Sustainable Agronomy

Sustainable Agronomy:

Principles and Practices

By

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PREFACE

Sustainable Agronomy comprises the set of principles and practices which ensure the agriculture system productive without damaging the natural resources like soil, environment and water. High population and changing climate have depleted the resources, sustainable crop production seems a good option to way forward to preserve the ecosystem. In this production system, safeguard of natural resource is major target so that future generation can fulfill their dietary need without compromising the environment. Principles of sustainable crop production ensures the efficient use of resources to reduce the environmental footprints and improving crop resilience. These includes the avoidance of soil degradation to maintain soil health by enhancing soil organic matter and biological activity. Similarly, the soil moisture conservation is also the core area to improve the water use efficiency through adopting efficient or innovative irrigation methods to reduce water pollution. Current practices are also the threat for water pollution as it adds up the fertilizer as well as the pesticide residues. Modern agriculture is highly relying on chemicals which are polluting our natural resources. In contrast, sustainable crop production system suggests the judicious use of inputs, prefer organic fertilizers, non-chemical insect pest management practices that may regenerate the land rather to degradation. These practices align with the three pillars of sustainability—environmental health, economic viability, and social equity.

In sustainable crop production, key practices include the conservation of land, water and nutrients to minimize its negative impact on the environment. Many practices like the conservation tillage, cover cropping, diversified cropping system can help to restore soil resource. Water use efficiency can be improved by optimized irrigation methods and mulching techniques to reduce the wastage. Similarly, the fertilizer management are the equal important where organic amendments like green manure, farm yard manure, compost, vermicompost, biochar and biofertilizers can be practiced. It can also improve the fertilizer use efficiency as well as reduces the emission of greenhouse gasses and thus the global warming. Insect pest management is another major component of sustainable crop production. Instead of chemicals which is disrupting the ecosystem, sustainable or non-chemical practices can be followed. This include the preventive measures, agronomic practices, resistant cultivars and biological control. These strategies contribute to heathier agriculture system by enhancing its dependency on natural products.

Globally the sustainable crop production practices are increasing seen which is the need of the time to maintain food security while mitigating the impact of climate change. In Pakistan, crop production system heavily dependent on chemical inputs, facing significant challenges. This motivated me for the urgent shift of agronomic practices toward sustainable approaches. In this book, we explore solutions that not only address these issues but also contribute to building resilient and healthy farming systems for future generations. Tailoring practices to the local agro-ecological conditions is vital for ensuring that sustainability goals are met while improving productivity and farmer livelihoods. The future of sustainable crop production will depend on the continuous evolution of practices, supported by scientific research, technological innovation, and policy reforms. Precision agriculture, zero waste agriculture, diversifies cropping system, use of artificial intelligence for input management, organic farming, biotechnology, and agroecological methods offer promising pathways to improving productivity while reducing the environmental footprint of farming. This book will explore key issues related to land degradation, irrigation mismanagement, fertilizer use, pest and weed management, and sustainable techniques that can lead us toward a more resilient and productive agricultural future.

I would be happy to express my gratitude to my parents and other family members for their unwavering support for this journey. To my wife, thank you for your encouragement, patience and understanding the long hour of working. Moreover, the children laughter and joy were the constant source of inspiration. I am also grateful to my colleagues and mentor whose expertise have enriched this work.

Dr Naeem Sarwar

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CHAPTER 1

INTRODUCTION

Current agronomic practices are crucial for enhancing crop production to meet the needs of the growing population, but they are also a threat to natural resources like soil, water and the environment. Farmers are practising intensive cultivation to maximize the short-term crop yield, which leads to soil degradation, altering the physical, chemical and biological properties of soil. Excessive application of chemicals in the form of fertilizers and pesticides contaminates the groundwater, pollutes rivers and lakes and reduces biodiversity. Moreover, widespread burning of stubbles and poor waste management strategies further pollute the environment, reducing air quality and contributing to smog formation. Such practices have also elevated the level of CO2 in the environment, which is impacting crop production and creating issues for plant protection. Elevated CO2 has introduced new weeds with high resistance, changed the nutrient distribution in the plants and caused mineral deficiency in the grains. Similarly, fertilizer production and its usage cause the emission of greenhouse gases and exacerbates the climate change. In this chapter, we will explore the critical issues posed by unhealthy agronomic practices, focusing on their impact on soil health, water quality and climate stability.

1.1 Soil degradation

The increasing global population has put significant pressure on land, which is deteriorating, leading to poor soil quality and, as a result, agricultural production has been adversely affected. Farming operations have greatly expanded and become more automated to fulfil the burgeoning population's demand for food. Food security is gravely threatened by soil degradation and shrinking agricultural land areas, which seriously undermine the nation's agricultural output. There are several physical, chemical, and biological processes that contribute to soil deterioration. For example, waterlogging, soil salinity, depleting soil fertility, dropping soil pH, increasing tillage, monocropping, soil erosion, nutrient leaching, soil compaction, loss of soil organic matter and soil pollution are causing soil degradation and reduced soil health index (Alam, 2014). In addition to being the principal resource upon which humans rely for the cultivation of food, feed, fibre, and alternative resources, the soil is crucial for maintaining the planet's intricate terrestrial ecosystems and climatic systems. According to Jie et al. (2002), soil degradation is defined as “measurable loss or reduction of the current or potential capability of soils to produce plant materials of desired quantity and quality” (p. 244). According to estimates, roughly 13% (8.7 billion hectares) of the land surface covered by soil is utilized for agriculture, and an additional 8 to 9 billion hectares of soil would be needed to fulfil the 9 billion population's demand for food, feed, and fibre through the year 2050 (Karlen & Rice, 2015). However, intensive farming methods already impacted land quality negatively. Some of the main drivers of land degradation are listed below;

1.1.1 Land use

Land use practices significantly contribute to land degradation which undermines soil health, fertility and ecosystems. Current agricultural practices are causing physical, chemical and biological damage to the soil. Many heavy implements are being used in crop production which are creating hardpan in the soil. Similarly, other intensive cultivation operations are also damaging the soil. Use of injudicious chemicals is another act which is causing chemical changes in the soil like pH of the soil, CEC etc. similarly the soil microorganisms are in major threat due to heavy chemical application. In developing countries like Pakistan, farmers follow intensive cultivation to feed the large population. They raise different crops through different sowing methods thus deteriorating the soil structure. There are different cropping systems like rice-wheat, cotton-wheat, sugarcane, maize-maize-wheat, along with different vegetables. Although farmers get good yield and fulfill their demands but at the cost of land degradation. To raise these intensive crops, farmers apply too much inorganic fertilizers, pesticides which is damaging the natural resources especially the soil.

1.1.2 Grazing

Overgrazing results in compaction of soil due to repeated movement of animals which results in loss of soil quality and also cause the soil erosion. This compaction, combined with reduced vegetation cover, also increases the risk of soil erosion by wind and water

1.1.3 Tillage practices

Tillage leads to increased soil erosion, loss of organic matter and emission of more greenhouse gasses in the atmosphere. Similarly, the tillage practices also create the hard pad due to the continuous use of heavy implements. In some areas where the cropping intensity is high, tillage practices damage the soil structure. Use of heavy machinery for different crop production process increases soil compaction, creates hardpan and damages the soil structure. It also causes depletion of soil nutrients (Karlen & Rice, 2015; Katra, 2020).

1.1.4 Inorganic Fertilization

Excessive use of inorganic fertilizers to replenish N, P, K, and micronutrients in the soil creates imbalance in soil nutrients, causes eutrophication and damages soil quality. Continuous use of inorganic fertilizers and missing the incorporation of crop stubbles reduces soil organic matter and the soil quality. Similarly, the heavy metals also deposit into the soil which is also a major threat for soil degradation.

1.1.5 Pesticide application

Yield increase is the primary goal of farmer to get maximum outcome by controlling insect pests, fungus, bacterial and viral diseases through pesticide applications. However, excessive use of chemical pesticides increases soil pollution, adversely affects the soil microbial ecosystem and speeds up the soil degradation process.

1.1.6 Flooding

Floods sweep away the top soil layer taking with them all the vital micro and macronutrients, organic matter, and microbial ecology. Runoff from floods has a significant effect on soil fertility and poses a major risk to the health of the soil.

1.1.7 Salinity

The global issue of salinization, or a rise in the amount of salt in the soil, has reduced the amount of agricultural land by 1- 2%. Salinity affects the wetlands, drinking water, rivers, irrigation land and is more intense in dryland areas. For instance, India, China, Pakistan and other countries are badly affected by salinity leading to reduction in crop productivity.

1.1.8 Impact of soil degradation on Plant health

Degraded soil has low levels of organic matter, beneficial microbes, plant nutrients, and poor physicochemical soil structure, all of which hinder the plant's ability to develop effectively and results in lower yields. The economic losses are obvious from soil deterioration as input significantly outweighs output burdening farmers financially and at the same time, reducing the availability of food, feed, and fibre. Remediation of soil quality is necessary to improve the yield of crop per unit area as well as to maintain the ecosystem stability and balance (Nayakekorale, 2020).

1.2 Fertilizer pollution

The 21st century has observed an increase in food production due to increase in global population and this has led farmers to experiment different methods/techniques to increase agricultural productivity. One of these extensively used agricultural techniques is the use of inorganic fertilizers, which replenish the soil's vital nutrients but substantially increase crop productivity. However, adding inorganic fertilizers to the same soil regularly without adding organic matter has the reverse effect and has contributed to the degeneration and deterioration of the soil by changing its physicochemical and biological properties (Al-Taai, 2021).

Excessive use of fertilizers is one of the factors contributing to the; poor soil quality, imbalance in soil nutrients, fluctuation of soil pH and reduction of soil organic matter. Using more than recommended dose of fertilizer causes buildup of mineral salts in the soil and ultimately compaction. The compactness of the soil slowly leads towards the soil degradation due to poor water-penetration and aeration, immobilization of phosphorus (P), decrease in soil porosity, reduction in soil microflora and enzymatic activities, and increase in erosion (Massah and Azdegan, 2020). More than recommended nitrogen (N) input into the soil adversely affects the soil microbial population (Singh, 2018). Similarly, high phosphorus inputs into the soil speeds up the phosphorus mineralization and insolubility. The salinity increases with excessive fertilizer input in monocrop culture over longer periods and this reduces the soil rhizosphere bacteria and fungi population which results in decreased soil carbon as well as bioavailable N and P. The overall impact on reduced microbial ecosystem population decreases soil health and hence, the healthy plant growth and development (Wołejko et al., 2020).

1.2.1 Types of Fertilizers

There are different types of inorganic fertilizers which are being used in crop production to fulfill the plant needs of various macro and micro nutrients.

Nitrogen-Based Fertilizers: There are different types of N-based fertilizers which replenish the inorganic or ionic form of nitrogen in the soil for their increased solubility, for example, Urea, ammonium sulphate ($(NH_4)_2SO_4$), ammonium nitrate (NH_4NO_3), anhydrous ammonia (NH_3), urea-ammonium nitrate, Nitrophos, diammonium phosphate ($(NH_4)_2PO_4$) (DAP) and ammonium nitrate +limestone.

Phosphorus-Based Fertilizers: P-fertilizer is derived from rock phosphate i.e., hydroxyapatite ($Ca_5(PO_4)_3OH$) and fluorapatite ($Ca_5(PO_4)_3F$). The P content is measured as a percentage of P in P_2O_5. The P- fertilizers are available in many different forms depending upon their active P as well as N content e.g., monoammonium phosphate (H_6NO_4P), diammonium phosphate ($(NH_4)_2PO_4$), triple superphosphate ($Ca(H_2PO_4)_2.H_2O$), Single super phosphate and ammonium polyphosphates ($[NH_4PO_3]_n(OH)_2$).

Potassium-Based Fertilizers: K-fertilizer is extracted from mineral ore potash and is usually supplied as potassium chloride (KCl) and potassium sulphate (KSO_4). The fertilizer is measured as a percentage of K in potassium oxide (K_2O).

Zinc Fertilizers*:* Zinc is an essential micronutrient that plays a critical role in plant growth and development. Zinc fertilizer can be supplied as *Zinc sulphate* ($ZnSO_4$), Zn-oxysulfates, *Zinc oxide* (ZnO), Zn-lignosulfonates (organically complexed zinc source) and ZnEDTA (a synthetic zinc chelate).

Iron Fertilizers*:* Iron is another essential micronutrient that is required for plants growth and development. Iron is present in the soil as either ferrous (Fe^{2+}) or ferric (Fe^{3+}) depending upon the pH of the soil. Iron fertilizers are available as *Ferric sulfate* ($Fe(SO_4)_3.4H_2O$), *Ferrous sulfate* ($FeSO_4.7H_2O$), *Ferrous ammonium phosphate* ($Fe(NH_4)PO_4 . H_2O$), *Ferrous ammonium sulfate* ($NH_4SO_4.FeSO_4.6H_2O$), and Iron chelates.

Boron Fertilizers*:* Boron fertilizers are commercially available as *Solubar* ($Na_2B_8O_{13}.4H_2O$), *Borax* ($Na_2B_4O_7.10H_2O$), *Fertilizer borate* ($Na_2B_4O_7.5H_2O$), *Boric acid* (H_3BO_3), *anhydrous borax* ($Na_2B_4O_7$), Colemanite ($Ca_2B_6O_{11}.4H_2O$), *Boron frits* (boric oxide glass) and *Ulexite* ($NaCB_5\ O_9.8H_2O$).

Copper Fertilizers: Copper deficiency is usually not very common and its fertilization is required at very minimal amounts. Copper fertilizers can be supplied as copper sulfates ($CuSO_4.H_2O$), *Copper oxides* (CuO, Cu_2O), Copper ammonium phosphate ($Cu(NH_4)PO_4\ .\ H_2O$) and copper chelates.

Other Minerals: Manganese (Mn) Molybdenum (Mo) and Chlorine (Cl) are other minerals required in trace amounts. Manganese is supplied as Manganese sulphate ($MnSO_4.4H_2O$), Manganese oxide (MnO) and Manganese chelate. Molybdenum is supplied as Molybdenum oxide (MoO_2, MoO_3), Sodium molybdate ($Na_2Mo_4.2H_2O$) and Ammonium molybdate ($(NH_4)_6Mo_7O_{26}$).

1.2.2 Environmental Impacts of Fertilizers

Inorganic fertilizers are manufactured on an industrial scale, using a significant amount of fossil fuels to power the production process, which generates heat and greenhouse gases (GHG) that are released into the environment. In the process of making ammonia, 2–7 tons of CO_2 is created for every ton of nitrogen, and the fertilizer sector alone emits 2% of the total CO_2 emission from other sources. On the other hand, N_2O is released in larger quantities than CO_2 in nitric acid industry which is particularly detrimental for the ozone layer and is causative agent for acid rains. Though other sources (transportation, dying, land, sewage water) contribute to N_2O release, fertilizer industry's share is about 6% of all N_2O produced. The byproducts of phosphorus fertilizers contain fluorine, fluorosilicic acid, and phosphogypsum. The phosphogypsum may contain traces of radioactive metals as well as heavy metals which could cause heavy metal pollution in the soil. Continuous use of fertilizers, such as N-fertilizers, causes nitrate leaching, which pollutes ground water and makes soil more acidic. The nitrate contaminated water could lead to health issues to humans. Some of the adverse environmental impacts driven by fertilizer are listed below;

1.2.2.1 Eutrophication

Eutrophication is one of the most common forms of fertilizer pollution. When fertilizers containing high levels of nitrogen and phosphorus are applied to fields, they can run off into nearby waterways where they promote the growth of algae and aquatic plants. This can lead to oxygen depletion in water bodies, resulting in the death of fish and other aquatic animals. A study conducted in China found that eutrophication caused by fertilizer runoff was responsible for the decline in water quality in a major river system (Zhou et al., 2020).

1.2.2.2 Groundwater Contamination

Fertilizer pollution can also contaminate groundwater, which is a primary source of drinking water for many communities. A study conducted in India found that high levels of nitrate, a common fertilizer ingredient, were present in groundwater in agricultural regions (Sharma et al., 2020). This can pose a serious health risk, particularly to infants and young children, as high levels of nitrate can lead to methemoglobinemia, also known as 'blue baby syndrome'.

1.2.2.3 Air Pollution

Fertilizer application can also lead to air pollution. When nitrogen fertilizers are applied, they can volatilize and form ammonia gas, which can contribute to smog and acid rain. Most of the applied nitrogen goes into the environment in the form of nitrous oxide. Still, we have about 30 % nitrogen use efficiency which means that major share of nitrogen is going into the environment and causes air pollution ((Xu et al., 2021). Nitrous oxide is very important greenhouse potential which is more potent than other gases and have higher global warming potential. Similarly, CO2, which is another greenhouse gas, also emits from the stubbles burning as well as from the aerobic decomposition of the plant waste. Continuous accumulation of greenhouse gases causes global warming which is the major threat for crop production due to changing climate. High temperature has caused many issues for the growers as it causes fluctuation in rainfall, floods, and droughts. Global temperature has been rising continuously and it will increase up to 4.5 Celsius at the end of the

21st century. This raised temperature will reduce the crop yield and may cause the food security issue.

Burning of the plant residues is the common practice among farmers which results in the wastage of organic matter and stored nutrients in the plant residues. Moreover, this practice is also a source of greenhouse gasses in the atmosphere which is potential current climatic threat. Concentration of atmospheric CO2 has increased from about 280 to 406 ppm. If this increasing level maintains, it is expected to reach up to 550 ppm until 2050 (IPCC, 2014). This increased CO2 level may have direct impact on plant metabolism and its response to nutrients and soil moisture (Ziska et al., 2012). Currently, the cumulative effect of these gases and agricultural practices is the formation of smog which has badly impacted major area of Punjab province.

1.3 Pesticide problems

A wide range of both inorganic and organic compounds make up the insecticides. The majority of xenobiotic pollutants in soil are pesticides. More than four million tons of major pesticides are being used annually in contemporary agriculture. Soil serves as a pollution absorber because it may hold onto a variety of contaminants, including pesticides, heavy metals, and PAHs (polycyclic aromatic hydrocarbons). They tend to contaminate the food supply chain which may well be detrimental to human health and environment. Insecticides, fungicides, and weedicides make up the bulk of the three groups that make up the pesticides. In the year 2020, there were 2.66 million metric tons of pesticides consumed globally. According to Oberemok et al. (2015), there will be a 2.7-fold increase in pesticide use in agriculture by 2050 compared to 2000, which might result in a rising threat to human health and future generations. The active ingredients in pesticides pollute the soil environment impacting microorganisms that live there. The Food and Agriculture Organization (FAO) claimed in 2001 that over 700 pest species were pesticide resistant. The World Health Organization's (WHO) classification system of toxic classes of substances falls into three basic categories: Extremely toxic (Ia), Highly toxic (Ib), Moderately toxic (II) and Slighty toxic (III). Most of the insecticides (51), fungicides (8) and herbicides (5) belong to class Ia and Ib while rest of the classes, Ia and Ib pesticides (22), are intended for other pathogenic control.

Pesticide residues pollute the soil, fresh-water streams, and rivers. The surface leaching, direct run-off, equipment washing, and industrial waste-disposal contaminate the aquatic environments (Kadiru et al., 2022).

Wheat, rice, corn, cotton, vegetables and fruit trees are the major site of pesticide consumption worldwide. Among the widely used pesticides, organochlorines, pyrethroids organophosphates, and carbamates comprise the greatest share. Most of the organochlorines persist for longer periods in the soil and water (Shahid et al., 2021). China was identified in 2021 as a location with a high risk of pesticide contamination and water scarcity. Tang et al. (2021) discovered that 34.1% of the world's high pesticide contamination risk areas (about 4.18 million km2) are situated in biodiversity rich zones. Particularly, China, South Africa, Australia, India, Argentina, Ecuador and Mexico are at high risk of pesticide pollution (entail 31% of the total 64% global agricultural land). Pesticides misuse exacerbate the loss of endangered species specially in the hotspot areas like China, Australia, Gautemala, and Chile among others. Propanil and molinate pollution is evident in the rice cultivation regions of Greece (Konstantinou et al., 2006). In India, dichlorodiphenyltrichloroethane (DDT), endosulfans and hexachlorocyclohexanes are the major pollutants in surface waters of rivers and sediments (Ashesh et al., 2022). These toxic pesticides are found in the fresh water fish and are therefore, a big threat to biotic life as well as human health. Pakistan is not included in the list of high-risk pesticide pollution region as reported by Tang et al. (2021). However, in a 2014 study, the fish in Ravi River was found to be contaminated with DDT and dichlorodiphenyl dichloroethylene (DDE) with above food standard limits. Above all, Pakistan is the second highest consumer of pesticides in South Asia. In contrast to the global average, it was revealed that Pakistan had enormous pesticide usage, with a worrisome surge during the previous two decades (Rashid et al. 2022).

1.3.1 Pesticides degradation

Pesticide degradation is dependent on the soil pH, its physicochemical properties, biological activities, rhizosphere bacteria and temperature. Some pesticides retain in the soil for longer periods of time (organochlorine pesticides) and cause inhibitory effects to soil microbes and higher organisms. Pesticides also influence the soil enzyme activities which indirectly influence the soil microbial population and plant growth and development. The higher concentrations of cypermethrin, monocrotophos and quinalphos adversely affect the dehydrogenases. Both the insecticides and herbicides reduce the microbial and enzymatic activity of soil at higher concentrations while the lower doses have no effect.

The overuse of pesticides has been shown to contribute to the development of resistance in many plant and insect species. This resistance can make it difficult to control pests and can lead to the need for higher doses or different types of pesticides. Recent studies have demonstrated the impact of pesticide resistance on agriculture and ecosystems. A study published in the journal *Nature Ecology & Evolution* found that resistance to pesticides in pests is increasing at an alarming rate, with some populations evolving resistance in as little as two years (Stevens et al., 2017). Another researcher found that the use of insecticides led to resistance in mosquitoes, which increased the risk of diseases such as malaria (Toé et al., 2014).

Research has also shown that the overuse of pesticides can have negative impacts on the environment and human health. The use of pesticides was linked to the decline of bee populations, which has significant implications for pollination and food production (Goulson et al., 2015). Similarly, exposure to pesticides was linked to increased risk of certain cancers, including prostate, lung, and non-Hodgkin lymphoma (Alavanja et al., 2013).

1.3.2 Impact on Nitrifying Bacteria

Pesticides usage adversely impacts the soil populations of nitrogen-fixing bacteria. In a study conducted by Mohamed et al. (2021), it was revealed that higher concentrations of Glyphosate and paraquit negatively impacted the four different rhizobacterial species (*Pantoea agglomerans, Rhizobium nepotum, Rhizobium radiobacter,* and *Rhizobium tibeticum*) and resulted in decrease of nodulation, nodule size, nodule fresh and dry weight and nitrogen content in *Bituminaria bituminosa* (Mohamed et al., 2021; Akter et al., 2022). Organochlorine pesticides (benzene hexachloride, chlorpyrifos, dieldrin, and endosulfan) inhibited the growth, biofilm formation, cell viability and phosphate solubilizing activities of *Enterobacter cloacae* at higher concentrations (Shahid et al., 2021; Ashesh et al., 2022).

Similarly, insecticides also affect the rhizosphere bacteria in a dose-dependent manner (Ramani, 2011). The insecticides fipronil, imidacloprid, pyriproxyfen and thiamethoxam decrease the P-solubilizing activity of *Klebsiella* sp. among which pyriproxyfen caused the greatest toxicity (Ahemad and khan, 2011). All the tested insecticides also decreased the IAA, siderophores and exopolysaccharides production by the *Klebsiella* sp.

1.3.3 Multidrug resistance mechanism

Pesticide resistance is frequently acquired by soil bacteria due to continuous use of pesticides, their accumulation in the soil and rapid adaptation of the bacteria to the changing environmental conditions.

Bacteria dwelling in contaminated environments adapt to multiple resistance mechanisms by mutations in their genes which allow for overproduction of enzymes that are responsible for breakdown of pesticides. Genetic alterations in the bacterial DNA to overexpress stress responsive enzymes like esterases, oxidases, and glutathione transferases cause reduction in pesticide receptors as well as mutation in resistant genes leading to the adaptation to resistance mechanisms in bacteria (Rangasamy et al., 2018). Pesticide-resistant bacterial strains develop co-resistance to antibiotics through evolution of pesticide degradation pathways which triggers the multidrug resistance in bacteria. Cycling of pesticide resistant bacteria through food chain into human causes multidrug resistance and therefore, adversely affects human health due to lack of efficacy of existing antibiotics. Though the antibiotic and pesticide degradation pathways are different from each other, yet the co-adaptation of both pathways is common in response to excessive use of pesticide. Some of the tactics used to adapt antibiotic-pesticide cross resistance include biofilm formation, analogous active sites for both antibiotics and pesticides, up-regulation of stress tolerance regulation genes, copy number expansion of stress enduring genes, acquisition of new antibiotic resistance genes via soil bacteria into pesticide resistance gene clusters, and horizontal gene transfer. For instance, resistance to antibiotics ampicillin, chloramphenicol, tetracyclin, ciprofloxacin and kanamycin was observed in wild type *E.coli* and *S. typhimurium* by continuous exposure to 2, 4-D, Kamba, roundup. Increased pesticide use may lead to the accumulation of heavy metals in the soil thereby, negatively affecting the rhizosphere bacteria and entering plant system which could eventually end up in causing health issues in human or animal body (Rangasamy et al., 2018).

1.4 Poor Irrigation Management Practices

The 80% of global arable land is rain-fed and contributes to 60% of grain yield while 20% global arable land is self-irrigated and contributes to remaining 40% of grain yield. According to world data, irrigated land coverage peaked at 47 million ha (hm^2) in year 1900, from an estimated 8 million ha (hm^2) in the year 1800. India, China, United States, and Pakistan were the four biggest irrigated areas in 1900. The global irrigated area exponentially increased from 50 million ha (hm^2) in 1900 to 324 million ha (hm^2) in 2012. South Asian countries (India, Pakistan) are using 36% of their freshwater resources for irrigation and its likely to reach up to 41% until 2030 (Faurès et al., 2002). The primary cause of the growing global freshwater shortage is typically attributed to agriculture, which consumes roughly 70% of the freshwater pulled worldwide (Angelakıs et al., 2020).

Beyond the production of food and fibre, irrigation has been crucial in the economic growth of many nations. It enabled the colonization and creation of vibrant communities in many parts of the world while converting lands with little or no obvious economic value into extremely successful and market-driven agricultural systems. The horizontal expansion of population is imposing a competition between arable and residential land in developing countries. Globally, 70% of agricultural land is irrigated by freshwater which is either ground extracted, coming from melting glaciers, surface run-off waters and supplied through extensive canal networks driven mainly by gravity flow. The underground freshwater reservoirs are depleting faster than water recycling back into them (Shahdany et al., 2018). The irrigated lands though have 2 to 2.5-fold higher crop yield and productivity but this is not free from the adverse outcomes. Water storage and diversion for irrigation have a significant negative ecological impact on native flora and animal habitats as well as the natural hydrology of streams. In addition, the application of huge amounts of water to irrigated regions may cause soil erosion and streambed sedimentation. At the same time, bacteria and other disease-causing agents may be carried into rivers, streams, or aquifers together with salts, organic debris, solids of different sizes, fertilizers, and pesticides that have been leached out of the soil.

Irrigation practices make use of surface water (canals, rivers) and underground water (tube wells) in irrigated regions. The efficient management in both these systems depends upon the water storage capacities, equal distribution of water through tributaries and link-canals, operational management of canal systems, loss of water through evaporation, availability of electricity to run water pumps and water availability throughout drought periods (Yohannes et al., 2017).

According to World Bank predictions, there will be an increase of 10 billion people in world population by 2050, necessitating a massive increase in food production of up to 70%. There would also be an intensive demand for water allocation between different sectors like agriculture, industrial, drinking and household. A thorough review of water re-allocation and distribution is necessary because the agricultural sector accounts for 70% of freshwater inputs. The efficient use of irrigation water is even more critical in water scarce regions and under rapidly changing climatic conditions (Angelakis et al., 2020).

Main constraints in irrigation water management account for; poor policies, institutional inefficiency and inadequacy, financial impediments along with inefficient water delivery systems, water drainage, lack of farmer's knowledge and conventional flood irrigation practices. Moreover, government and private entities such as basin authorities, irrigation agencies, water users and farmer associations, agricultural and water ministries, typically lack the collaborative atmosphere and essential resources to perform their duties. Watershed deterioration and the ensuing floods, soil erosion, and sedimentation are major dangers to sustainable irrigation system. Floods commonly cause damage to irrigation facilities such as dams, headworks, barrages, and canals, and excessive sedimentation from the degraded uplands. However, in agricultural areas, the effectiveness of irrigation depends on farmers' irrigation practices as well as equipment maintenance and functional characteristics of irrigation equipment. Moreover, the adaptability of the farmer to shift to contemporary water conservational irrigation practices (sprinkler, drip) depends not only on his vision but on the economic/financial conditions and the landholding capacity (shahdany et al., 2018). In addition to the ineffectiveness of irrigation schemes, improper irrigation and water management also have negative effects on the environment. Climate change has affected the frequency and distribution of rainfall which enhanced the problems of floods in Pakistan. Flood affects much of the crop area annually by draining out soil nutrients and impairing drinking water quality. Higher nitrate, phosphate and potassium contents in drinking water basically originate from fertilization in crop area and leaches or drains in underground water and have many drawbacks for consumers. Water is essential component of human life which should be in better quality for healthier living. In developing countries like Pakistan, food and health securities are the biggest issues which need to be tackled properly. Most of the water supply is intermittent and outbreak of waterborne diseases such as gastroenteritis, giardiasis, hepatitis, diarrhoea and typhoid. It has been reported that 30% of all diseases and 40% of all deaths in Pakistan are caused by drinking contaminated water. As a result, every fifth citizen in Pakistan suffers from waterborne disease causing 0.1 million deaths every year. Conventional ways of fertilization and following old agronomic practices are some reasons for water quality damage which is further enhanced by consecutive floods.

Similarly, crops are irrigated following the old method such as the flooding which is most inefficient strategy. In this method, a large amount of water is wasted and due to unlevelled field, homogenous irrigation is not possible for all the field. Water accumulates at downside and causes the nutrient leaching which further pollutes the underground water. It is needed to plan, implement, and run eco-friendly irrigated cropping systems, preventing gradual and permanent degradation of land and water resources.

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CHAPTER 2

SUSTAINABLE SOIL MANAGEMENT

2.1 Introduction

Cropping intensity has increased worldwide to meet the demand of larger population. Although this practice is needed to feed the big population yet it has also damaged the natural resources especially the soil resources. Sustainable practices are needed for crop production which may meet the food demand without compromising the soil resources.

Agricultural activities encompass land manipulation which depletes soil nutrients; thus, in order to sustain and boost crop output and support agriculture in the long run, effective and efficient means of minimizing depletion and restoring nutrients to the soil will be required. The agricultural sustainability may be jeopardized through continuous cultivation and inadequate restorative practices. The primary cause of soil degradation is nutrient depletion due to higher cropping intensity and lower soil organic matter. While developing nutrient management approaches, precise understanding of the pattern of plant nutrient depletion from soil should be used as a tool to establish indicators for the sustainability of agricultural systems and to comprehend the degree of the degradation of soil health. A set of indicators for soil management for sustainable agriculture are discussed in forthcoming sections of this chapter.

2.2 Conservation tillage practices

Tillage is defined as "the mechanical manipulation of the soil for the purpose of crop production affecting significantly the soil characteristics such as soil water conservation, soil temperature, infiltration and evapotranspiration processes." (Busari et al., 2015, p. 120). Tillage has emerged as a complementary practice to increase yields but over the time, it affects the soil structure like porosity, nutrient loss, moisture, microbial ecosystem and also speeds up the soil degradation process. Increasing population needs larger area for crop production so, the uncultivated land can be the target rather than the higher cropping intensity which may lead to further land degradation. Land could function both as a sink or source for air pollution, thus in order to increase yields, soil degradation must be kept to a minimum and the land must be prepared to function as a sink to reduce air pollution (Kibblewhite et al., 2008). Traditional agricultural practices rely on intensive ploughing which has been associated with soil erosion issues, surface and subsurface water contamination, and increased water demand. Conservational agriculture, on the other hand, is aimed to manage agro-ecosystems to preserve and enhance the environment and resource base while improving the sustainable production, maximize profits and food security. To meet these goals, conservation tillage has been introduced to ensure sustainable cropping and food production. Conservation tillage system implies the concept of land preparation in a manner to protect agro-ecosystem while ensuring food security, profitability, and nutrient conservation. The conservation tillage directly affects the soil structure by promoting the soil organic content, minimal soil erosion, water conservation, decrease temperature fluctuations in soil, and enhance soil health (Cooper et al., 2020).

The annual and perennial crops are cultivated in conservation agriculture in a way to leave the topsoil layer undisturbed and cover crops are established for a permanent soil cover for natural enhancement of organic matter in the soil. Three basic components of conservation tillage entail minimal land disturbance, crop diversification and organic crop cover. Approximately 30% of crop waste residue is kept on the surface of soil to reduce soil erosion. The crop residue promotes soil cohesion and aggregation while promoting soil biodiversity and bioactivity (Ghosh et al., 2021; Kubar et al., 2020).

2.2.1 Types of Conservation Tillage (CT)

Depending upon the soil manipulation, different conservation tillage techniques are used. The conventional tillage practice ensures the heavy tillage for soil preparation while in conservational method, tillage practices are reduced while enhancing the soil organic matter in the soil.

Zero Tillage: In this type of CT, the crop is sown without following tillage operations like a plough, planking, etc. The seed is sown with a single-pass tractor to seed directly with a seed drill in unploughed land. Specialized drills (ZT drill) are used for direct seeding. This practice is currently being used in rice-wheat cropping systems. The ZT-drill with inverted T-openers creates 6-13 narrow slits for seeding and fertilization. Zero tillage in wheat is a widely adapted technology in South Asia with substantial yield benefits to farmers. Zero tillage systems improve soil quality by promoting the biological activity of the soil, soil structure, and fertility. The low organic content in the rice-wheat system can benefit from the zero tillage, which enhances carbon content in the surface layer, reduces irrigation by 30% and weed growth by 30-40%, and reduces farm mechanized operations to reduce the farmer investment (Hossain et al., 2009; Kubar et al., 2020;).

Minimal tillage: In minimum tillage, overall tillage operations are reduced to prepare the land. The land is not completely ploughed and turned over, but minimal strip pattern tilling is conducted one time followed by seeding immediately. Minimal tilling can have many variations e.g., opening the compact soil and planting in the wheel tracks, attaching a planter behind the plough, and seeding as one time plough or ploughing narrow slits and then planting in them. All these methods minimize the land preparation and therefore, reduce the cost of land preparation.

Mulch tillage (leaving mulch on the ground): Previous crop straw is uniformly distributed across the soil surface as a mulch, holes are drilled through the mulch below its surface using disc cutters, fertilizer is added below the surface of mulch if needed, and seeds are sown. Primary tillage implements are used for soil preparation. The amount of mulch depends upon the environmental conditions like dry or humid weather, more mulch is left in former case while lesser mulch is mixed in soil under humid environments. However, mulching reduces the soil nitrogen content and more often requires nitrogen fertilization to maintain C:N Ratio for decomposition.

Ridge tillage (planting along the ridges): Beds are formed above mean average height of ground which is also known as raised bed and the seeds are sown at the ridges. In areas where flood irrigation is followed, ridge system allows the movement of water across the field between the ridges while protecting the plant from flooding. Ridges also increase soil fertility through soil organic matter enhancement and provide efficient water management and erosion control (Busari et al., 2015).

Contour tillage (planting alongside the slope): Tilling along the slopes on hilly or sloppy fields is termed contour tillage and is meant to stop soil erosion. The micro-topography is altered by contour tillage, which also increases surface roughness. Through the action of intercepting and dispersing flowing water, changes in surface features decrease the velocity of surface runoff and enhance the soil water levels as well as increase water infiltration. The slopping angle in this type of farming is critical to maintain water storage capacity at maximum and decrease water flow velocity through uneven soil structure (Busari et al., 2015).

2.2.2 Effects of Conservational Tillage on Soil Properties

Tillage practices alter the soil's physical as well as biochemical structure. The goal of the CT practices is to maintain the soil organic matter, soil moisture, and rhizosphere microflora and improve the soil aggregate formation as well as its water-holding capacity.

Physical properties: Tillage type usually depends upon the choice of cropping system, soil type and weather conditions. The contour tillage is best suited for sloping sandy soils as it decreases hydrophobicity of the soil and at the same time, slows down the erosion process. Conservation tillage significantly affects the top few centimeters of soil structure. The well-drained and light soils with low organic and humus content effectively responds to the conservation tillage generating stable aggregates, more water storage and improved water use efficiency. Zero tillage imposes a direct impact on the soil porosity such as the water holding capacity. While reduced tillage improves the water use efficiency in comparison to the conventional tillage.

Similarly, the process of evaporation from the soil surface is influenced by a variety of soil characteristics, environmental ecosystem and tillage. Lower soil temperature has been associated with conservation tillage because there are more plant remains on the surface and more water-holding capacity in the topsoil, which reduces evaporation. Using the stable isotope technique, Busari et al. (2013) found that under conventional tillage as opposed to zero tillage, soil-water stable isotopes ($\delta^{18}O$ and δD) were considerably concentrated towards the soil surface implying accelerated water loss.

Biochemical Properties: Soil organic carbon (C) content is the biological component of soil that is most impacted by tillage. The concentration of soil organic matter has a substantial influence on the behaviors of microorganisms and these behaviors in turn have an influence on the dynamics of soil organic Carbon. Earthworms, which make up a large percentage of the soil macrofauna, exert a significant influence in the dynamics of soil fertility because their burrowing activities increase soil aeration and water retention. Ploughing significantly reduces the soil earthworm population as compared to the zero tillage systems. Similarly, the fungal mycelia are also broken down by tillage practices. The microbial degradation of the