition of litter both above and below ground (Ramos *et al*., 2018; Noumi *et al*., 2018). Therefore, in general, a shift from cultivation with no trees to agroforestry can improve the soil organic carbon stock in the soil which can be a good mechanism to mitigate climate change (Amadi *et al*., 2018). The process of competition and synergism occurs when different functional groups of plants are planted in an agroforestry system. Especially in the tropics, the efficient cycling of nutrients by tress in agroforestry is well studied. The availability of the nutrient stock in the soil of an agroforestry system depends on the process of litter decomposition and mineralization. Moreover, other source of available nutrients in agroforestry is nutrient leaching from leaves and nutrient-enriched rainfall (Limon *et al*., 2018).

Agroforestry can also be used for phytoremediation with inclusion of certain types of tree species with metal remediating capacity such as *Melia azedarach* (Kaur *et al*., 2018). In terms of soil biota, agroforestry improves the soil microbial health through the decomposition of organic matter, efficient nutrient cycling and improving the physical and chemical status of the soil. Therefore, agroforestry is regarded as a practice that offers several promises in improving soil health for the present as well as for future generations. By enriching soil organic carbon than the monocropping systems, enhancing soil nutrient cycling and availability, and increasing the soil microbial dynamics all results in good soil health. It is imperative that this practice as a multifunctional land-use strategy need increased attention from agriculture communities and policy makers to use agroforestry as a viable way to sustain soil health successfully.

4.9. Land Management for Soil and Water Conservation

Soil and water conservation are essential for maintaining the fertile top soil and preventing it from flowing into the water channels and eventually reservoirs which ultimately contributes to their pollution and decrease their carrying capacity. Soil and water conservation are essential for sustaining agricultural productivity as well as preventing soil erosion and degradation, which is important for achieving SDGs. Soil conservation is defined as minimizing the soil loss with simultaneous maintenance of its high productivity by conserving nutrients. Soil conservation aims at promoting appropriate land use, maintaining soil fertility, preventing soil erosion, restoring fertility of eroded land, reducing water run-off and regulating water resources, preventing soil and water pollution by carried-off eroded soil, and promoting appropriate irrigation and drainage. Water conservation is defined as the efficient management of water in order to reduce its losses along with timely availability of necessary quantity of water. Water conservation practices include water resources development, collection and storage of surface water, recharge of ground water, flood control measures, soil moisture conservation practices, etc. (Ojekunle and Eruola, 2016).

Soil management strategies should be based on the following principles (FAO, 2000):

1. Increase in soil cover.
2. Increase in soil organic matter content.
3. Increase in water infiltration and retention capacity of soil.
4. Reduction in run-off.
5. Improvement in rooting conditions of soil.
6. Improvement in fertility and productivity of soil.
7. Reduction in production costs.
8. Reduction in soil and

environmental pollution.

Increase in soil cover reduces wind and water erosion, increases rainwater and irrigation water infiltration, reduces moisture loss by evaporation, increases soil moisture availability, buffers soil temperature, provides optimum soil conditions for seed germination, adds organic matter, enhances structural stability of soil aggregates, stimulates activities of soil flora and fauna, increases soil porosity, stimulates biological pest control and suppresses weed growth (FAO, 2000). Soil organic matter improves the stability of soil aggregates, enhances soil moisture retention capacity particularly in sandy soils, improves soil nutrient retention capacity, and increases soil biological activity. Thus, soil organic matter is essential component in improving soil quality. By reducing run-off, loss of soil, water, nutrients, fertilizers, and pesticides through erosion is decreased as well as moisture availability to crop is increased.

Soil conservation can be done by both physical or mechanical and agricultural practices. Mechanical measures include terracing, contouring, strip cropping, *etc.* whereas management of crops and soil forms the part of agricultural practices. Conservation tillage is an effective tool for soil and water conservation. Conservation tillage has many types like zero tillage, strip tillage, tined tillage, ridge tillage, and reduced tillage (FAO, 2000). Contour farming is useful in reducing soil erosion in steep areas. In contour farming, the crops are cultivated in the rows perpendicular to the slope gradient. Contour farming is recommended in the areas having slope less than 3 per cent and less slope length. Green manuring also helps in improving soil quality and conserving soil (FAO, 2000).

Terraces can considerably reduce soil loss due to erosion if they are well planned, correctly constructed and properly maintained. Objectives of terraces are reduction of run-off volume and run-off velocity, decrease in loss of soil, seed and fertilizers, improvement in infiltration for increasing soil moisture content, and smoothening the topography for improved mechanization. Terraces are generally recommended for slopes of 4 to 50 per cent. Terraces can be classified using various criteria. On the basis of destination of the intercepted water, terraces are classified as absorption terraces and graded terraces. Absorption terraces are the level terraces which collects and holds runoff in the terrace channel such that the runoff water ultimately infiltrates and the sediment accumulates. Absorption terraces are mainly recommended for land having less than 8 percent slope, low rainfall, and permeable soils. Graded terraces are sloping terraces which are designed to intercept runoff and diverting the excess water above infiltration capacity of soil into the protected waterways. Graded terraces are recommended for land having slope between 8 and 20 percent, high rainfall regions, and slightly or moderately permeable soils. On the basis of shape, terraces are of two types *i.e.* common or normal terraces and bench terraces. Common terraces consist of a ridge or bank and a channel constructed on across the slope. Common terraces are generally used in areas having slope less than 20 percent. Bench terraces are series of level or nearly level benches or steps constructed along the lines of equal contour. They are recommended in land with slopes of more than 20 percent (FAO, 2000).

Recovery and stabilization of gully in severely eroded areas is important. Recovery of gully is done by filling it with soil mass and is recommended for small gullies. It is recommended for areas having good productivity. If recovery of the gully is not possible, then stabilization of gully is recommended. For stabilization of small gullies having small catchment area, vegetation especially graminaceous forage crops can be used. Alternatively, appropriate tree species well-adapted to the particular region with rapid growth rate should be used. Planting of vegetation should be done in lines perpendicular to the slope of the gully in order to form small defensive barriers. These defensive barriers reduce water velocity inside the gully and deposits the carried sediments which again supports the growth of fresh vegetation. For larger gullies, temporary or permanent structures of vegetation, barriers by branches, wire netting, stones, and logs constructed

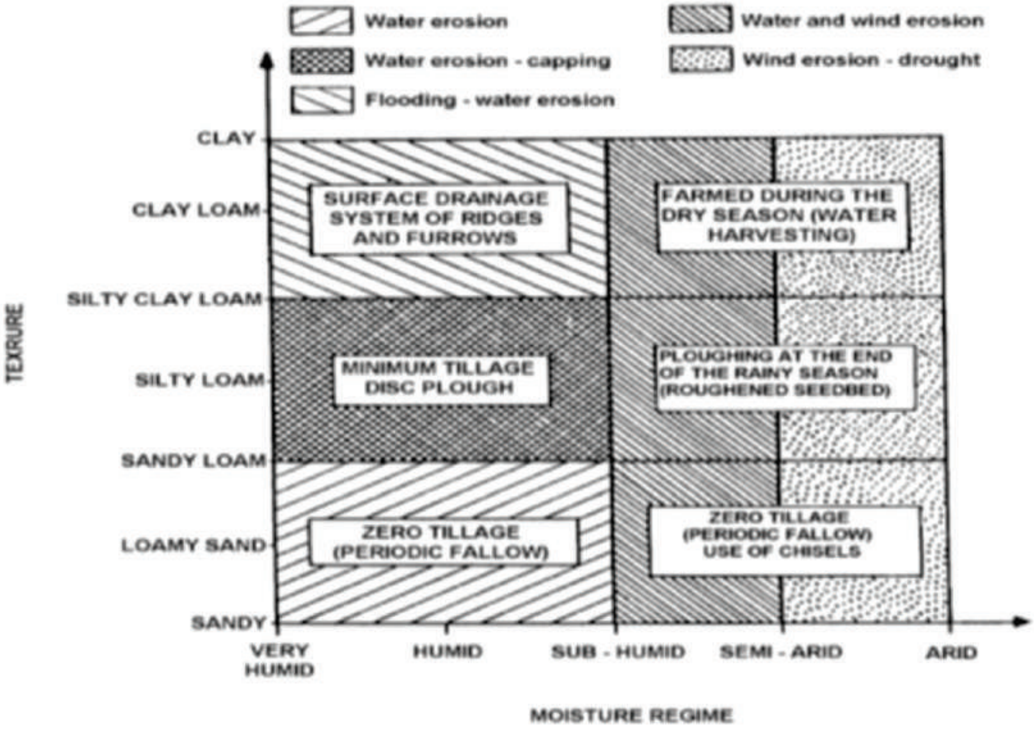


Figure 3: Appropriate Tillage Systems for the Tropics (Lal, 1985)

along the bed of the gully is recommended (FAO, 2000).

Water conservation can be done by *in-situ* capturing of rain water through cultivation of crops on ridges and by ploughing. Irrigation by drippers, sprinklers and micro-pivots also conserves water. The techniques suitable for adopting any particular tillage practice depends upon the soil texture and moisture regime as shown in figure 3:

Land Capability classification and utilizing the classified land according to its potential is very essential in terms of managing land with the objective of soil and water conservation. Klingebiel and Montgomery (1961) of the United States Soil Conservation Service have classified both arable and non-arable land based on their degree and type of limitations. The primarily advantage of land capability classification is that appropriate planning for conservation practices could be done at farm level (FAO, 2000).

4.10. Precision Farming

Precision farming is information and technology-based farm management system, in which spatial variability of agricultural fields is identified, analysed and managed by utilizing various inputs in precise and required amount and at required time in order to enhance production efficiency, improve quality of produce, increase efficiency of applied chemicals, and reduce environmental pollution. It is better than the traditional cultivation methods from the ecological point of view. It is relevant in achieving the Sustainable Development Goals of Zero Hunger, good health and well-being, and climate action. Following tools and equipment are required for precision agriculture (Hakkim *et al*., 2017):

Global Positioning System (GPS): GPS provides the accurate positional information *i.e.* latitude, longitude and elevation, of the within field variability in terms various parameters like soil type, pest incidence, weed invasion, etc. such that the inputs for managing them are applied in the desired location in the necessary amount.

***Sensor technologies*:** Various sensors based on properties like electromagnetic, conductivity, photo electricity and ultra sound are used to detect and quantify humidity, vegetation health, temperature, soil texture and structure, physical characteristics, humidity, nutrient levels, vapour, *etc*. Remote sensing data obtained either from sensors of satellite or from ground-based sensors mounted on drones are used to distinguish crop species, locate stress, identify the incidence of pests and weeds, and monitor soil and plant conditions. By utilising sensors, *in-situ* data are obtained without laboratory analysis.

***Geographic Information System (GIS)*:** GIS form digital maps to provide information on topography, soil type, soil fertility, irrigation, chemical application rates, crop yield, *etc*. This information is analysed to understand the relationships among the various factors influencing crop on a particular site. It can also be used to evaluate various management options to achieve the target output.

***Variable-rate technology*:** Variable-rate technology (VRT) systems are automatic systems to set the rate of delivery of farm inputs depending on the variability in the spatial map of a particular parameter. Information acquired from the GIS can control application of seeds, fertilizer, herbicide pesticide, herbicide selection at variable rate in the right site at the right time. Recently, sprinkler irrigation with GPS based controllers are released for commercial use which utilize motion control, wireless communication and sensor technologies to monitor soil and surrounding conditions to apply water efficiently for crop use (Hakkim *et al*., 2017).

***Software*:** Software are required in adopting precision farming to conduct various tasks *i.e.* providing interface for display-controller, mapping of information layers, pre and post processing of collected data for analysis and interpretation, accounting of inputs per farm field, and so on.

***Yield monitor*:** Yield monitor consists of several components to record the yield continuously by measuring the force of the grain flow on a sensible plate in the clean grain elevator of the combine. Location of the yield data in yield monitor is recorded using GPS receivers to create yield maps. In case of forage crops, yield monitoring systems record weight, moisture, and other information on per-bale basis. Recently, mass flow sensor is developed which transmits microwave energy and measures the backscattered portion from the stream of grains flowing through the chutes (Davis *et al*., 2005).

Therefore, precision farming is novel approach for solving contemporary agricultural issues of sustaining productivity without harming environment. It is the integration of advanced information technology for analysing and modelling spatial variability in soils and crops along with their site-specific management which provides economic benefits, as well as reduce energy input and the harmful impacts on environment.

4.11. Nanotechnology

Nanotechnology is the technology associated with the materials, systems and processes operating at the scale of 100 nanometres (nm) or less. At nano-scale, the properties of the materials are vastly different. Nanotechnology works on two approaches: top down approach in which size is reduced to the nano-scale, and the bottom up approach which includes manipulation of individual atoms and molecules to form nanostructures. Nanotechnology is the emerging technology for managing soil. Nano-sensors could be used to determine the amount and time of application of fertilizers and pesticides at various parts of the crop field which may optimize the use of inputs. Thus, they can be used in precision farming. Nano encapsulated slow release fertilizers could be used to reduce fertilizer consumption and to minimize environmental pollution. Therefore, nano encapsulated slow release fertilizers provide better alternative of soluble fertilizers because they release nutrients at a slower rate during crop growth period which allows maximum nutrients absorption by plants without leaching loss. These fertilizers can be formed by using zeolites loaded with nitrogen, potassium, phosphorous, calcium and micronutrients (Liu *et al*., 2006). Research is going on regarding controlled release pattern of essential nutrients using clay nano-clay polymer composite.

Nano scale particles have potential to contribute towards environmental remediation technologies. Porous nano-polymers similar to the pollutant molecules could be used for separating organic pollutants of soil and water. Nano fibre-based fabrics are reported to be used to capture and isolate pathogens. These nano fibres in this fabric are embedded with antibodies against specific pathogens to detect the presence of pathogen by changing colour (Hager, 2011).

4.12. Slow Release / Control Release Fertilizers:

Slow release fertilizers are those compounds from which releases plant nutrients at slower rate compared to the actual fertilizers which readily supply plant nutrients when applied in soil. For an example, if X is a nitrogenous compound only can be tagged as slow release fertilizer if rate of nitrogen release is from X is slower than urea/ammonium nitrate or ammonium sulphate. According to Tolescu and Lovu (2010), slow release fertilizers are such compounds which contain at least one plant available nutrient that (i) availability of supplied plant nutrient gets delayed after its application in uptake and utilization processes of the plants, or (ii) plant nutrient supplied will be available for longer period compared to standard conventional chemical fertilizer. Slow release fertilizers made by coating conventional fertilizers with various materials like sulphur, polymer, oil and other synthetic chemicals, which regulate their nutrient release behaviour in such a way that nutrient release will synchronize with plant needs. Their use in crop production reduces loss of applied nutrients and their by enhance nutrient use efficiency reported by many researchers.

Kabat and Panda (2009) reported that application of basal furrow placed control release N fertilizer (CRN)-6C + prilled urea (PU) at 3:1 ratio increases 25 per cent more grain yield and nitrogen use efficiency in directly sown rice. Sarkar *et al*. (2013) reported that application of fertilizer loaded nanoclay polymer composites (NCPC) improves total mineral nitrogen in soil significantly compared to conventional fertilizer at same fertilizer dose. Further, low dose of fertilizer (LDF) as NCPC results statistically at par with that of high dose of fertilizer (HDF) as CF (CF-H) in terms availability of nutrients at critical growth stages. Sonalika (2016) studied the role clay addition in NCPCs for nutrient release behaviour. With increment in clay concentration from 6 to 18 per cent, the rate of urea release in aqueous medium from NCPCs was decreased. In green house experiment involving both wheat and rice 12 per cent and 18 per cent clay NCPCs showed better performance in terms of yield and nutrient recovery than conventional urea fertilizers. NCPCs doped with 12 per cent and 18 per cent clay can decrease nitrogen dose by 25 per cent over urea fertilizer without affecting yield and N uptake.

There are some difficulties associated with slow release fertilizers (SRFs) or controlled released fertilizers (CRFs); these SRFs/CRFs are costly, non availability in local market, sometimes release of nutrient is too slow to meet plant need, and the presence of harmful chemical in coating material. Most of the SRFs/CRFs focused to increase N use efficiency neglecting other nutrients such as P, K and micronutrients, which leads to imbalanced nutrition.

4.13. Waste Management and Remediation

The increasing trend of urbanization with every passing year has also led to the clearing of several land forms and pollution of land, water and air. Among all these types of environmental pollution, soil pollution with the waste is one of the commonly referred problems. Soil acts as sink of the pollutants which deteriorate the soil health. The degree of chemical contact with these wastes determines the level of contamination to soil and underground water. Soil pollutants can be of different kinds such as fertilizers and pesticides, municipal waste, heavy metals, flying ash, wastewater irrigation, *etc*. To meet the increasing food demand of the raising human population, fertilizers and pesticides are used in huge amounts to increase the crop yield. Most of these fertilizers contain minute amounts of non-degradable heavy metals such as cadmium and lead. When pesticides are applied to the plants for weed control and pest control, it is accumulated in huge amounts and ultimately goes to soil.

Repeated and long-term application of these fertilizers and pesticides to soil and plants leads to build-up of heavy metals in soil and pass through our food chain. The presence of these heavy metals reduces the important minerals, vitamin C and carotene in edible parts of fruits and vegetables grown in contaminated soil. Solid wastes from industry, urban use, etc. are accumulated on large areas on soil which ultimately contaminates the soil for long term. Heavy metal accumulation not only affects the biological health of the soil but also disturbs the growth of the crops by affecting their germination, photosynthesis, respiration and reproductive stage. Vehicle exhausts, mining, coal burning, *etc*. release fly ash to atmosphere and finally accumulates in soil through absorption and settlement. These heavy metals pose a great risk to human life as it is non-biodegradable and can oxidized itself to a more toxic form. Thus, their persistence in soil creates the most serious issue of all pollution types. Through our human food chain, the heavy metals enter the human body and create havoc by causing several diseases such as cancer, liver dysfunction, stunted growth, *etc*.

Several technologies are available in order to remediate these pollutants in soil. Through electroremediation, a wide range of heavy metals is extracted from the soil through ion-exchange resins or adsorption to the electrodes that are inserted in the contaminated soil. When current is passed through an anode and a cathode inserted in soil in two opposite sides, a magnetic field is generated that forces the ionic heavy metals attract towards their respective electrodes (Lindgren *et al*., 1994). Electroremediation is not used widely as sometimes due to excessive heterogeneity of the soil, it might not work. Another *in-situ* method of soil remediation is soil flushing, through which heavy metals are extracted from the contaminated soil through a fluid injected in the soil to which the heavy metals are absorbed. Soil flushing woks on all kinds of soil pollutants but it will work effectively in those soils with large spaces to allow the extraction fluid to enter through the soil (Di Palma *et al*., 2003). In order to remove volatile organic pollutants through evaporation, soil vapour extraction methods is used through which a vertical or a horizontal wall are made in the soil and into it, a vacuum is blown to allow the evaporation of the volatile pollutants that are being collected in an extraction well places at one end of these walls (Barnes *et al*., 2002). However, kerosene and diesel oils and any other heavy pollutants could not be removed with this method.

In order to reduce the mobility and solubility of the pollutant, stabilization method is employed. Stabilization can be done through chemical and physical means by using immobilizing agents such as farm yard manure, basic slag, lime etc. (Anderson and Mitchell, 2003). The heavy metals toxicity is reduced in the soil through precipitation, adsorption etc. Lime and basic slag manipulate the pH of the soil thus affecting the solubility of the heavy metals in the soil. Through asphalt batching, hydrocarbon contaminants can be treated by addition of a petroleum contaminated soil to a hot bitumen mixture, forming an aggregate from which the soil contaminants are further extracted to volatilize the volatile compounds (Alpaslan and Yukselen, 2002). Vitrification is another technique that uses high temperature of 1600-2000°C to melt the soil as well as the pollutants contained in it and avoiding the movement of the pollutants to non-polluted areas (Khan *et al*., 2004). Soil washing uses solvents such as water to separate soil into finer and larger particles because fine soil particles are more susceptible to adsorption of pollutants due to its larger surface area. Therefore, by separating these finer soil particles, pollutants can also be removed (Riser-Roberts, 1998).

Soil remediation can also be carried out through biological process by suing bio-piles. In this type of bio-remediation/biodegradation, contaminated soils are aerated with microbes at an optimum temperature and pH for proper growth and activity of the microbes. This method works well with cleaning of petroleum, pesticide, volatile organic compounds, *etc*. Moreover, its design is easy and short-term. Therefore, in order to achieve full cleaning, it must be used along with other cleaning methods (Filler *et al*., 2001). Phytoremediation is another widely researched method for remediating soil contaminants. Certain types of plant species that can grow in contaminated soil with higher biomass are selected and are grown in the soil to extract the heavy metals from the soil in its biomass and thus reducing their availability in soil (Ali *et al*., 2012). Induced phytoremediation by using mobilizing agents such as EDTA can enhance the remediation process. The problem of phytoremediation is of the disposal of these plants after harvesting as they are not fit for consumption.

4.14. Modelling and Decision Support Systems

Crop simulation models consider the complex interactions between weather, soil properties and management factors, which influence crop performance. Crop growth simulation models are tools that enable us to integrate knowledge about crop growth, to test hypotheses about how different parts of the system interact, and to develop understanding about the system as a whole (Acock and Reynolds, 1989). Crop simulation models can provide an alternative, less time-consuming and inexpensive tool taking critical decisions in deciding the optimum nutrient, irrigation and tillage requirements for improving crop yield and improving input use efficiency under varied soil and climatic conditions.

Various crop simulation models are APSIM, InfoCrop, DSSAT, STICS, *etc*. Soil Carbon simulation models are very effective tool for understanding the complex soil carbon dynamics and predicting soil carbon sequestration under different land use; climate and management practices provided they are well calibrated and validated with long - term datasets. They are multi-compartment, dynamic and analytical mathematical models which represent the transformations of C in soil - plant systems with the quantity of soil organic components as a state variable. They are generally process - based models which follow first order of decomposition. Roth - C and CENTURY are most widely used and tested soil carbon sequestration models. These models incorporate the effects of various factors like temperature, moisture, clay content, decomposition rate constants of various soil carbon pools, composition of added organic source, etc. to predict the carbon sequestration potential of an area. Global Environment Facility Soil Organic Carbon (GEFSOC) Modelling system allows estimation of SOC stocks and its change at national and sub – national level by integration of GIS with Roth - C and CENTURY models (Milne *et al*., 2007).

Decision Support System (DSS) is interactive computer-based system that help decision makers solve unstructured problems under complex and uncertain conditions by providing access to data through procedures and analytical reasoning. DSSs are designed to undertake complex tasks involving various disciplines of agriculture, enabling us to simulate the essential requirements of crop with respect to the ambient land characteristics in order to achieve the target specified by the user (Qasim *et al*. 2015). Several DSSs are designed to recommend site-specific and need-based inputs for nutrient management resulting in optimized fertilizer management strategy. Various Nutrition Management Decision support tools are developed and are available to the farmers through online portals. This facilitates farmers to use their services without using computers. An example of such DSS is Haifa Nutri-Net which is operated over the web and helps farmers to get the schedule of irrigation and crop nutrition by taking into account various cultivation parameters (Achilea *et al*. 2005). FarmN is another such type of web-based DSS for Integrated Nutrient Management recommendations (Jorgensen et al. 2005). DSS for Planning Land Applications of Nutrients for Efficiency and the Environment (PLANET), provides best management practice tool for farmers and their advisors to adopt in the use of organic manure and fertilizers (Gibbons *et al*., 2005).

5. Soil Health Programmes in India

Recently, the Government of India launched Soil Health Card Scheme on 19th February 2015 for providing soil health cards to the farmers indicating the crop-wise fertilizers recommendations. This scheme aims at improving the productivity of farmers' fields by promoting judicious use of fertilizers. This card depicts the status of soil with respect to 12 parameters *i.e.* N, P, K, S, Zn, Fe, Cu, Mn, B, pH, Electrical Conductivity, and Soil Organic Carbon. Based on these parameters, fertilizer recommendations and soil amendments are indicated on the soil health card of the particular farm. It is used to assess the current status of soil health and their changes with time as affected by land management practices.

6. Policy Needs

There is a need to formulate policy on soil management in accordance with land capability classification in order to achieve overall economic and ecological benefits. Policy interventions are required to promote the above stated technologies for achieving the sustainable development goals.

7. Conclusion

Agriculture is one of the backbones of UN-sustainable development goals. In order to improve the productivity, maintenance of soil health is a must as it is the foundation where the production of food will take place. Institutes must also undertake more research on enhancement of human resources. Several forms of technologies are available in the research papers, but their adoption and commercialization are limited to the farmers. Farmers are generally aware of their soil health but due to their socio-economic constraints they couldn't adopt these technologies in order to replenish their soil. Increasing nutrient deficiencies and environmental pollution on the other side has troubled the farmers in several ways. Subsidies are the administration's favoured tool instrument to advance agricultural technology in India. Each technology, from quality seeds to new machines, is supported by high subsidies. Whenever structured well, this can quicken adoption of the technologies and make impetuses for advancement. In a nation predominated by smallholders, moderate access to any capital-intensive innovation needs monetary and institutional advancements. However, the way in which we believed is changing, and keeping in mind that the old custom of harvest cutting by utilizing crop cutting examinations is as yet occurring, we are also utilizing satellite imagery and other such substantial scale information gathering frameworks to know the genuine crop yield and productivity from an area.

The genuine need is for direct use of computerized and different advancements to increase farm productivity and address the undeniably unmistakable environmental change impacts. Remote sensing, GIS, yield and soil heath monitoring, *etc*. are typical. New advancements can goad development, value, and maintainability, yet are not substitutes for human and institutional improvement. The tremendous system of Panchayats and FPSs (Fair Price Shops) ought to be tapped to embrace awareness and outreach activities so as to accomplish efficiency, sustenance, and health advantages. Inadequate connectivity in rural places, high costs of services, and absence of fundamental PC learning and education prevent fast improvement of e-agribusiness. Generous venture is required in physical infrastructure, broadband, and transportation also.

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