CLIMATE SMART AGRICULTURE: PRINCIPLES AND PRACTICES Editors Badal Verma

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CONTENT

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1. Climate Resilient Agriculture Potential and Productivity

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Abstract:

Climate change is long-lasting change (i.e., over the decades) in the statistical distribution of weather pattern which pose a great problem towards ecology and persist for long periods with its toxic level. It is well established fact that climate change is supported by greenhouse gas (GHG) emission. Agriculture is both a target of and a contributor to climate change. Agriculture was the second highest source of GSGs emission (19.6% of total emissions) (FAOSTAT), among this India's total GHGs emissions in 2014 were 3,202 million metric tons of carbon dioxide equivalent (Mt CO2e), totalling 6.55% of global GHG, mainly due to the use of chemical fertilizers, low nutrient use- efficiency pesticides, enteric fermentation, transplanted rice cultivation etc. Additionally, 1/3 of food produced globally is either lost or wasted (www.worldbank.org). Resilience is the ability of a system and its component to anticipate, absorb, accommodate or recover.

From the effect of hazardous event in a timely and efficient manner (IPCC, 2012). Adverse influences of global warming include reduced crop quantity and quality due to the reduced growth period following high levels of temperature rise, reduced sugar content, and reduced storage stability in fruits, increase of weeds, blights, and harmful insects in agricultural crops, reduced land. Climate resilient agriculture increase the capacity of the system to bounce back and it changes in such a way that it doesn't go back to the previous situation. For us Climate resilient agriculture is a new term but this adaptation and mitigation mechanism is already present in the nature from immortal, but the problem is rapidity of the climate change, it changes too fast that nature can't synchronize with this.

Climate change can be natural (i.e., due to continental drift, volcanos, earth's tilt, ocean current) or anthropogenical (i.e., due to urbanization, industrialization, burning of fossil fuel, deforestation, unscientific agricultural practices); natural climate change can be synchronizing with the nature but the anthropogenically caused climate change dominate over the nature's synchronization power, but with some mitigation and adaptive green technologies ,nature also combat the human induced or anthropogenically caused climate changes.

Keywords:

Climate resilient agriculture, Agricultural potential and Productivity, Disasters, Adaptation, Mitigation, Climate change, Greenhouse gases, etc.

1.1 Introduction:

Climate resilient agriculture (CRA) is a sustainable approach for converting and reorienting agricultural systems to support food security under the new realities of climate change through different adaptation and mitigation mechanisms. Agricultural systems are extremely vulnerable to climate change, given their sensitivity to variations in different threats like temperature, precipitation and incidence of natural events and disasters such as droughts and floods with this on an average the extreme weather patterns can impact farm incomes in the range of 15-18 %. Threats can be reduced by increasing the adaptive capacity of farmers as well as increasing resilience and resource use efficiency in agricultural production systems. CRA promotes synchronized actions by farmers, government, scientist, private sector, and policy-makers through three main action areas:

A. Building the capacity to identify the threats;
B. Curing the threats through adaptation and mitigation process
C. Sustain their adaptive mechanisms over a long time.

The vulnerability of existing conditions of poverty, malnutrition and increasing populations puts intense pressure on finite natural resources, especially land, water and energy all of which are integral to agricultural systems. Climate change has become an important area of concern to ensure food and nutritional security for growing population. In India, significant negative impacts have been implied with medium-term (2010-2039) climate change, predicted to reduce yields by 4.5 to 9 %, depending on the magnitude and distribution of warming. In the context of climate change and variability, farmers need to adapt quickly to enhance their resilience to increasing threats of climatic variability such as droughts, floods and other extreme climatic events.

Concentrated efforts are required for mitigation and adaptation to reduce the vulnerability of agriculture to the adverse impacts of climate change and making it more resilient. As most of our farmers are marginal their adaptive capacity is limited, and hence, economically viable and culturally acceptable adaptation techniques need to be developed and implemented. Over the years, an array of practices and technologies have been developed by researchers towards fostering stability in agricultural production against the onslaught of seasonal variations.

Adoption of such resilient practices and technologies by farmers appears to be more a necessity than an option. On-farm demonstration of site-specific technologies will go a long way in enabling farmers cope with current climate variability. Indian agriculture is highly prone to the risks due to climate change caused by increase in the concentration of atmospheric greenhouse gases (GHGs) i.e., carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O). The recent Assessment Report of the Inter-Governmental Panel on Climate Change (IPCC) reiterated that the warming of the climate system is unequivocal and may intensify in coming decades. Climate change can affect agriculture through direct and indirect effects on the crops, soils, livestock and pests.

Development of technologies for adaptation and mitigation and their uptake at speedy rate by the farmers are essential for climate change management. Potential adaptation strategies include developing cultivars tolerant to heat and salinity stress and resistant to flood and drought, modifying crop management practices, improving water management, adopting new farm techniques such as resource conserving technologies (RCTs), crop diversification, improving pest management, better weather forecasts and crop insurance and harnessing the indigenous technical knowledge of farmers. There is a need to develop policy framework for implementing the adaptation and mitigation strategies so that the farmers are saved from the adverse impacts of climate change and the food and nutritional security of the country is ensured. Agriculture is crucial for ensuring food, nutrition and livelihood security of India.

It engages almost two-third of the workforce in gainful employment and accounts for a significant share in India's Gross Domestic Product (GDP). Several industries depend on agricultural production for their requirement of raw materials. On account of its close linkages with other economic sectors, agricultural growth has a multiplier effect on the entire economy of the country. Although in recent years, Indian agriculture has made a significant progress, currently it is facing many challenges too. Stagnating net sown area, plateauing yield levels, deterioration of soil and quality, reduction in per capita land availability and the adverse effects of climate change are the major challenges for Indian agriculture. On the other hand, the increased rate of population is pressurizing the agricultural sector for enhanced food production. The task is very challenging because about 60% of the net cultivated area is rained and exposed to stresses arising from climatic variability and climate change.

More than 80% of Indian farmers are marginal and small with poor coping capacity. Furthermore, the Indian farms are diverse, heterogeneous and unorganized. Climatic change and variability are likely to aggravate the problem of future food security by putting pressure on agriculture affecting its sustainability. Change in the global climate scenario results in warming of atmosphere and ocean, melting and/or diminishing glaciers, rise in sea level and increase in the concentrations of greenhouse gases. However, the most prominent environmental issue due to climate change is the global warming, caused by increase in the concentration of atmospheric greenhouse gases (GHGs) i.e., carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O). These GHGs trap the outgoing infrared radiation from the earth's surface and thus raise the atmospheric temperature. Recent observations show increase in temperatures, hot days, hot nights and heat waves; increasing frequency of heavy precipitation events; increased snow melt and rise in sea level.

The Inter- Governmental Panel on Climate Change (IPCC), in its Fifth Assessment Report reiterated that the warming of the climate system is unequivocal. Anthropogenic influence on the climate system is evident from the increasing greenhouse gas concentrations in the atmosphere and positive radiative forcing. Global climate change has considerable impacts on the crops, soils, livestock and pests. The paper discusses the impacts of climate change on Indian agriculture and the strategies and technologies for climate resilient agriculture.

1.2 Climate Resilient Agriculture Potential and Productivity:

Climate Resilient Agriculture (CRA) is defined as the incorporation of adaptation, mitigation and other practices in agriculture which increases the capacity of the system to respond to various climate related disturbances by resisting damage and recovering quickly. Such perturbations and disturbances can include events such as drought, flooding, heat/cold wave, erratic rainfall pattern, long dry spells, insect or pest population explosions and other perceived threats caused by changing climate. In short it is the ability of the system to bounce back. Climate resilient agriculture includes an in-built property in the system for the recognition of a threat that needs to be responded to, and also the degree of effectiveness of the response. CRA will essentially involve judicious and improved management of natural resources viz., land, water, soil and genetic resources through adoption of best bet practices.

1.3 Impact of Climate Change on Indian Agriculture:

Climate change impacts agriculture both directly and indirectly. The type and magnitude of impact will vary depending on the degree of change in climate, geographical region and type of production system. Assessment of impact of climate change is carried out through controlled experimentation and simulation modelling. Experimental results obtained are extrapolated on regional basis in relation to the projected climate change under different scenarios.

The key influences are:

- Change in productivity, with reference to quantity and quality of crops.
- Change in agricultural practices like water use and application of fertilizers,
- insecticides, and herbicides etc.
- Environmental influences, particularly in relation to the frequency soil drainage which may lead to loss of nitrogen through leaching, soil erosion and reduction of crop diversity.

Climate change and agriculture are interlinked, both of which take place on a global scale. Agriculture is particularly vulnerable to climate change. There is different type of threats governed by the climate change, among them temperature, CO2, rainfall affect directly to the plant growth and indirectly by land availability, irrigation, weed growth, pest and diseases outbreak etc. The climatic potential yield, which depends mainly on the climatic condition get reduced due to the vagaries of the threats. Since 1970 the global average temperature has been rising at a rate of 1.7°C per century (Marcott et al., 2013). High temperature will tend to reduce quality and yield of crops, it also encourages the weed and pest proliferation.

In general, the temperate regions appear to be less vulnerable to climate change than the tropical regions due to the fact that higher temperatures in temperate areas shift biological process rates toward optima, and beneficial effects are likely to ensure (Rosenzweig, C., et all.1992).

Increases in temperature will also extend the frost-free season in temperate regions, allowing for longer duration crop varieties to be grown and offering the possibility of growing successive crops.

In tropical locations where increased temperatures may move beyond optima, negative consequences may dominate over benefits. A 1°c increase in mean temperature resulted in considerable decrease in grain yield of C3 plant like rice by 6% (Saseendran., 2000) and in wheat, soybean, mustard, groundnut, potato by 3 to 7 % (Dagar et all., 2012).

In north-western India specially in wheat every 1°c increase in temperature reduce yield by 4 Mt (Reddy, 2019). But in elevated CO2 Level, C3 plant get benefited more than C4 plant due to the fact that C4 plant close their stomata early then C3 as C4 plant have less CO2 compensation point (0-10 ppm) and high PEP carboxylase activity thus reduce the transpiration and induce the leaf temperature lead to temperature stress within leaf level. Increase in CO2 to 550 ppm increase the yield C3 plants like rice, wheat, legumes, and oil seed by 10-20% (Venkateswarlu, 2014).

The combined effect of temperature and CO2 is complex but the negative effect of temperature is more prominent over positive effect of CO2, as high temperature induce respiration, mineralization, reduce nutrient use efficiency, net assimilation in crop. Due to terminal heat stress, plant lead to forced maturity thus reduction in crop yield.

In general, vegetative growth is positively co-related with elevated CO2 level but the reproductive stage of the crop is more linked with an optimum temperature, thus the economic yield reduced with increasing in temperature as it not gets the particular temperature at the critical stages and increased vegetative growth resulted by elevated CO2 use the all-residual soil moisture quickly so reproductive stages faces two stresses i.e., temperature and water as well. Change in precipitation pattern increase the Probability of short-run crop failures and long-run production letdowns.

Erratic rainfall with high CV% lead to erosion loss and waterlogged situation. A trend of increasing monsoon seasonal rainfall has been found along west coast, norther Andhra Pradesh, and north-western India (+10 to +12% over the last 100 years) while a trend of decreasing monsoon seasonal rainfall has been observed over eastern, north-eastern India and some Gujrat and Kerala (-6 to -7% over the last 100 years) (Reddy., 2019).

Changes in precipitation pattern alter the interaction between insect-pest and their host crop, changes in the pattern of rainfall will cause the alteration of water availability, which ultimately lead to weed shift thus application rate of agricultural chemicals increased copiously lead to environmental pollution. Farmers always prefer a production system with less variation in yield over the year but increased drought and flood are likely to increase production variability.

Drought reduce the quality of forage available for grazing livestock. Increased temperature in sea and river temperature are likely to affect fish breeding and migration. Increasing acidity of world's ocean, could harm shellfish by weakening their shell which is made up of Ca.

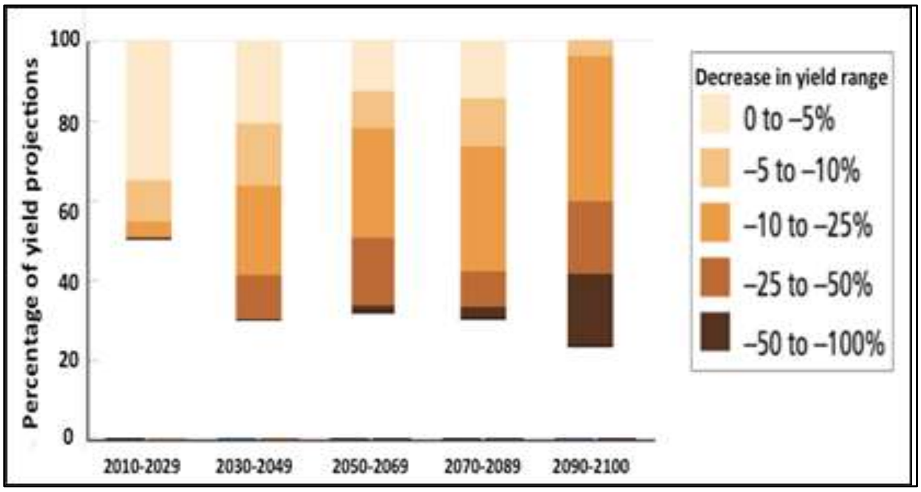


Figure 1.1: Studies show that a decrease in crop yield under global climate change (Source; Climate change and food Security IPCC 2014 5th assessment)

1.4 The Probable Impacts of Climate Change on Various Sectors of Indian Agriculture Are:

1.4.1 Effects on Crops:

A. Increase in ambient CO_2 is beneficial since this leads to increased photosynthesis in several crops, especially crops with C_3 mechanism of photosynthesis such as wheat and rice, and decreased evaporative losses. Despite this, the yields of major cereals crop especially like Wheat is likely to be reduced due to decrease in crop growth duration, increased respiration, and /or reduction in rainfall/irrigation water supplies due to rise in atmospheric temperature.
B. Enhanced frequency and duration of extreme weather events such as flood, drought, cyclone and heat wave; that adversely affect agricultural productivity.
C. Reduction in yield in the rained areas due to increased crop water demand and changes in rainfall pattern during monsoon.
D. Declined quality of fruits, vegetables, tea, coffee, aromatic, and medicinal plants.
E. Alteration of agricultural pests and diseases because of more pathogen and vector development, rapid pathogen transmission and increased host susceptibility.
F. Threatened agricultural biodiversity by rainfall uncertainty and temperature increase, sea level rise, and increased frequency and severity of drought, cyclones and floods.
G. Contrary to all the above negative impacts, predictions have been made for decreased cold waves and frost events in future due to the atmospheric temperature rise, which would lead to a decreased probability of yield loss associated with frost damage in northern India in crops such as mustard and vegetables.

The major effect on crop is due to shortening of crop duration which is related to the thermal environment. Increase in temperature will hasten crop maturity. In annual crops, the shortening of crop duration may vary from 2-3 weeks, thus, adversely impacting productivity.

Another direct effect in crops such as rice, wheat, sunflower etc., is on reproduction, pollination and fertilization processes, which are highly sensitive to temperature. The indirect influences operate through changes in water availability due to inadequate or excess rainfall and effect of increase in temperatures on pest and disease incidence.

Modelling studies have indicated that changing climate will decrease yields in major crops like wheat, rice and maize. On the other hand, the impacts could be neutral to positive in groundnut, soybean and chickpea.

1.4.2 Effects on Water:

A. Increased irrigation demands with increased temperature and higher evapo-transpiration. This may also result in lowering groundwater table at some places.
B. Melting of glaciers in the Himalayas may lead to increased water availability in the Ganges, Brahmaputra and their tributaries in the short run but in the long run the availability of water would decrease considerably.
C. A significant increase in runoff is projected in the wet season that may lead to increase in frequency and duration of floods and also soil erosion. However, the excess water can be harvested for future use by expanding storage infrastructure. The water balance in different parts of India is predicted to be disturbed and the quality of groundwater along the coastal track will be more affected due to intrusion of sea waters.

1.4.3 Effects on Soil:

A. Reduced quantity and quality of organic matter content, which is already quite low in Indian soil.
B. Under elevated CO2 concentration, crop residues have higher C: N ratio, which may reduce their rate of decomposition and nutrient supply.
C. Increase of soil temperature will increase N mineralization but its availability may decrease due to increased gaseous losses through processes such as volatilization and denitrification.
D. Change in rainfall volume and frequency and wind intensity may alter the severity, frequency and extent of soil erosion.
E. Rise in sea level may lead to saltwater ingression in the coastal lands turning them less suitable for conventional agriculture.

1.4.4 Effects on Livestock:

A. Climate change has pronounced effect on feed production and nutrition of livestock. Increased temperature results in enhanced lignification of plant tissues and reduced digestibility. Increased water scarcity would also decrease food and fodder production.

B. In cooler areas, climate change has major impacts on vector-borne diseases of livestock by the expansion of vector populations. Changes in rainfall pattern may also influence expansion of vectors during wetter years, leading to large outbreaks of disease.
C. Global warming would increase water, shelter and energy requirement of livestock for meeting projected milk demands.
D. Climate change is likely to aggravate the heat stress in dairy animals, adversely affecting their reproductive performance.

1.4.5 Effects on Fisheries:

A. Increasing sea and river water temperature is likely to affect fish breeding, migration and harvests.
B. Impacts of increased temperature and tropical cyclonic activity would affect the capture, production and marketing costs of the marine fish.
C. Coral bleaching is likely to increase due to higher sea surface temperature.

1.5 Climate Resilient Agriculture Working:

Climate-resilient agriculture (CRA) is an approach that includes sustainability with existing natural resources through crop and livestock production systems to achieve long-term higher productivity and farm incomes under climate variabilities, it differs from climate smart agriculture (CSA) that, climate smart agriculture (CSA) is too advanced and smart that it doesn’t allow any adverse situation of climate change over ecology as well as productivity, but climate resilient agriculture (CRA) is an inbuilt mechanism of the system to recognition the threats that need to be responded to, with effectiveness.

Climate smart means anything which is planned effectively in advance to encounter vagaries of climate change so that its effect may be minimized. This may involve avoiding stress or tolerating stress with any set of procedures. However, climate resilient is something which is capable of tolerating the stress arising out of a set of conditions.

1.5.1 Climate-Resilient Agriculture (CRA) Include 3 Phases:

A. Recognition Phase:

“System recognize its adverse threats quickly”. Such threats include event such as erratic rainfall, cyclone, drought, flood, heat or cold wave, long dry spell, frost, insect and pest outbreaks and other threats caused by climate change.it is also known as initial phase of CRA.

B. Curing Phase:

“System cure itself through different adaptive and mitigative mechanisms”. Such mechanism includes conservation agriculture, cover crops, integrated farming system, carbon sequestration, direct seeded rice, precision farming, and site specific nutrient management. It is the intermediate phase of CRA.

C. Sustaining Phase:

"System should sustain their adaptive mechanisms over a long time". CRA with these mechanisms building itself in such a way that it can break through any hurdle that would come its way. It is the final phase of CRA.

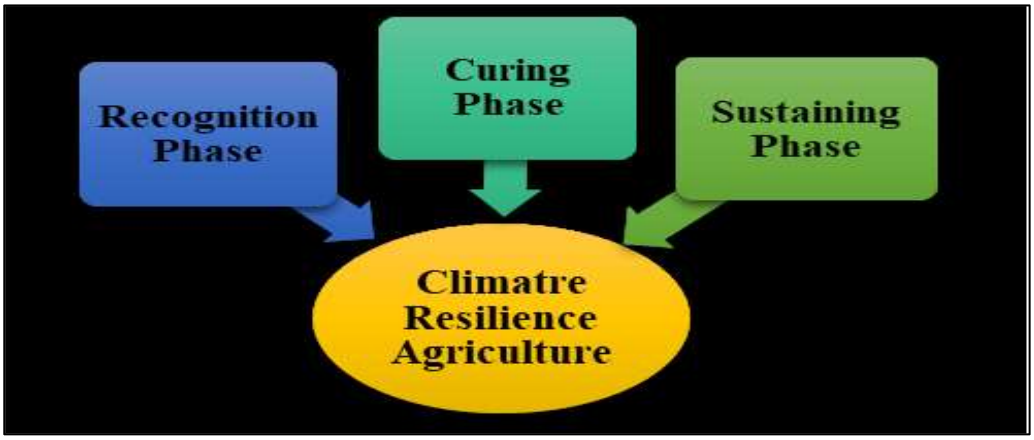


Figure 1.2: Recognition Phase, Curing Phase, Sustaining Phase, act together to bring the climate resilient agriculture

1.6 Recognition of Threats in Agriculture:

In recognition phase, system (i.e., agricultural system) recognize its threats, but now as rapidity of climate change is increased so human intervention is required for recognition of threats. Threats can be 2 types, i.e., long term threats and short-term threats. Long-term threats include ground water depletion, crop burning, pattern change in rainfall, soil organic carbon degradation, atmosphere and groundwater pollution, urbanization, industrialization, etc.

Short-term threats include flood, drought (early-season, mid-season and terminal drought), frost, heat/cold wave, cyclone, hail-storm, insect pest attack etc. Scientist community play an important role in detection of long-term threats by their extensive research, it is now possible to figure out the long-term threats. Here for the first time, ground water depletion was reported in regional-scale basis through long-term study (1996–2014, using more than 19000 observation locations) in situ and decadal (2003–2014) satellite-based groundwater storage measurements in western and southern parts of India (Bhanja, S. N et al, 2017). Extension workers creates awareness to these threats to the farmers. Over the time being the short-term threats create problems which is resultant of the long-term threats, is more devastating and erratic in nature. If we aware with these long-term threats and act accordingly then the vulnerable effect of short-term threats is not being there. Recognition of long-term threats act like a prevention mechanism, and always prevention is better than cure. For short-term threats weather forecasting play a significant role. Medium range weather forecast is for a period of 3 to 4 days to two weeks, which is more significant in relation to agricultural purpose.

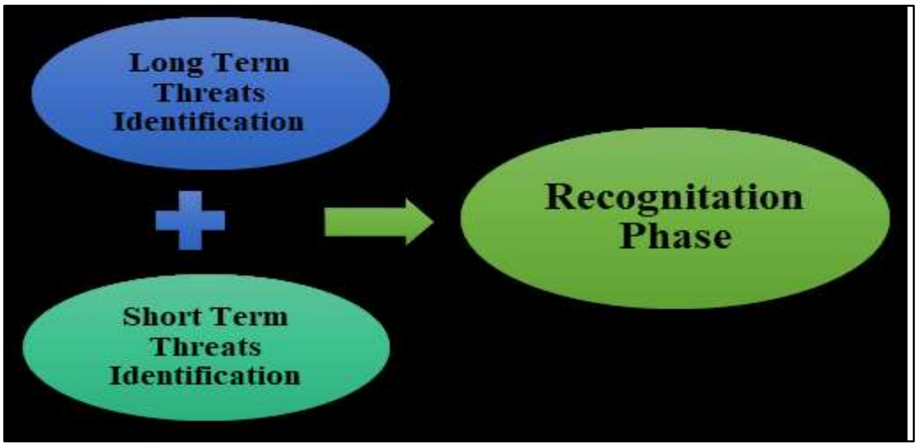


Figure 1.3: Both long- and short-term threats identification help to CRA

1.7 Curing of the Threats to Reduce the Effect of Climate Change:

Adaptation and mitigation are two important strategies to bring resilience to the effect of climate change. Adaptation is referring to "adjustment in ecological, social, or economic system in response to actual or expected stimuli and their effects or impact. The term refers to change in process practice and structure to moderate potential damages or to benefit from opportunities associated with climate change" (IPCC. 2001). Mitigation means using new technologies and renewable energies to making older equipment more energy efficient or changing management practices or consumer behavior (Chary et al., 2008). Mitigation mainly focused in the use efficiency of that system to reduce the greenhouse gas effect. By reducing GHG emission and enhancing removals from atmosphere increase the efficiency of mitigation of climate change.

1.7.1 Improved techniques for adaptation to climate change:

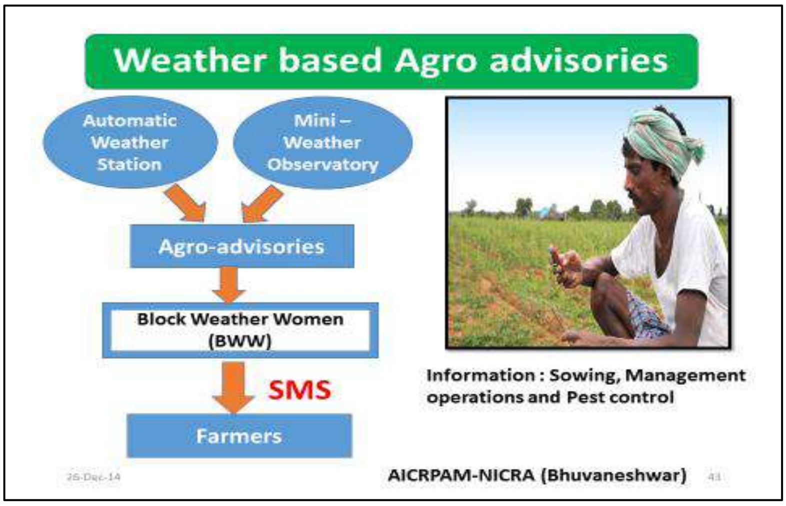
Adverse effect of climate change can be reduced by implanting program like weather based agro-advisories, crop and variety selection, efficient cropping system, water harvesting for conserving water resources, Custom hiring of farm machineries, contingency planning etc.

A. Weather Based Agro-Advisories:

Programmed weather stations at KVK and mini-weather observatories in village level are established to record real time weather parameters such as rainfall, temperature, relative humidity and wind speed etc. And to increase the customized agro-advisories and improve weather literacy among farmers. The agro advisory based on this is then presented in respective languages in the form of a wallpaper at public places such as Panchayat Buildings or Schools or any favorable place from where all farmers get information. Mobile phones are being used to give the personal message to the farmer for short coming weather condition and it is now ever-increasing appeal to rural users. Weather based agro advisory helps to the farmer to act accordingly, thus the upcoming ill-effect of the weather can be reduced in farmer's level.

B. Smart Crop and Variety Selection:

Selection of a climate-smart crop variety is the best adaptation option, crop which have more sowing windows can be sown in broad sowing dates. Different weather calamities like heat/cold wave, flood, cyclone, frost, hail storm, reduce the potential climatic yield of a particular zone. So based on the weather forecasting and long-term research data, we have to select a crop which is suitable for this particular region. Sometime reallocation of crop in alternatives areas can also be a great option against climate change, for example in basmati rice, tea, coffee, are sensitive to temperature increases as temperature reduce the quality, so alternative areas that become suitable for this crop from quality point of view need to be allocated. In rice-wheat cropping system introduction of a short duration summer legume like moong bean as break crop or catch crop after wheat harvesting maintain the soil quality as well as it adds some organic matter and reduce the N_20 emission from the field as the residual nitrogen can be used by mungbean after wheat.



Weather based Agro advisories

Automatic Weather Station

Mini – Weather Observatory

Agro-advisories

Block Weather Women (BWW)

SMS

Farmers

Information : Sowing, Management operations and Pest control

26-Dec-14

AICRPAM-NICRA (Bhuvaneshwar)

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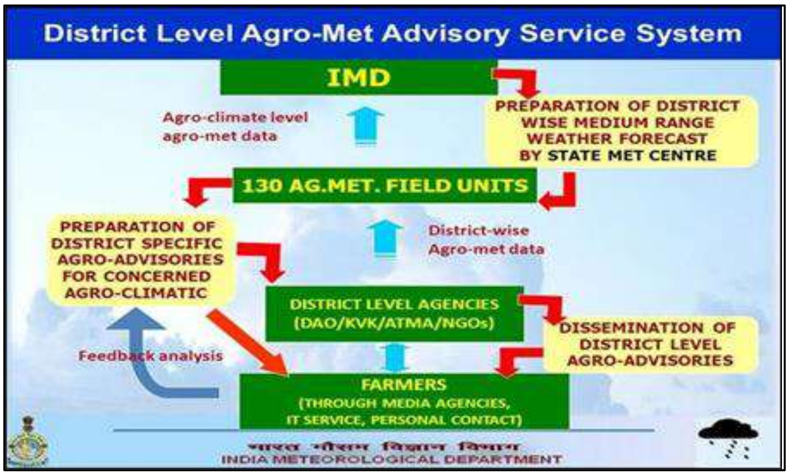

District Level Agro-Met Advisory Service System

IMD

Agro-climate level agro-met data

PREPARATION OF DISTRICT WISE MEDIUM RANGE WEATHER FORECAST BY STATE MET CENTRE

130 AG.MET. FIELD UNITS

PREPARATION OF DISTRICT SPECIFIC AGRO-ADVISORIES FOR CONCERNED AGRO-CLIMATIC

District-wise Agro-met data

DISTRICT LEVEL AGENCIES (DAO/KVK/ATMA/NGOs)

DISSEMINATION OF DISTRICT LEVEL AGRO-ADVISORIES

Feedback analysis

FARMERS (THROUGH MEDIA AGENCIES, IT SERVICE, PERSONAL CONTACT)

भारत मौसम विज्ञान विभाग

INDIA METEOROLOGICAL DEPARTMENT

Figure 1.4: Flow Chart of Agromet Advisory (Source: IMD)

C. Efficient Climate-Based Cropping System:

Efficient cropping system means a location specific cropping system which can fulfil the market demand, soil health, consumer choice, as well as control weed and minimize the pest outbreaks. Mixed cropping, intercropping, relay cropping reduces the climatic vulnerabilities. Farmers can get at least one crop if any adverse situation is there. Pigeon pea either as a base crop or inter crop performed better, particularly in the sorghum, cotton, pearl millet-based cropping system (AICPRDA, 2013). Inclusion of a legume in cropping system add sustainability to this system through soil cover, addition of biological nitrogen. Cultivating of a legume, usually after the principal cereals crop, is a well-known strategy under rainfed agriculture. An efficient cropping system always meet the climatic requirement based on the particular region.

Table 1.1: Potential Cropping Systems in Relation to Rain Fall and Soil Type in India

Rainfall (Mm)	Soil Type	Effective Growing Season (Week)	Suggested Cropping Systems
350-650	Alfisols and shallow vertisols	20	Single rainy season cropping
350-600	Deep aridisols and Entisols	20	Single cropping either in *kharif* and *rabi*
350-600	Deep Entisols	20	Single post rainy season cropping
600-750	Alfisols, Vertisols, and Entisols	20 -30	Intercropping
750-900	Entisols, Deep Vertisols, Deep Alfisols, and Inceptisols.	30	Double cropping with monitoring
More than 900	Entisols, Deep Vertisols, Deep Alfisols and inceptisols	More than 30	Double cropping assured.

D. Water Harvesting:

According to World Bank, India with the geographical area of 3.29-million-km2, supports more than 18% of world’s population but has only 4.2% of fresh water resource. Climate change shall have implication on water resources and agriculture. An increase in temperature will increased demand for water for evapotranspiration by crops and natural vegetation and will lead to more rapid depletion of soil moisture. According to one projection, a rise in 1°c will increase the crop water demand by 2%. Climate change significantly affect sea level with potential impacts on the salinity of the surface and groundwater in coastal areas.

The rising levels of CO_2 concentration, warmer atmosphere and more intense precipitation may have significant effects on the hydrological and Regional Water source availability. Cyclone which is now more often, created by oceanic temperature rising above 26.5°c lead to devastating loss in the coastal areas.

Increased precipitation induces run off, whereas increase in temperature may enhance the evapotranspiration demand So, water harvesting shall be a boon for the resource saving adaptation programme in water management.

During the rainy season in dry and dry land farming areas, a rain harvesting system (water tank, dug well, percolation tank, farm pond) is used to catch and collect rainwater. The rain harvesting system reducing the electricity that would otherwise be needed for pumping in lift irrigation. This water is then available for people to use and consume during the dry season when there is a shortage of clean water.

Likewise, micro-catchments (around 1000 sq. m), small farm reservoirs (1000 to 500,000 cu.m), rooftop systems, water spreaders, inter row harvesting, runoff farming On-farm systems (Contour ridges, Semi-circular and trapezoidal bunds, small pits, small runoff basins, run-off strips, macro-catchments and flood water system, may reduce the water stress to the crop. 1-2 supplemental irrigations from this water harvesting structures sometime give reasonable yield to the growers.

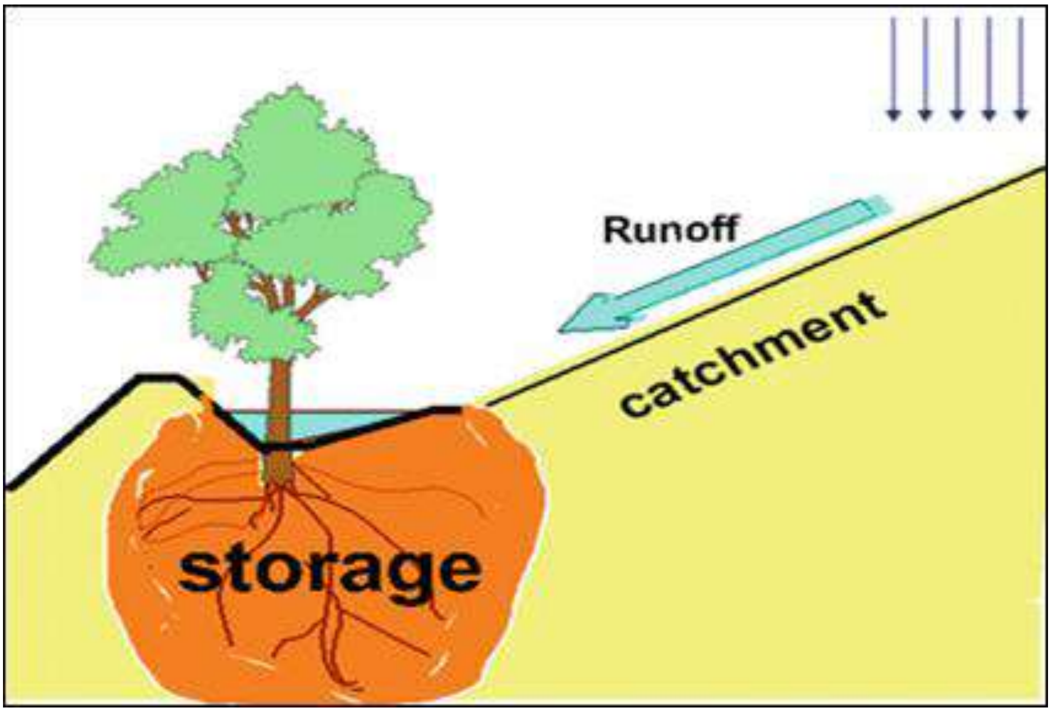

Figure 1.5: Collection, Accumulation, Or Storing of Storm Water for Its Eventual Reuse

E. Balanced Fertilization:

Balanced Fertilization is the proper supply of all nutrients (macros and micros) throughout the growth of a crop for optimum growth, yield and quality. Applying of fertilizer in optimum ratio and adequate amounts is called "Balanced Fertilization". Nitrogen is required for protein synthesis, for this plant required optimum amount of energy and enzyme which is provided through phosphorus and potassium. So, application in balanced amount reduce the losses of nutrient from the system. Balanced fertilization provides optimum plant growth, with highly efficient nutrient use, thus less adverse effect on environment. Balanced fertilization reduces the N_2O-N emission by controlled use of nitrogen fertilizer.

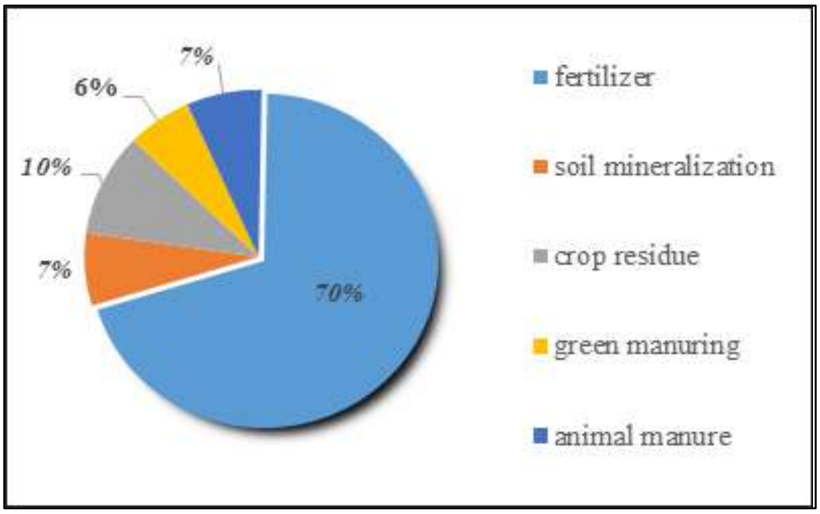

Figure 1.6: Emission of N_20 - N from different sources of agriculture soil (Pathak et al. 2010)

F. Custom Hiring of Farm Machineries:

In a village level, land fragmentation is great problem, so community nurseries, community farm machinery hiring reduce environmental pressure due to reduced use for cultivation practices. The Community managed custom hiring centers are setup in each village to access farm machinery for timely sowing/planting. This is an important intervening to contract with variable climate like delay in monsoon, inadequate rains needing replanting of crops.

G. Contingency Planning:

Contingency crop planning for reverent rainfall refers to planning for alternate, crop and cultivator to suite the resource endowments of rainfall and soil in a given location (Reddy, 2019). In rain fed areas as a general rule, early showing of crop with the onset of monsoon is the best-bet practises for obtaining maximum yield. Generally resowing, thinning the crop, removing the alternate crop, dead furrow, 2% urea or KNO_3 or DAP application, growing storm resisting crop (e.g., ginger, pineapple etc.) are some promising contingency cultivation practices to combat the climate change.

1.7.2 Improved Techniques to Mitigate Climate Change:

Mitigation process acts from the base, its effort to reduce or prevent the emission of greenhouse gas which is the main culprit. The adverse impact of climate change can be mitigated by reduction of food losses and waste, improved crop management practices, recarbonization of soil, No-Till farming, site specific nutrient management, integrated farming system etc.

A. Reduction of Food Losses and Waste:

In 2011, FAO presented the estimate that around 1/3 of the world's food was lost or wasted every year. We generally concerned about how to increase the food production, but if we reduce the food losses then it improves efficiency in the use of resources as less pressure of food production on farmer, and food production industries. In the home, one of the best ways to reduce food waste is to plan meals ahead, rotate time-sensitive foods in the fridge and cupboards and freeze surplus garden vegetables. Process or dehydrate surplus or damaged fruit, produce and meats. Compost kitchen waste which is at least increase the soil health.

B. Improved Crop Management Practices:

Carefully managed crop land offers many opportunities to induce the sustainability in crop production. In India rice majorly grown as a transplanted, which not only harm the groundwater resources but also possess some sentimental related problem also. Intermittent irrigation reduces the CH4 production by 40%, but increase the N20-N emission by 6% due to more water filled pore space, low bulk density in surface reduces the diffusion of O2 into the soil, however the total carbon flux is reduced by this process. In rice CH4 emission peak in the tillering to reproductive stage and in this stage 90% of the CH4 passes through the aerenchyma tissue. To reduce this CH4 production from rice field our system has to be resilient one like direct seeded rice (DSR), alternate wetting and drying (AWD). DSR and AWD reduce the CH4 emission about 80-90% and 30-40% respectively (Bhatia et al., 2010).

Along with this DSR reduce 30-40% water with an advantage of early sowing.

C. Re-carbonization of Soils:

Soil organic carbon management is the key for achieving the soil resilience to climate change. Increasing soil carbon storage can increase infiltration, increase fertility and nutrient cycling, decrease wind and water erosion, minimize compaction, enhance water quality, and generally enhance environmental quality. Enhancing the carbon sequestration through best management practices (BMPs) like residue management, eliminating fallow period by permanent plant cover in soil, diversified crop rotation with legume, agroforestry etc. Retention of crop residue without burning lead to add some carbon to the soil, 1 tonne of rice residue burning emit 1515 kg CO2, 0.4kg SO2, 2.5kg CH4, 92kg CO, 3.83 kg NOX and non-methane volatile organic compound (Andreae and Merlet., 2001) which can increase the vagaries of the climate change.

For retention of CO2 in the soil, ratio of C: N is so much important so the N source from the legume play an important role to control the C-sequestration. Agroforestry is a great option for recarbonization through global carbon sequestration generally involved in carbon capture and the long-term storage of atmospheric carbon dioxide. In agroforestry system the carbon stored in soil ranges from 30 to 300 Mg C/ha up to 1m (Nair et al., 2010).

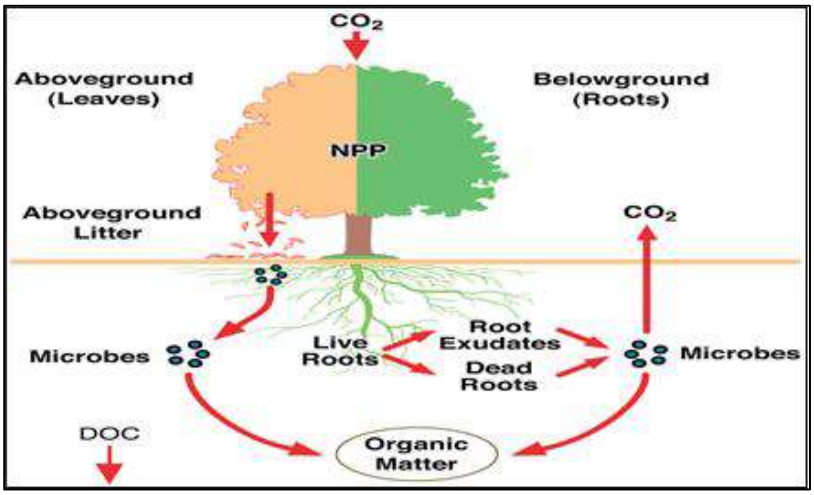

Figure 1.7: Forest Carbon Sequestration

D. No-Till System:

Soil tillage practices have a profound influence on the physical properties of soil and the greenhouse gas (GHG) balance. By not tilling their fields, farmers can save labour and fuel costs, reduce soil erosion and preserve precious nutrients. No-till also increases the accumulation of soil organic carbon, thereby resulting in sequestration of atmospheric carbon dioxide. It has been recorded that a significantly higher net global warming potential under conventional tillage systems which is 6–31% higher than zero tillage systems (Mangalassery, et al, 2014). According to the environmental protection agency, 2009, in no-till system we can save 35 liters for land preparation, one-liter diesel contains 0.74 kg C and emit 2.67 kg, so through this no-till system, global worming potential of a particular system can be reduced.

E. Site Specific Nutrient Management:

Agriculture contributes 70-90% of nitrous oxide (N_2O) emissions, mostly from N fertilizer (cgiar.org). Site Specific Nutrient Management (SSNM) is an approach of supplying plants with nutrients to optimally match their inherent spatial and temporal needs for supplemental nutrients by using of SSNM through right amount, right source, and right rate of application, right time, and right method. It is a dynamics system by which we can optimise the production. SSNM should be prescriptive type and corrective type. In prescriptive type we add nutrient through soil test, crop, and climate basis. And in curative type, means on field management, some of the examples are chlorophyll meter (SPAD meter), leaf colour chart (LCC), Nutrient expert.

Though SSNM approach does not specifically aim to either reduce or increase fertilizer use, it aims at applying nutrients at optimal rate and times to achieve the high nutrient use efficiency, yield as well as low cost and also low environmental pressure. Efficient N management can help in adaptation and mitigation while reducing other environmental threats such as eutrophication, acidification, air quality and human health. SSNM reduces N2O emissions by reducing total N application and/or timing applications to crop needs, thus avoiding N losses to volatilization, leaching and runoff.

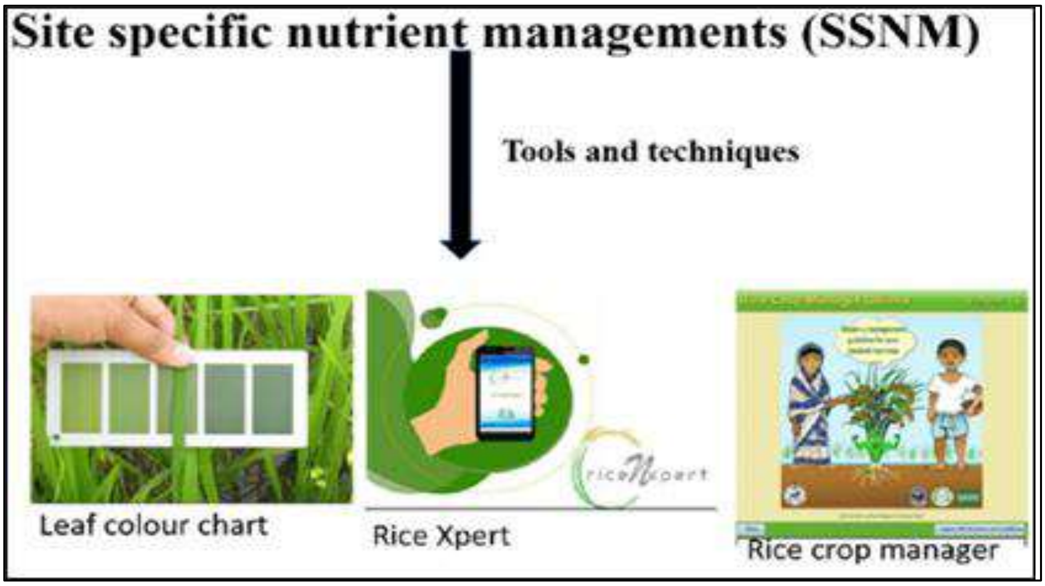

Figure 1.8: Some Prominent SSNM Tools for CRA

F. Integrated Farming System (Ifs):

Integrated farming has enormous potential to make farmers climate resilient through the cultivation of different crops on the same land and using farm resources sustainably. IFS is often less risky, because it managed the farm more efficiently, thus reduce the dependence of output. IFS benefited by the synergisms among enterprise, and it is environmentally sound. Intermittent use of farm produces proper recycling on by-products, crop residue, weed, an all-other farm waste combined with Conservation of farm resource have been found to reduce chemical load in the form of inorganic fertiliser by 36% (Gangwar et al., 2014).

G. National Programmes to Mitigate Climate Change:

The National Mission of Sustainable Agriculture was implemented in 2010 under the National Action Plan on Climate Change (NAPCC) to promote the effective utilization of existing resources and this was one of the eight missions under NAPCC. In 2015 the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) was launched to address the issues of water resources and provide a permanent solution that envisages Per Drop More Crop by promoting micro / drip irrigation for the conservation of maximum water.

GREEN INDIA Mission was launched by the GOI in 2014 under the umbrella of NAPCC with the primary objective of protecting, restoring and enhancing India's diminishing forest covers, thereby reducing the deleterious effects of climate change. Additionally, Neem-Coated Urea was also introduced to minimise the excess addition of urea fertilizers, thereby protecting soil health and supplying plant nitrogen.

1.8 Sustaining or Maintaining the Measures to Reduce the Effect of Climate Change:

Effect of climate change is very much frequent, to combat this situation CRA should always be prepared with their best adaptive and mitigative mechanisms. Climate resilient agriculture not only to be implemented, it should be sustained or maintained over the time being through different village level awareness programme. Government plays an important through different schemes, subsidies. Technology demonstrations under the National Initiative on Climate Resilient Agriculture are currently in operation in 100 vulnerable districts identified based on their exposure to repeated climatic vulnerability.

The goal of technology demonstration component under NICRA is to mainstream some of the successful practices and technologies that promote resilience to climate risk under the National Mission on Sustainable Agriculture (NMSA), other National Missions and on-going government schemes such as Rashtriya Krishi Vikas Yojana (RKVY), Mahatma Gandhi National Rural Employment Guarantee Programme (MGNREGP) and National Food Security Mission (NFSM).

The aim is to up-scale the proven practices in all the vulnerable districts in the country by the end of XII five-year plan to make Indian agriculture more resilient to climate variability.

1.9 Conclusion:

Enhancing the resilience of Indian agriculture to cope with climatic variability and climate change is boon for the livelihood security of millions of small and marginal farmers in the country. Climate-resilient agriculture (CRA) achieve long-term higher productivity and farm incomes under different climate variabilities through improved crop and livestock management. It is a way for farmers to cope with the climate change, but despite the superficial benefits, rates of adoption by smallholder farmers are highly variable, if government and other responsible organizations step forward to encourage the practice of CRA then it is easier to reduce the effect of climate change.

Climate change and climatic variability are likely to affect sustainability of agricultural production thereby affecting national food security. Adoption of climate resilient technologies can help in coping up with the challenge of climate change. Some climate resilient technologies like growing changes in crop management practices, adoption of water management technologies, increasing nutrient-use efficiency, development of improved farm machineries and adoption of resource conserving technologies and better pest management, access to weather forecasts, introduction of crop insurance products can help in agricultural adaptation to the changing climate.

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2. Conservation Agriculture and Carbon Sequestration

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Abstract:

In order to increase productivity, technologies use, crop rotations, minimal soil disturbance, and cover crops or crop residue to provide permanent soil cover. Although there are various obstacles that prevent CA from being widely adopted, efforts to develop, improve, and disseminate conservation-based agricultural technology have been ongoing in India for about 20 years and have achieved significant progress since then.

Much work has been done, in particular, on no-till wheat in the Indo-Gangetic plains, where there is a rice-wheat rotation. Through the use of CA technology, it is possible to lower production costs, conserve water and nutrients, boost yields, diversify crops, optimize resource utilization, and protect the environment. However, there are still barriers to the promotion of CA technologies. These include the lack of suitable seeders, particularly for small and medium-sized farmers, the conflict between CA use and livestock feeding over crop residues, the burning of crop residues, the lack of skilled and scientific labour, and the need to change people's perceptions about tillage. When managed properly, soils have the capacity to absorb carbon from the atmosphere. Recent reports from the Intergovernmental Panel on Climate Change (IPCC 2019) indicate that even if significant cuts in human-caused carbon emissions are made in the near future, efforts to sequester previously emitted carbon will still be required to maintain safe levels of atmospheric carbon and to reduce climate change. (Smith et al. 2014).

By boosting soil carbon inputs and strengthening key soil mechanisms that guard carbon against microbial turnover, a number of agricultural management methods appear to store soil carbon.Other advantages of raising soil carbon include enhancements to soil fertility, structure, and water-holding capacity, which outweigh any potential drawbacks. We will go over the fundamentals of soil carbon, how it may be sequestered, promising management approaches, and the controversy around the idea that agricultural soils could act as a wedge for climatic stability.

Keywords:

Conservation agriculture, Conventional agriculture, Constraints, Resource use efficiency, Zero tillage, tillage, climate, carbon sequestration, soil carbon.

2.1 Introduction:

A farming method that keeps crop residue on the soil's surface while requiring the least amount of soil tillage. With the retention of crop residue in the soil cover, minimal tillage, and no tillage, CA is a management strategy that helps to maintain a soil cover. Despite the fact that the phrase "conservation agriculture" was first used in the 1990s, the concept of minimizing soil disturbance dates back to the 1930s, during the Dust Bowl in the United States of America. In the 1970s, no-till training programmes and experiments were pioneered by CIMMYT in South American maize and wheat systems. In South Asian agronomy projects in the 1980s, this technique was also applied. In the 1990s and the early 2000s, CIMMYT started collaborating with conservation agriculture throughout Latin America, South Asia, and Africa. According to FAO 2012, the term "conservation agriculture" (CA) describes a set of soil management techniques that aim to minimize disruption of the natural biodiversity, composition, and structure of the soil. The state of California has the potential to increase crop yields while enhancing farming's long-term financial and environmental sustainability.

The rice-wheat-dominant region is surrounded by rice/sugarcane-wheat growing regions, western Uttar Pradesh and Haryana, where a large amount of rice and wheat crop residues are generated but their disposal is a problem due to a low population of dairy/draught animals. As a result, framers burn the crop residues in-situ to clear the fields and prepare them for the next crop, which causes a very serious problem with atmospheric pollution, especially Stress from heat and moisture are two more significant problems in crop production. As a result, conservation agriculture has a lot of potential in this strategically significant area.

2.2 Why We Need Conservation Agriculture?

There will be significant effects on natural resource bases, global climate change, and energy security for India, Asia, and the rest of the globe depending on how Asian nations choose to meet their food and energy needs over the coming decades. These difficulties highlight the urgent need for solutions to risks to Indian and Asian agriculture brought on by resource degradation, rising production costs, and climate change (Gupta and Jat 2010). No-till conservation agriculture is thought to be fundamentally important in addressing these issues. Asian farmers and academics will still require support as they refocus their agriculture and practices to produce more with fewer resources by adopting less vulnerable options and approaches (Pittelkow et al. 2014). Therefore, continuing with current practices in conventional agriculture does not appear to be a viable option for sustainable increases in the production of food-grains, and thus, in the majority of ecological and socioeconomic settings of Asian Agriculture, CA-based crop management solutions tailored to local needs will have to play a crucial role. The following opportunities exist for CA promotion in an Asian/Indian context:

A. **Lower production costs:** This is a significant component in the quick adoption of zero-till technologies. The majority of studies revealed that producing wheat costs Rs. 2,000 to 3,000 ($ 33 to $50) less per hectare. Savings on diesel, labour, and input expenses, particularly pesticides, are credited with the cost decrease (Malik *et al.*, 2005).

B. **Decreased occurrence of weeds:** When zero-tillage is used, which results in less pesticide use, most studies tend to show decreased occurrence of *Phalaris minor*, a significant weed in wheat.

C. **Nutrient and water savings:** Limited experimental findings and farmer experience suggest that zero-till planting, particularly in laser leveled and bed planted crops, can produce in significant fertiliser and water savings (up to 20 to 30%). According to De Vita *et al.*, (2007), lower water evaporation during the preceding time was suggested by the higher soil water content under no-till than under conventional tillage. Also, they discovered that throughout growing seasons, no-till had a 20% higher soil water content than conventional tillage.

D. **Increased yields**: Wheat yields were consistently higher in properly maintained zero-till planted fields than in traditionally prepared areas for comparable planting dates. Due to associated effects like the prevention of soil degradation, improved soil fertility, improved soil moisture regime (due to increased rain water infiltration, water holding capacity, and reduced evaporation loss), and the advantages of crop rotation, CA has been reported to increase the yield level of crops. In the Indo-Gangetic plains, no-till wheat yield increases of 200 to 500 kg ha^{-1} are observed when compared to conventional wheat in a rice–wheat system (Jat *et al.*, 2012).

E. **Environmental benefits**: Crop residue burning, which produces significant amounts of greenhouse gases including CO_2, CH_4, and N_2O, can be completely eliminated by conservation agricultural practices like zero-till and surface managed crop residue systems. Burning crop leftovers causes a significant loss of plant nutrients that, with good management, might be recycled. Burning crop leftovers on a large scale poses a severe health risk as well (Hobbs and Gupta, 2004).

F. **Crop diversification opportunities**: Conservation is adopted Crop diversification options are available in agricultural systems. Agro-forestry systems and crop rotations can improve natural ecological processes when used in the right geographical and temporal patterns.

G. **Resource improvement**: When no tillage is used in conjunction with surface management of crop residues, the gradual decomposition of residues starts a process that improves the structure of the soil and increases nutrient recycling and availability for plant growth. Remains on the earth's surface serve as mulch to lower soil temperatures, stop evaporation, and stimulate biological activity.

2.2.1 The Advantages of Conservation Agriculture (CA) Include:

- Maintaining permanent or semi-permanent soil cover
- Minimum soil disturbance
- Integrated disease and pest management
- Higher efficiency in the sense of more output for a lower input
- Regular crop rotation
- Improvement of air quality.
- Utilization of green manures/ cover crops

- Time saving and reduction in labour requirement
- Reduction of costs.
- Reduction in Green House Gas (GHG) emission and fuel uses
- No burning of crop residues
- Controlled/ limited human and mechanical
- Organic matter increase
- Carbon sequestration.
- In-soil water conservation
- Biodiversity increase.
- Improvement of soil structure
- Reduction in soil erosion.
- Improvement of water quality. (Behera et al. 2010)

2.3 Philosophy of Conservation Agriculture:

"*There is nothing wrong with our soils except our interference*". It can be said with considerable truth that the use of tillage actually destroyed the productivity of our soils (Abrol & Sangar 2006; Faulkner, 1942). Soil does not need tillage for effective crop production.

A. The Ca Philosophy Is Based on This:

- Crop residues are a very valuable part of farming system and must be retained in full and remain on the surface as a mulch.
- Permanent all year-round soil cover is essential.
- Control and promotion of natural biological soil process through rotation.
- Soil degradation and erosion is a symptom of an unsuitable farming system.

Table 2.1: Global scenario of Conservation Agriculture FAO (2019)

Country	**Area (Mha)**	**Share (%)**
USA	35.61	22.70
BRAZIL	31.81	22.30
ARGENTINA	29.18	18.60
CANADA	18.13	11.70
AUSTRALIA	17.70	11.30
CHINA	6.70	4.30
RUSSIAN FEDERATION	4.50	3.90
INDIA	3.50	2.90
PARAGUAY	2.00	1.30
KAZAKHSTAN	1.50	1.10
OTHERS	6.68	4.10
TOTAL	**156.99**	**100**

B. Principles of Conservation Agriculture:

Conservation agriculture is a method of managing agro-ecosystems that aims to increase and sustain production boost earnings, and ensure food security while protecting and enhancing the environment and the natural resource base (Behera *et al*., 2010; Lal, 2013). It depends on the practical application of three interconnected principles, as well as other pertinent good agricultural practices (GAPs) of crop production, and therefore needs to be handled carefully with regard to appropriate design, planning, and execution procedures. These three principles are

2.3.1 CA Is Based on Three Principles Applied Simultaneously (FAO, 2012):

A. Minimum mechanical soil disturbance: The word "minimal mechanical soil disturbance" refers to no-till, permanent low soil disturbance, no-till weeding, and no-till direct sowing. The main goal of soil biological processes is to create extremely stable soil aggregates and pores with a range of sizes that allow for proper air and water infiltration. The biological processes that shape the soil cease to exist when the soil is mechanically disturbed by tillage or other farming techniques. Maintaining the ideal composition of respiration gases in the root zone, moderate soil organic matter oxidation, sufficient porosity for soil water transport, retention, and release, and preventing the re-exposure and germination of weed seeds all depend on minimal soil disturbance (Kassam and Friedrich, 2009).

B. Permanent organic soil cover: In conservation agriculture, a permanent soil cover is essential to prevent the soil from suffering negative effects from exposure to rain and sunlight, to maintain a constant food supply for soil micro and macro organisms, and to alter the soil microclimate for the growth of soil organisms and plant roots. This enhances soil aggregation, soil biological activity, soil carbon sequestration, and soil biodiversity (Ghosh *et al*., 2010). With the help of biomass produced by crop waste, cover crops, and stubble, soil can be covered. According to FAO (2014), crop residues must cover at least 30% of the total area that is cultivated.

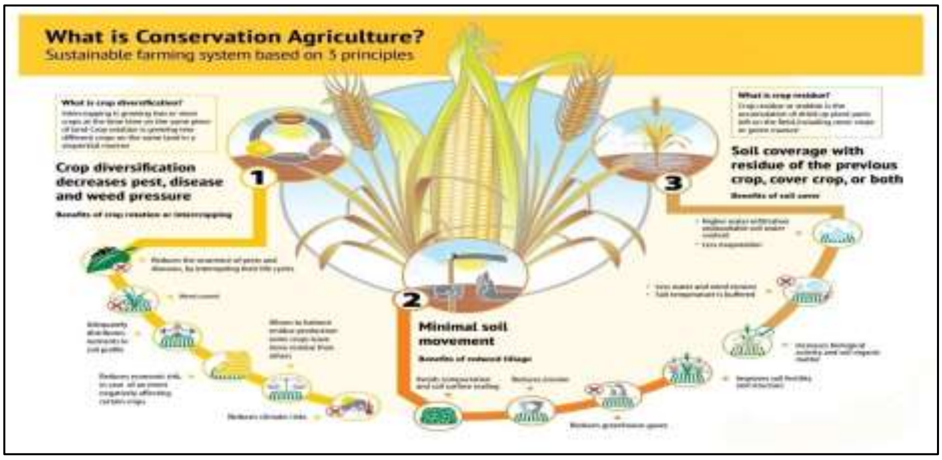

Figure 2.1: Conservation Agriculture

D. Diversified crop rotations:

The rotation of crops must be varied in order to feed the soil microorganisms and allow the crops to use the nutrients that have been leached into the various soil layers. To achieve this, alternate deep-rooted crops with shallow-rooted crops.

A variety of crops grown in succession also affect the flora and fauna of the soil negatively. Legumes play an important role in crop rotations because they help biological nitrogen fixation, disrupt the life cycles of pests to prevent pest infestations, and increase biodiversity (Kassam and Friedrich, 2009; Dumanski *et al*., 2006).

2.4 Conservation Agriculture Practices Includes:

A. Conservation Tillage
B. Mulching
C. Crop Residues Management
D. Crop Rotation

2.4.1 Conservation Tillage:

A technique for growing crops that uses other methods, like crop rotation and reintroducing organic matter to the soil, while minimizing mechanical disturbance to the soil. "Any tillage or planting system in which at least 30% of the soil surface is covered by plant residues after planting to decrease erosion" is the definition of conservation tillage (Sangar *et al.* 2005).

A. The Systems Listed Below Can Be Used with Conservation Tillage:

- Strip tillage or zonal tillage
- Tined tillage or vertical tillage
- Ridge tillage

B. Type of Conservation Tillage System:

Zero tillage:

For pasture renovation, this method was initially used in the USA in 1950. The father of zero tillage is regarded as G.B. Triplet. An extreme form of minimum tillage is zero tillage. Secondary tillage is restricted to seedbed preparation in the row zone while primary tillage is completely avoided. In this system 50 to 100 % residue remaining in the field.

Due to its numerous advantages, zero tillage farming, commonly referred to as no till farming, and is getting popular among farmers in the United States and around the world. Approximately 47% of zero tillage Technology practice in South America, 39% in USA and Canada, 9% in Australia, 3.9% Europe, Africa and Asia (Gathala *et al.* 2011; Derpsch *et al.* 2010).

Figure 2.2: Type of Conservation Tillage System

Table 2.2: Advantages and disadvantages of Zero Tillage

Advantages	**Disadvantages**
Surface runoff is reducing due to presence of mulch.	Initial investment for zero-tillage machinery (the upfront costs can be high, but they should be recouped through higher crop yield and fuel and labour savings).
Organic matter content increases due to less mineralization.	Seedling establishment in zero tillage is 20% less than conventional method.
Less soil erosion from wind and water.	Higher dose of Nitrogen has to be applied due to slow mineralization of organic matter.
Less soil compaction.	Large population of population of perennial weed appear in zero tillage plots.
More fertile and resilient soils	Higher numbers of volunteer plants build up.

Advantages	Disadvantages
Less moisture evaporation.	Increased use of herbicides.

C. Minimum tillage: This idea was developed in the USA in 1974 as a result of the high cost of tillage brought on by sharp increases in oil prices. Like strip-till, minimum tillage is soil conservation technique that aims to manipulate the soil as minimum as possible while still producing a good crop. It is a form of tillage that does not disturb the soil, as opposed to intense tillage, which uses a plough to alter the soil's structure. Primary tillage is entirely avoided with minimum tillage, and only minor amounts of secondary tillage are used. The term "minimal tillage" refers to techniques like minimal furrowing, the use of organic fertilizer, the use of biological pest management methods, and the minimal use of pesticides (Sharma *et al.* 2012).

D. Tillage Can Be Reduced in Two Ways:

- By omitting operation which do not give much benefit when compared to the cost.
- By combining agricultural operations like seeding and fertilizer application.

Table 2.3: Advantages of Minimum Tillage

Advantages	Disadvantages
Improved soil conditions due to decomposition of plant residues *in situ.*	Seed germination is lower with minimum tillage.
More infiltration brought on by plants on the soil and channels created by dead root decay.	More nitrogen must be provided in minimum tillage because organic matter decomposition proceeds slowly.
A better structure results in fewer barriers to root growth.	Nodulation is affected in some leguminous crops like peas and broad beans.
Reduced soil erosion and less soil compaction compared to conventional tillage due to the decreased movement of large tillage vehicles	Sowing operations are difficult with ordinary equipment.

E. Different Methods of Minimum Tillage Practiced:

Row Zone Tillage: After first tillage with a mould board plough, disking and harrowing procedures are minimized. Only in the row zone is secondary tillage carried out.

Plough-plant Tillage: A specialized planter is used to pulverize the row zone and sow seeds in one pass across the field after the soil has been ploughed.

Wheel Track Planting: Ploughing is done as usual. Tractor is used for sowing and the wheels of the tractor pulverize the row zone.

2.4.2 Mulch Tillage:

Crop residues are left on the surface under a system called mulch tillage, whereas they are largely unaffected by subsurface tillage. In dry land regions, the mulch is mostly left on the surface; in more humid areas, some of the mulch is buried. Intercropping broadens the mulch-provided erosion protection in rainy areas. Intercrops are often small grains or sod crops, such as alfalfa or clover, grown between the rows of a field crop that mature quickly after the field crop has been established and provide mulch cover for a considerable amount of time.

Mulching: Mulching is the process of adding a layer of plant residue or other materials to the soil's surface, either naturally or artificially. In other words, it may be described as a protective layer placed on the ground around plants, such as bark chips, straw, or plastic sheeting, to control weed development, hold in moisture, or prevent the freezing of the roots (Sharma *et al.* 2005).

Figure 2.3: Mulch Tillage

- This technique improves soil structure, inhibits the growth of weeds, and helps to preserve soil moisture. Mulching improve soil structure due to decomposition of organic mulch materials.
- Mulching significantly minimizes soil loss by shielding the soil from the direct impact of raindrops, lowering the sediment carried by runoff, and reducing evaporation. In order to sustain soil biodiversity, organic wastes are also helpful (Sharma *et al.* 2005).

2.4.3 Crop Residue Management (CRM):

Figure 2.4: Crop Residue Management (CRM)

Soil and water are conserved by using crop residue management (CRM) techniques. CRM systems incorporate conservation tillage techniques like zero-till, reduced-till, bed planting, and other techniques that offer enough residue cover to shield the soil surface from the erosive effects of wind and rain (Singh *et al*. 2005).

A. Impact of Crop Residue Burning:

Effects of burning stubble in addition to having negative effects on the environment, human health, and soil quality, open-field residue burning also has a negative effect on the world economy. Below, in the following subheadings, are discussed these negative effects:

- Impact on air
- Impact on soil
- Impact on agricultural productivity
- Impact on the economic development
- Decline soil microbial biomass
- Loss soil biodiversity
- Loss of soil organic carbon
- Chronic heart and lungs disease

- Climate pollution
- Smog and haze
- Aerosols and particulate
- Atmospheric environment
- Soil environment
- Human environment

2.4.4 Crop Rotation:

Figure 2.5: Crop Rotation

Crop rotation, as opposed to a one-crop system or unplanned crop successions, is the cultivation of various crops in succession in a predetermined order on the same land.

Crop rotation is the process of planting various crops in succession on the same piece of land to enhance soil health, maximize nutrients in the soil, and reduce insect and weed burden. Take the case of a farmer who has a field of corn planted.

A. Advantages of Crop Rotation:

- Enhanced soil fertility and microbial activity
- Avoid accumulation of toxic substance
- Better utilization of nutrients and soil moisture
- Insurance against natural devastation
- Higher chances to provide diversified commodities
- Slow but steady income, which is beneficial to marginal and small farmers
- Deep rooted crops work the soil below plough layer

B. Limitations to The Use of Conservation Agriculture:

Hobbs and Govaerts (2010) pointed out that overcoming the bias or mindset about tillage is likely the most crucial element in the implementation of CA. It is considered that one of the biggest obstacles to adopting CA widely is encouraging farmers that effective agriculture is still achievable with minimal or no tillage (Hobbs & Govaerts 2010).

- Lack of appropriate seeders especially for small and medium scale farmers.
- The wide spread use of crop residues for livestock feed and fuel.
- Burning of crop residues.
- Lack of knowledge about the potential of CA to agriculture leaders, extension agents and farmers.
- Skilled and scientific manpower.

2.5 Carbon Sequestration:

The process of removing, securing, and storing carbon dioxide from the atmosphere is known as carbon sequestration (CS) (Lal, 2004). The goal is to prevent carbon from warming the atmosphere by stabilizing it in both solid and dissolved forms.

CS is the provision of long-term carbon storage in the terrestrial biosphere, underground, or the oceans in order to slow or stop the increase of atmospheric carbon dioxide concentration (Lal, 1995).

It reduces the amount of carbon dioxide that enters the atmosphere as a result of sources like deforestation, forest fires, and primarily emissions from burning fossil fuels. This process is also referred to as carbon capture. The act of diverting CO_2 away from emission sources and storing it in the ocean, terrestrial settings (vegetation, soils, and sediments), and geologic formations is referred to as "carbon sequestration."

This process can be either natural or intentional. Carbon dioxide levels in the atmosphere have significantly increased as a result of human activity, particularly the combustion of fossil fuels like coal, oil, and gas (Jenkinson and Rayners, 1977). Global warming is being observed as a result of the rise in atmospheric CO_2 during the past 250 years, from around 280 to more than 400 parts per million (ppm).

Potential negative impacts include an increase in sea level, a rise in the frequency and intensity of wildfires, floods, droughts, and tropical storms, changes in the quantity, timing, and distribution of rain, snow, and runoff, and the disruption of coastal marine and other ecosystems.

A more acidic ocean could have negative impacts on marine plankton and coral reefs due to rising oceanic CO_2 levels and increased CO_2 absorption by seawater. To lessen the effects of rising atmospheric CO_2, technically sound and economically viable measures are required. In order to minimize human caused CO_2 emissions and remove CO_2 from the atmosphere (Wilson *et al.*, 2009).

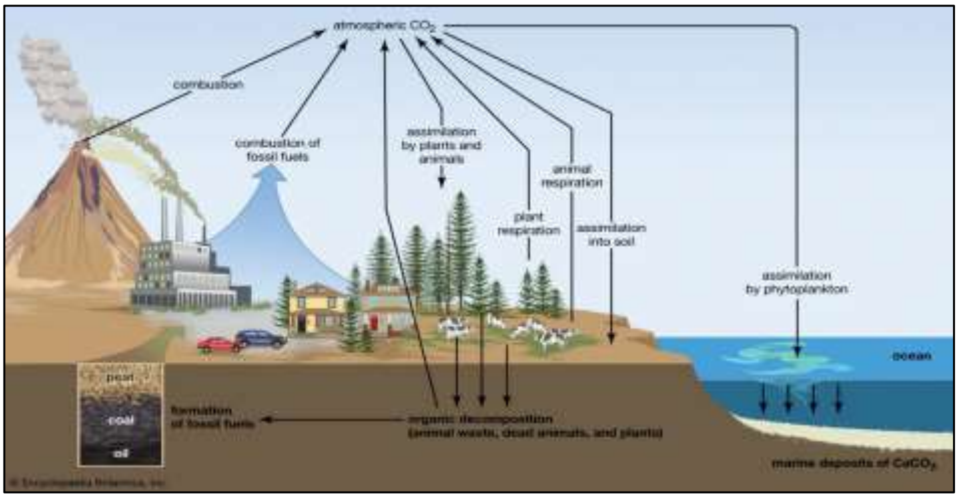

Figure 2.6: The process of Carbon sequestration

A. In What Ways Do Soils Sequester Carbon?

Soil carbon is successfully enhanced in the labile and slow pools by increasing the net balance of carbon that enters the soil each year relative to what is lost because the stable pool's size is typically unchanged. Govindarajulu *et al.*, (2005) this dynamic is significantly influenced by agricultural managers in four ways:

- Reducing soil disturbance (i.e., tillage) levels to improve the soil carbon's physical protection in aggregates.
- Enhancing soil inputs of plants and animals in quantity and quality.
- Increasing the diversity and richness of soil microbes.
- Ensuring that soils always have a living plant cover.

B. Why Now the Time to Act Is:

The overall quantity of carbon stored in American forests is greater than the cumulative historical CO_2 emissions from fossil fuels in the US. According to projections, total U.S. emissions will double by 2050 and rise by a factor of three to four by 2100 if current trends continue.

Sequestration and emission reduction over the next two to three decades could potentially have a significant impact on long-term opportunities to stabilize atmospheric CO_2 levels and mitigate the effects of climate change, according to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change from 2007.

C. Why C-Sequestration Is Required:

- To improve soil fertility status
- To improve soil quality

- Improve crop yields
- To improve farmer's income
- Improve Rehabilitation of degraded land
- In climate change mitigation
- Enhancing carbon removal.

2.5.1 Carbon Sequestration Methods:

A. Natural Processes

a. Terrestrial Sequestration
b. Ocean Sequestration

B. Human Techniques:

a. Carbon Capture and Storage (Geologic Sequestration)

a. Terrestrial Sequestration:

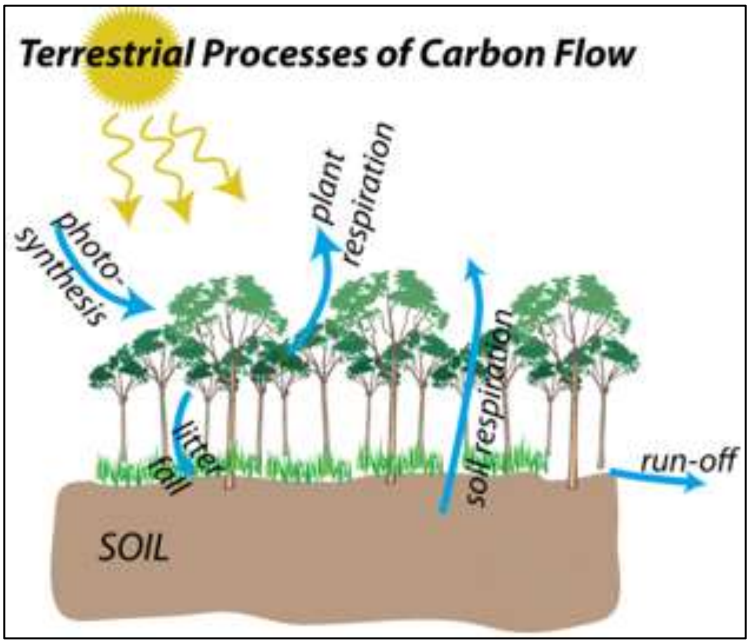

Figure 2.7: Terrestrial Sequestration

Terrestrial sequestration, also known as "biological sequestration," is primarily achieved by soil and forest conservation techniques that improve carbon storage (by building and regenerating forests, wetlands, and grasslands, for example) or lower CO_2 emissions (such as reducing agricultural tillage and suppressing wildfires). When dead roots and leaves decay, some of that CO_2 is released into the soil (Jandl *et al*. 2007; Batjes, 1996).

Uptake Saturation: Beyond a certain point, increased sequestration of carbon is no longer possible in plants due to saturation. When a tree reaches maturity or the amount of organic carbon in the soil becomes a constraint, this happens (Six et *al.*, 2002).

i. Enhancing Terrestrial Sequestration:

- **Agricultural Practices:** A lot of agricultural land is bare between planting seasons. Increase biomass sequestration by providing temporary cover with cover crops like grasses and weeds.
- **Sequester livestock:** To promote light, even grazing and thorough soil tilling, grazing should be restricted to shorter grassland for a brief period of time. Deeper root insertion into the soil is encouraged as a result.
- **Cover bare paddocks** with hay or dead vegetation to protect soil from the sun and to allow a higher water content, making the soil more appealing to carbon-capturing microbes.
- **Reforestation:** is the process of replanting trees in arid and marginal agricultural and grazing lands.
- **Afforestation:** is the process of establishing a forest in a place where none previously existed. This is done to increase biomass for the purpose of absorbing carbon dioxide.
- **Wetland Restoration:** Re-establishing or rehabilitating a wetland in order to return its original biological, geological, and chemical processes. This encourages carbon to be trapped in the sediments below. Wetlands make up only 5 to 8% of the planet's land, yet they hold 20 to 30% of its soil carbon, especially in coastal wetlands like mangroves, sea grasses, and salt marshes (Schnitzer *et al.* 2011)**.**

b. Ocean Sequestration:

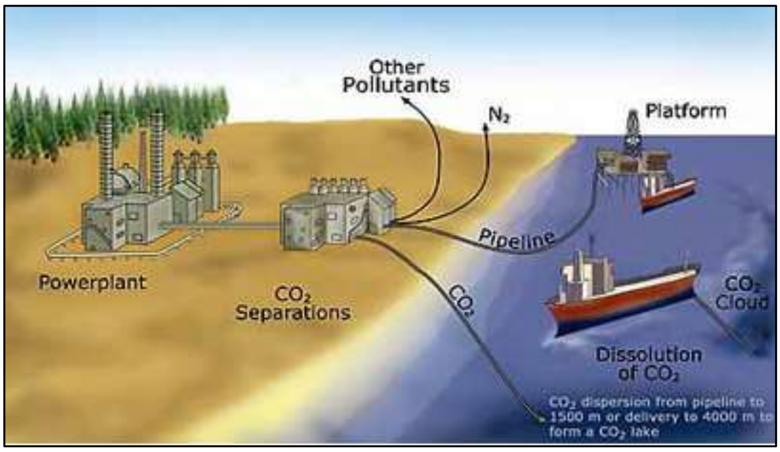

Figure 2.8: Ocean Sequestration

The largest long-term sink for CO_2 emissions from human activity is the ocean, which now absorbs around 2 gigatonnes of carbon yearly. The seas, which now absorb a third of the carbon produced by human activity, or about two billion metric tonnes annually, are one of the most promising areas to sequester carbon (Lal, 2004).

The amount of carbon that would cause the load in the atmosphere to double would only result in a 2% increase in the concentration in the deep ocean. 38,000 gigatonnes (Gt) of carbon are sequestered by the ocean each year (1 gigaton = 1 billion tonnes). This is sixteen times more carbon than the terrestrial biosphere is capable of storing (Macias and Arbestain 2010).

Process of Ocean Sequestration: Plankton at the ocean's surface employ photosynthesis to transform carbon dioxide into sugars, which is a process known as ocean sequestration. Plankton is eaten by sea life, which contributes carbon to the marine ecology.

Marine life eventually perishes and sinks to the ocean floor, where it accumulates in sedimentary layers and is stored as carbon. In order to keep it from exchanging with the atmosphere over millennia, the residence period of carbon molecules in deep ocean sediment is expected to be at least 3,800 years (Kell 2012; Robertson and Grandy 2006).

i. Physical Sequestration: Carbon Capture and Storage (CCS):

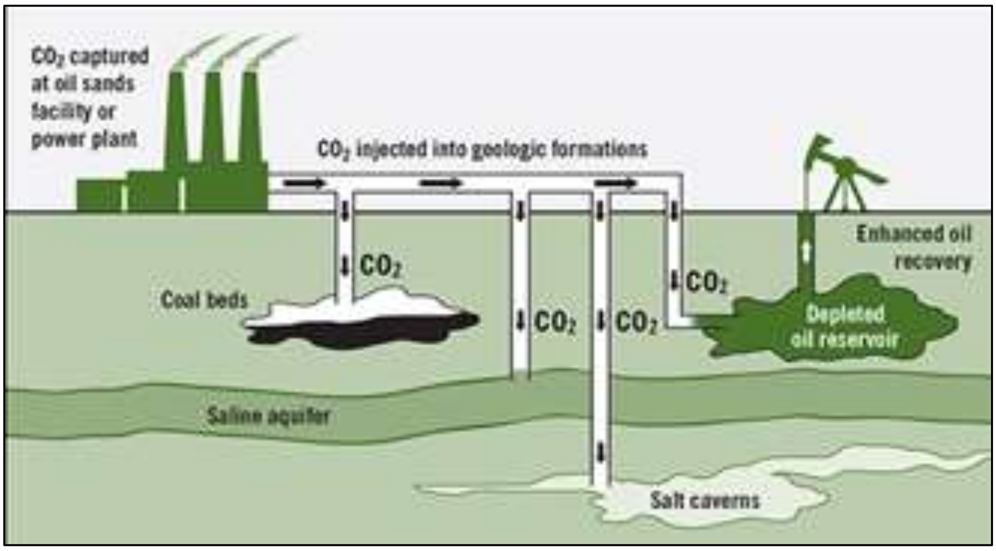

Figure 2.9: Physical Sequestration: Carbon Capture and Storage (CCS)

A geo-engineering technique called carbon capture and storage is used to physically stop significant amounts of CO_2 from being emitted into the atmosphere. It is being used as a promising complement to natural sequestration techniques all around the world. CCS has the capacity to collect up to 90% of the carbon dioxide emissions produced when fossil fuels are burned to produce electricity and in industrial processes (Duke and Powles, 2008).

2.6 Conclusion:

- Food security depends on healthy soils, and climate change has jeopardised it by changing the soil's properties. In such circumstances, conservation agriculture is a suitable strategy to maintain soil fertility and improve the sustainability of agriculture.

- Numerous advantages of conservation agriculture include improved soil physical, chemical, and biological health; sustaining crop production through resource conservation and soil quality; cost, energy, and labour savings; improved water and nutrient use efficiency; reduced greenhouse gas emissions by carbon sequestration; reduced soil erosion and environmental pollution due to the elimination of the need to burn crop residues; and climate change mitigation.
- No tillage, crop residue, judicious use of fertilizer & INM, cropping system and biochar application can easily be adopted and these practices have positive impact on soil carbon sequestration and crop productivity.
- Crop diversification and intercropping could be viable options for enhancing carbon sequestration in changing climatic scenario. For sequestering the atmospheric carbon and for maintaining sustainability, integrated nutrient management has a pivotal role.

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3. Conservation Agriculture in India, History, Status, Implications and Sustainability Uses

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Abstract:

Conservation agriculture (CA) technologies involve minimal soil disturbance, permanent soil covers through crop residues or cover crops, and crop rotations to increase productivity. Efforts in India to develop, refine, and disseminate conservation-based agricultural technologies have been ongoing for nearly two decades and have made significant progress since then, despite several constraints that impede CA adoption. In particular, tremendous efforts have been made in the Indo-Gangetic plains to achieve no-till wheat under a rice-wheat rotation. There are more payoffs than tradeoffs for CA adoption, but the balance between the two was understood by both adopters and promoters. CA technologies offer opportunities to reduce production costs, save water and nutrients, increase yields, diversify crop production, improve resource efficiency, and benefit the environment. However, there are still barriers to CA technology promotion, such as a lack of appropriate seeders, particularly for small and medium-scale farmers, crop residue competition between CA use and livestock feeding, crop residue burning, the availability of skilled and scientific manpower, and overcoming the bias or mindset about tillage.

To promote CA in the region, it is critical to develop a policy framework and strategies. This article examines the emerging concerns caused by the continued adoption of conventional agriculture systems, as well as the constraints, prospects, policy issues, and research needs for conservation agriculture in India.

Keywords:

Conservation agriculture, Conventional agriculture, Principles, Constraints, Prospects, Implications and Sustainability uses.

3.1 Introduction:

The concept of conservation agriculture is relatively using of new and modern cultivation practices. Conventional agricultural practices promote the extensive soil tillage, burning of crop residues and external inputs Such practices lead to soil degradation through loss of organic matter, soil erosion and compaction. In India more than 70-75% farmers are small land holding farmer they are still using traditional farm practices and are major contributor in total food production.

Yet, for many, farming is a struggle often with only rudimentary tools and implements available. Conservation Agriculture is a method of planning and managing sustainable and resource-conserving agricultural systems (CA).

It aims to improve, preserve, and make better use of natural resources through integrated management of soil, water, crops, and other biological resources in conjunction with selected external inputs. Agriculture could be resource-saving and effective, while also improving production in a sustainable manner, with such a technological setup.

Conservation agriculture includes direct planting through crop residue, minimum tillage, organic soil cover, improved on-farm water management, and appropriate crop rotations to prevent disease and pest issues.

Burning crop wastes (as in the rice-wheat cropping system) contributes to pollution, greenhouse gas emissions, and the loss of important plant nutrients. Initiating processes that improve soil quality and boost resource quality when crop residues are left on the soil surface and no tillage is used.

In order to fulfil the goals of sustainable agriculture production, Conservation agriculture has evolved as a new approach. It's a significant step in the direction of sustainable agriculture.

Therefore, there are major benefits to Conservation agriculture. Direct advantages to farmers include

- lower cultivation costs due to manpower,
- time, and farm power savings, and
- increased input usage efficiency.

More importantly, CA techniques stop the depletion of resources. By increasing nitrogen balance and availability, soil infiltration and retention, lowering water loss due to evaporation, and enhancing the quality and availability of ground and surface water, CA results in long-term gains in the effective use of water and nutrients.

3.2 Conservation Agriculture Definition and Goals:

Conservation agriculture is a management system that maintains a soil cover through surface retention of crop residues with no till/zero and reduced tillage. It is described as a concept for resource saving agricultural crop production which is based on enhancing the natural and biological processes above and below the ground. Conservation agriculture (CA), is not "business as usual," based on optimizing yields while utilizing the resources of the land and agro-ecosystem.

A balance of agricultural, economic, and environmental benefits is achieved by CA by optimizing yields and profitability. It argues that the social and economic benefits of both production and environmental preservation-including lower input and labor costs—are larger than those of production alone.

By using pesticides, fossil fuels, and other harmful substances, as well as by preserving the integrity of the environment and its services, farming communities may provide a wider population with better hygienic living conditions.

As per FAO definition CA is to:

- achieve acceptable profits
- high and sustained production levels, and
- conserve the environment.

It aims at reversing the process of degradation inherent to the conventional agricultural practices like intensive agriculture, burning/removal of crop residues.

Hence, it aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs. It can also be referred to as resource efficient or resource effective agriculture.

Table 3.1: Distinguishing Features of Conventional and Conservation Agriculture Systems

Sr. No	Parameters	Conventional Agriculture (Ct)	Conservation Agriculture (Ca)
1.	Practice	Disturbs the soil and leaves at a bare surface	Minimal soil disturbance and soil surface is permanently coverd
2.	Cropping system	Monocropping / less efficient rotations	Diversified farming / more efficient rotations
3.	Residue management	Burning or removal	Retention on the soil surface
4.	Erosion	Maximum wind and water erosion	Less erosion
5.	Soil health	Poor	Good
6.	Water infiltration	Infiltration will be lowest after soil pores clogged	Good infiltration
7.	Organic matter content	Low	High

Sr. No	**Parameters**	**Conventional Agriculture (Ct)**	**Conservation Agriculture (Ca)**
8.	Weeds	Control weeds and also produce more weed seeds to germinate	Weeds are problem only during early stages of adoption, later good control of weeds
9.	Timeliness	Operations can be delayed	Optimal timeliness
10.	Yield	Lower due to delayed operation	More yield when timely planting done

3.2.1 How Is Conservation Agriculture Different from Sustainable Intensification?

Sustainable intensification is a process to increase agriculture yields without adverse impacts on the environment, taking the whole ecosystem into consideration. It aims for the same goals as conservation agriculture.

Conservation agriculture practices lead to or enable sustainable intensification.

3.2.2 How Is Conservation Agriculture Differing from Organic Agriculture?

Conservation agriculture and organic farming both use crop rotation to maintain a balance between agriculture and resources and to protect the organic matter in the soil.

The main distinction between these two types of farming is that organic farmers use soil tillage, whereas conservation farmers use natural principles and do not till the soil.

Tillage is used by organic farmers to remove weeds without the use of inorganic fertilizers. Farmers who practice conservation agriculture use a permanent soil cover and plant seeds through it.

They may initially use inorganic fertilizers to control weeds, particularly in low fertility soils. Agrichemical use may be reduced or phased out gradually over time.

3.2.3 How Is Conservation Agriculture Differing from Climate-Smart Agriculture?

While conservation agriculture and climate-smart agriculture are similar, their goals are not. Conservation agriculture seeks to use natural processes to sustainably intensify smallholder farming systems while also having a positive impact on the environment. It enables farmers to adapt to and increase profits in the face of climate risks.

Climate-smart agriculture aims to adapt to and mitigate the effects of climate change by sequestering soil carbon and reducing greenhouse gas emissions, and finally to increase the productivity and profitability of farming systems to ensure farmers' livelihoods and food security in a changing climate. Conservation agriculture systems can be considered climate-smart because they meet the goals of climate-smart agriculture.

3.3 Principles of Conservation Agriculture:

Conservation agriculture practices used in many parts of the world are built on ecological principles making land use more sustainable. Adoption of Conservation Agriculture for enhancing Resource use efficiency (RUE) and crop productivity is the need of the hour as a powerful tool for management of natural resources and to achieve sustainability in agriculture.

Conservation agriculture basically follows 3 principles, which must be considered together for appropriate design, planning and implementation processes. These are:

3.3.1 Minimal Mechanical Soil Disturbance:

The biological activity of the soil creates very solid soil aggregates and holes of different sizes that enable the infiltration of air and water. This method, which is sometimes referred to as "biological tillage," is incompatible with mechanical tillage.

The biological health and life processes of the soil will be destroyed by mechanical soil disturbance. A minimum amount of soil disturbance promotes/maintains ideal levels of respiration gases in the rooting zone, moderate organic matter oxidation, porosity for water transport, retention, and release, and restricts re-exposure of weed seeds and their germination.

3.3.2 Permanent Organic Soil Cover:

It is imperative in conservation agriculture to protect the soil from harmful effects resulting from exposure to rain and sun; to provide constant food supply to the soil; micro and macro -organisms, together with the plant roots. Soil cover is attained with biomass obtained from crop residues and cover crops.

3.3.3 Diversified Crop Rotations:

Crop rotation is essential not just to provide a variety of "food" for soil microorganisms, but also to search through different soil levels for nutrients that have leached to deeper layers and can be "recycled" by the crops in rotation.

Rotation produces a variety of soil flora and fauna. By disruption of life cycles, biological nitrogen fixing, reduction of off-site pollution, and enhancement of biodiversity, the sequence and rotation of cropping with legumes contributes to the lowest rates of population build-up of pest species.

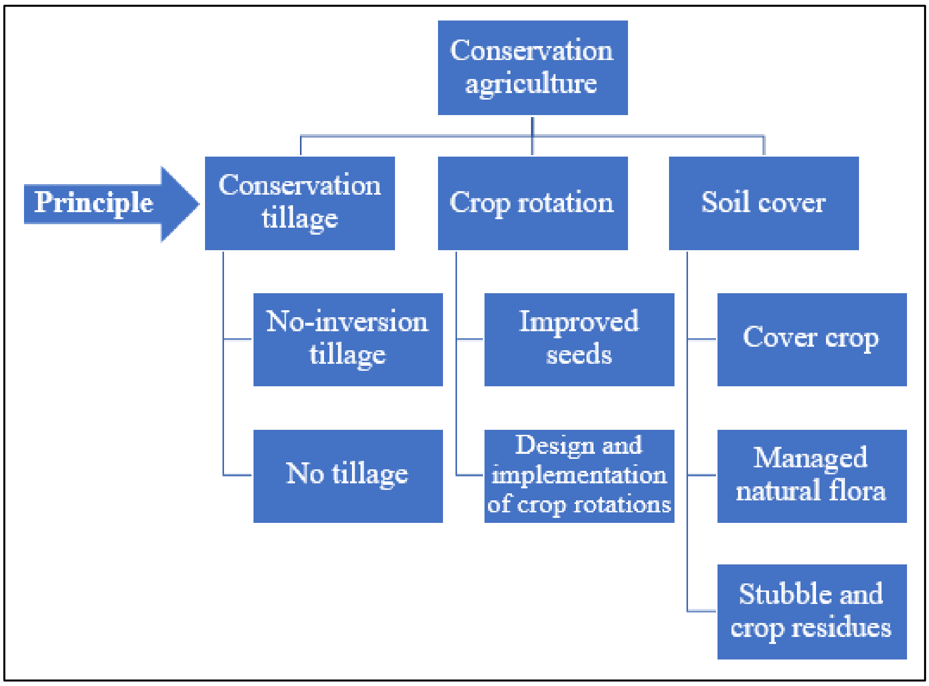

Figure 3.1: Principles of Conservation Agriculture.

3.4 History and Status of Conservation Agriculture in India and World:

The term “conservation agriculture” was coined in the 1990s, but the idea to minimize soil disturbance has its origins in the 1930s, during the Dust Bowl in the United States of America. CIMMYT began work with conservation agriculture in Latin America and South Asia in the 1990s and in Africa in the early 2000s. Today, these efforts have been scaled up and conservation agriculture principles have been incorporated into projects such as CSISA, FACASI, MAs Agro, SIMLESA, and SRFSI. Farmers worldwide are increasingly adopting conservation agriculture.

In the 2015/16 season, conservation agriculture was practiced on about 180 mega hectares of cropland globally, about 12.5% of the total global cropland — 69% more than in the 2008/2009 season. In approximately 125 million ha. of high-potential environments worldwide, CA is used. USA (26.5 M ha), Brazil (25.5 M ha), Argentina (25.5 M ha), Canada (13.5 M ha), and Australia are the top CA-practicing nations (17.0 M ha). The adoption of CA is still in its early stages in India. Over 1.5 million hectares have adopted zero tillage and CA over the past few years (Jat et al., 2012; www.fao.org/ag/ca/6c.html).

In the rice-wheat (RW) system of the Indo-Gangetic plains, zero-till (ZT) wheat is one of the main CA-based technologies being used (IGP). In other crops and cropping systems, the conventional agriculture based crop management systems are gradually undergoing a paradigm shift from intensive tillage to reduced/zero-tillage operations. In addition to ZT, other concept of CA needs to be infused in the system to further enhance and sustain the productivity as well as to tap new sources of growth in agricultural productivity.

The CA adoption also offers avenues for much needed diversification through crop intensification, relay cropping of sugarcane, pulses, vegetables etc. as intercrop with wheat and maize and to intensify and diversify the RW system. The CA based resource conservation technologies (RCTs) also help in integrating crop, livestock, land and water management research in both low-and high-potential environments. Spread of these technologies is taking place in the irrigated regions of the Indo-Gangetic plains where the rice-wheat cropping system dominates.

Zero-till seed-cum fertilizer drills for sowing wheat in rice-wheat systems have received the majority of attention in the development and promotion of conservation technologies. Additional interventions include alternatives to the rice-wheat system, raised bed planting techniques, land levelling assisted by laser technology, residue management techniques, etc. According to reports, the amount of wheat planted with the zero-till drill has been growing quickly (Sangar et al., 2005), and 25% to 30% of the wheat grown in rice-wheat-growing regions of the Indo-Gangetic plains of India is currently zero-tilled. The farmers in the northwest are also progressively implementing raised-bed farming and laser ground levelling.

3.4.1 Benefits of Conservation Agriculture:

Conservation farming seems to be the ideal solution for global problems. It improves crop productivity, the environment, and biodiversity. Farmers are increasingly using this farming method for its effectiveness:

- Improve soil structuring.
- Increasing soil’s organic matter.
- Enhance soil infiltration.
- Improve soil nutrients.
- Protection against soil erosion.
- Decrease weed population.
- Organic crop protection saves biodiversity.
- Reduce farm finance.

A. Economic Benefits: The introduction of conservation agriculture has three important economic benefits:

- Save time and reduce labor cost.
- Reduce technical cost., fuel, machinery, etc.
- High efficiency lower input, high output.

B. Agronomic Benefits: The introduction of conservation farming leads to an increase in soil productivity:

- Increase soil organic matter.
- Increase conservation of soil water.
- Improve soil structure.
- Improve crop root anchoring.

C. Environmental Benefits:

Adaptation of conservation agriculture improves environment and biodiversity:

- Reduce soil erosion.
- Reduce infrastructure maintenance cost, roads, dams, power plants.
- Improve water quality.
- Filter atmosphere and improve air quality.
- Increase soil bio-diversity.
- Restore soil carbon content.

3.4.2 Prospects of Conservation Agriculture:

Now a day's different countries do so many things to meet the food and energy needs for coming decades which will have great impact on natural resources bases, global climate change and energy security for India and world. A shift to no-till conservation agriculture is perceived to be of much fundamental value in meeting these challenges.

Asian farmers/researchers will continue to need assistance to reorient their agriculture and practices for producing more with less cost through adoption of less vulnerable choices and pathways. Therefore, business as usual with conventional agriculture practices does not seem a sustainable option for sustainable gains in food-grain production, and hence CA-based crop management solutions adapted to local needs will have to play a critical role in most ecological and socio-economic settings of Asian Agriculture. The promotion of CA under Indian/Asian context has the following prospects:

- Reduction in cost of cultivation – it is the key factor contributing to rapid adoption of zero-till technology. Cost reduction is to save money in accounts of diesel, labor and input costs, especially herbicides.
- Reduction incidence of weeds – due to adoption of zero tillage it reduces weed incidence and it reduce herbicides.
- Saving in water and nutrients – It shows that significant fertilizer and water savings are made possible by zero-till planting, especially for crops that are laser levelled and planted in beds. These savings can range from 20% to 30%. No-till soils had higher soil water contents than conventionally tilled soils, which suggested that less water had evaporated during the earlier period. Also, they discovered that the soil water content under no-till was around 20% higher than under conventional tillage over the course of growing seasons.
- Increased yields were consistently higher in properly maintained zero-till planted crops than in traditionally prepared fields for identical planting dates. Due to concomitant effects like the prevention of soil degradation, improved soil fertility, improved soil moisture regime (due to increased rain water infiltration, water holding capacity, and reduced evaporation loss), and the advantages of crop rotation, CA has been reported to increase the yield level of crops. Nevertheless, during the early stages of adoption, there are no yield gains and potentially a yield decline.
- Environmental benefits – Crop residue burning, which produces significant amounts of greenhouse gases including CO2, CH4, and N2O, can be completely eliminated by

conservation agricultural practices like zero-till and surface managed crop residue systems. Burning crop leftovers causes a significant loss of plant nutrients that, with good management, might be recycled. Crop residue burning on a large scale is also a severe health risk.

- Crop diversification opportunities – Adopting Conservation Agriculture systems offers opportunities for crop diversification. Cropping sequences/rotations and agroforestry systems when adopted in appropriate spatial and temporal patterns can further enhance natural ecological processes.
- Resource improvement – No tillage when combined with surface management of crop residues begins the processes where by slow decomposition of residues results in soil structural improvement and increased recycling and availability of plant nutrients. Surface residues acting as mulch, moderate soil temperatures, reduce evaporation, and improve biological activity.

3.4.3 Constraints in Adoption of Conservation Agriculture:

Farmers in a country or region, where CA is not practiced, face a number of problems which make adoption difficult. These problems are of diverse nature, such as intellectual, social, biophysical and technical, financial, infrastructural and policy. Most farmers are facing, several of these problems, if not all, at the same time to the effect that only very few bold pioneer farmers adopt CA. Farmers are not in the position to start with a blank sheet and to weigh objectively the merits and disadvantages of CA against conventional tillage farming.

A. Intellectual Constraints to Adoption:

New technologies that are quickly adopted often have obvious advantages, resulting in rapid acceptance and enthusiasm. In many cases, this enthusiasm fades once the new technology is understood and the drawbacks become apparent. CA works in the opposite direction: it contradicts so much of what a farmer has learned and been told that the benefits of CA are not immediately apparent. However, once the gradual adoption process begins, CA's performance improves over time. The more experience producers have with CA, the more convinced and positive they are about it. The less practical experience people have with CA, the more critical and negative their attitude towards it. A study carried out with European and American no-till farmers and agricultural experts came to similar conclusions. It was found that the experts, mostly without practical experience in CA, anticipated many problems for its adoption.

In their opinion, the problems outweighed the benefits, resulting in an overall negative attitude. Farmers who were actually practicing CA and had experience with the system, on the other hand, had an overall positive perception, with the benefits clearly outweighing the problems (Tebrugge and Bohrnsen 2000). CA has two intellectual barriers to overcome: the first is that the CA concept and principles are counterintuitive and contradict the common tillage-based farming experience, which has worked for generations and has frequently created cultural values and rural traditions; the second is a lack of experiential knowledge about CA and the mechanism to acquire it. Soil tillage, and particularly the plough, has in most countries become part of the culture of crop production. Ploughing, cultivation and tillage are often synonyms for growing a crop.

Cropland is referred to as "arable" land, which is Latin for "plough able" land. The plough was part of the very early developments of agriculture and has the character of a brand symbol for what is 'correct'. People find it difficult to accept that the plough is suddenly dangerous and that crops can grow without tilling the land. Overcoming this "mental compaction" is frequently much more difficult than actually beginning no-till farming (Landers 2001). It's difficult to imagine a soil becoming softer and more structured without being tilled unless you've seen it happen. The second intellectual impediment to adoption is simply a lack of sufficient experiential knowledge about it and the means of acquiring it.

CA covers about 7% of agricultural land worldwide. Adoption is concentrated in a few countries, eventually exceeding 50%, while adoption in the rest of the world is less than 2%. This explains why most people have never seen a CA system in action. CA is rarely mentioned in the media because it is not yet represented in any labels or certification schemes and has no direct relevance to consumers. CA is also not included in university curricula, even at prestigious agricultural universities.

This explains why, despite having more than twice the adoption rate of organic farming, public awareness of CA is much lower. Even most agricultural professionals and many farmers have never heard of CA, or have only vague ideas about it. Permanent no-tillage farming and CA are frequently unfamiliar to farmers and thus do not appear on their radar. For actual CA adoption, the farmer would need to know not only about CA elements in general, but also how to implement CA elements under the specific conditions of an individual farm.

This knowledge is not typically available as an off-the-shelf technology package. Worse, CA is a complex and labor-intensive farming concept in which crop management must be planned ahead of time and is mostly proactive rather than reactive, as in traditional tillage-based systems. In tillage-based systems, soil compaction or uneven surfaces are corrected with tillage; in no-till systems, they must be avoided from the start. Weed and pest management in conventional tillage systems is frequently based on chemical or mechanical control as a response to the incidence, whereas in CA, the incidence of weeds and other pests is reduced through crop rotation planning.

This increased complexity necessitates the acquisition of experience and knowledge. This learning process and experiential knowledge has thus involved a lot of trial and error for early adopters until sufficient local experience and knowledge has been accumulated to make the adoption easier. However, farmers, not scientists, are best suited to develop solutions to these practical problems. Farmers' own adaptive "research and development" process typically produces more timely and applicable results than the so-called "Green Revolution" approach of leaving the development of a standard technology package "ready for adoption" to the scientific community.

B. Social Constraints to Adoption:

Farmers in developing countries are mostly conservative and risk opposition to this adoption. If any farmer doing different method of agriculture from others will therefore risk being excluded from the community.

This leads to social isolation and even to mocking, only very strong farmers can take a step forward. Even after seeing the success in individual farmer fields due to aversion created in their mind and due peer pressure other farmers not following. The pressure can be so bad that the community gets jealous of the success and instead of also adopting it, it leads to boycott including using ‘black magic’ and placing bad spells on the fields. For adoption of this process no need of any progressive farmer who can prove the success, but the farmers should socialize and integrated in the community. Other issues include traditional land tenure systems, in which no individual owns land, which makes it difficult for farmers to invest in long-term soil health and productivity improvement. Furthermore, communal grazing rights, which frequently include the right to graze on crop residues or cover crops after the harvest of the main crop, create conflicts that make the adoption of CA practices difficult.

These issues can be significant barriers to CA adoption, and conflicts arising, for example, from alternative uses of crop residues as mulch or animal feed cannot be resolved through orders or directives. Physical barriers, such as fences, may not be the best solution if they contradict the traditional social values of the respective cultures. Much more important in the process is that the entire community first understands the issues, as well as the changes and benefits associated with adopting CA, and then works together to find solutions.

C. Input Constraints:

Access to equipment, seeds, fertilizers, and herbicides is a major barrier to expanding CA in Africa. CA does not always necessitate more equipment than traditional agriculture, but some of the equipment is unique and not always available.

The most notable differences are found in land preparation and seeding. In silty or clayey soils, the soil surface is only penetrated in precisely targeted seeding lines or pits. Seeds are then deposited or inserted directly into the ground through the mulch or ground cover layer. Some conventional agriculture tools (e.g., certain weeding tools) can also be used for CA, while others can be modified for CA (e.g., hand hoes can be made narrower to dig CA planting basins). Equipment costs are relatively low for nonmechanized CA involving simple hand tools (if the requisite equipment is available at all). When using animal- or tractor-powered implements, costs skyrocket.

Access to (or affordability of) inorganic fertilizers, pesticides, and herbicides may also be a barrier to practising CA in the most productive way. However, one of the primary benefits of CA is that it can increase yields in situations where agrochemicals are unavailable or prohibitively expensive by encouraging biological processes and management practices that improve soil fertility, pest control, and weed control.

Nitrogen-fixing plants, which can include shrubs, annual herbaceous plants, or trees like *Faidherbia albida*, are an essential component of most CA systems. Intercropping with these species boosts yields, soil health, and soil chemical and biological properties while decreasing weed and pest problems. Despite these advantages, spontaneous adoption of cover crops for soil fertility enhancement is uncommon; instead, the plants must provide some direct benefit, such as human food or animal fodder.

D. Biophysical and Technical Constraints:

Although the concept of CA is universal, this does not imply that techniques and practises for every condition are readily available. Depending on the specific farming situation and agro-ecological conditions, the actual CA practise must be developed locally in most cases. Farmers in each location must discover and decide on crop rotations, cover crop selections, and crop-livestock integration issues. A wide range of issues arise, frequently involving weed management, residue management, equipment handling and settings, and planting parameters such as timing and depth, all of which must be discovered for the first time.

As a result, when CA is first introduced in a region, extension agents and advisors are unable to provide specific advice on practises and must instead develop these practises in collaboration with farmers. On the other hand, if properly applied, such an approach is much faster and more sustainable than the development of specific practises by scientists, because it taps into the vast pool of experience and innovation potential of the farmer community. Some cover crops have been developed from weeds, and farmers have developed practises such as growing paddy rice or potatoes under no-till in CA without scientists even considering such innovations.

CA with higher levels of fertilizer than conventional maize production has the potential to raise yields, but cash constraints are a barrier to widespread fertilizer use (regardless of tillage method). Most farmers in Mozambique grow maize without fertilizer (Bias & Donovan, 2003). The benefits from fertilizer use depend on soil conditions. Fertilizer use in Africa is generally low because of both demand side and supply side factors. Demand is often weak because of “the low -levels and high variability of crop yields on the one hand and the high level of fertilizer prices relative to crop prices on the other.”

Aside from financial or other constraints, another technical constraint is the simple lack of certain technologies or inputs. There are no cover crop seeds available in many countries where farmers begin with CA. The availability of equipment, particularly notill direct seeding equipment, is also frequently an issue. Most situations now have technologies available somewhere in the world. However, in some areas, farmers may be unaware of these technologies or may not have access to them. This is usually where external assistance, such as knowledge sharing, or even the introduction of specific technologies, such as direct seeding equipment, is required.

E. Financial Constraints:

Although CA is typically more profitable than conventional farming practises, there are still financial barriers to adoption, depending on the availability of capital to invest in this change of production system.

These constraints exist at all farm size levels, albeit to varying degrees and for various purposes. Converting a manufacturing system to CA is a long-term investment. In many cases, the change is motivated by the degradation of natural resources, particularly soil and water, as a result of previous tillage-based agriculture.

To begin with CA and successfully restore soil life and health, some initial investment in the land may be required, such as ripping existing compactions, correcting soil pH or extreme nutrient deficiencies, levelling and shaping the soil surface for the cropping system envisaged under CA. The capital for this type of investment is not available, particularly for small subsistence farmers.

Furthermore, the farmer requires new equipment, as most of the existing equipment is becoming obsolete and will most likely not find an attractive second -hand market. The larger the farmer, the more important this barrier, because a no-till seed drill, for example, is significantly more expensive than a conventional one.

This conflict between the potential improved profit margin on one hand and the very concrete and actual investment requirements on the other often leads to farmers deciding not to switch to CA, even if they are convinced of the benefits.

In general, CA is longer-term more profitable than traditional farming. Nevertheless, obtaining these long-term advantages could necessitate an upfront investment, which is frequently too costly or dangerous for small farmers to make on their own. Due to worries about household food security, vulnerable farmers are extremely risk conservative, and there is limited space for error.

However, while many farmers experience benefits in the first year of using CA, others take three to seven years to see a boost in yields or profitability. Farmers occasionally decide to stop using CA at this time, thus long-term adoption is more likely when CA offers large benefits in the first or second year. When CA is promoted along with sound agronomic procedures, improved seeds, and occasionally inorganic fertilisers, the likelihood of such an immediate benefit increases.

Credit facilities are one solution in these cases, but sometimes the availability of contractor services or technical advice on how to adapt and modify existing equipment as a low-cost intermediate solution to begin with can also be beneficial. Modification of existing equipment has, for example, provided an entry point for some farmers in Brazil and Kazakhstan to begin with CA and then, after benefiting from higher profitability, invest in proper equipment at a later stage. Homemade solutions for simple CA farm tools, particularly for small farmers, are an important component of CA adoption in Paraguay (Lange and Meza, 2004).

F. Infrastructural Constraints:

Conservation agriculture also necessitates some exogenous inputs in order to achieve high output levels. CA improves crop growth conditions and increases the efficiency of natural resources and input use, but it is not a 'perpetual motion' process that would allow crop intensification from endogenous resources. In order to increase production intensity, inputs should be available near the production area, processing units, and markets where produce is sold. Conservation agriculture produces better results than conventional agriculture even when no external inputs are used, but the difference is not significant.

Some inputs, such as fertilizer types, will differ only marginally from the requirements of conventional tillage-based farming. Herbicides, seeds for cover- and rotational crops, and especially equipment for direct seeding, planting, and residue management, on the other hand, are frequently completely different from those used in the past and must be introduced into markets. This necessitates not only a good input supply infrastructure, but also a proactive attitude on the part of the supply sector, such as dealers and manufacturers. It necessitates collaboration between the farming and input supply sectors, as well as some supportive policies.

G. Policy Constraints:

CA adoption can occur spontaneously, but it usually takes a long time to reach significant levels. Adequate policies can significantly shorten the adoption process, primarily by removing the previously mentioned constraints. This can be accomplished through information and training campaigns, appropriate legislation and regulatory frameworks, research and development, incentive and credit programmes, and other means. However, in most cases, policymakers are also unaware of CA, and many existing policies work against CA adoption. Commodity subsidies, which reduce farmers' incentives to use diversified crop rotations, mandatory prescription for soil tillage by law, or a lack of coordination between different government sectors are typical examples. In some cases, countries have legislation in place that supports CA as part of a sustainable agriculture programme.

If those countries have a programme to modernise and mechanise agriculture, the first items introduced under such a mechanization programme are usually tractors with ploughs or disc harrows. This not only sends the wrong signal, but it also works directly against the introduction and promotion of CA, while also passing up an opportunity to introduce tractors with no-till seeders instead of ploughs, assisting in overcoming this technological constraint. Even in countries where many farmers practice CA, policymakers frequently lack awareness of the practice, and in some cases, existing policies work against it.

Countries with their own agricultural machinery manufacturing sector frequently levy high import taxes on agricultural machinery to protect their own industry. This industry frequently lacks suitable CA equipment in the short term, but due to high import taxes, farmers who want to adopt CA are unable to import equipment from abroad. In other cases, the import tax on raw materials may be so high that local manufacturing of CA equipment becomes impossible.

To avoid such contradictory policies, policymakers and legislators must be made aware of CA and its ramifications. Where farmers do not farm their own land but rent land from others, there are additional issues with CA implementation: the accumulation of soil organic matter under CA is an investment in soil fertility and carbon stocks, which is currently not recognized by policymakers but is increasingly recognized by other farmers.

Farmers who still plough know that the mineralization of organic matter acts as a source of plant nutrients, allowing them to "mine" these lands with lower fertilizer costs. This allows them to pay a higher rent for CA land than the CA farmer can. Such cases can be found in both "developing" African and "developed" European countries.

To avoid this, some policy instruments are required to hold landowners responsible for maintaining soil fertility and carbon stock in the soil, which is difficult to achieve in the absence of agricultural carbon markets.

3.5 Conservation Agriculture's Challenges:

Challenges in conservation agriculture Conservation agriculture as an upcoming paradigm for raising crops will require an innovative system perspective to deal with diverse, flexible and context specific needs of technologies and their management.

Conservation agriculture R&D (Research and Development), thus will call for several innovative features to address the challenge.

A. Understanding the system – Unlike to conventional methods, conservation agriculture is far more difficult. The fundamental barrier to the adoption of CA systems has been site-specific expertise. Understanding the fundamental processes and component interactions that affect how well the system as a whole performs will be crucial to managing these systems effectively. For instance, crop leftovers that are kept on the surface operate as mulch, reducing the amount of water that evaporates from the soil and preserving a stable soil temperature regime. Crop leftovers can be a simple source of organic matter for decomposition, but they can also harbour pest populations that are undesirable or otherwise change the ecology of the system. No-tillage systems will influence depth of penetration and distribution of the root system which, in turn, will influence water and nutrient uptake and mineral cycling. Thus, the need is to recognize conservation agriculture as a system and develop management strategies.
B. Building a system and farming system perspective – A system perspective is built working in partnership with farmers. A core group of scientists, farmers, extension workers and other stakeholders working in partnership mode will therefore be critical in developing and promoting new technologies. This is somewhat different than in conventional agricultural R&D, the system is to set research priorities and allocate resources within a framework, and little attention is given to build relationships and seek linkages with partners working in complementary fields.
C. Technological challenges - While the basic principles that underpin conservation agriculture practises, such as no tillage and surface managed crop residues, are well understood, the key challenge is implementing these practises in a variety of farming situations. These difficulties are related to the development, standardisation, and adoption of farm machinery for seeding with minimal soil disturbance, as well as the development of crop harvesting and management systems.
D. Site specificity - Although adaptation strategies for conservation agriculture systems will be highly site specific, learning across sites will be a powerful way of understanding why certain technologies or practises are effective in one set of situations but not in another. This learning process will hasten the development of a knowledge base for sustainable resource management.
E. Long-term research perspective - Conservation agriculture practises, such as no-tillage and surface-maintained crop residues, result in resource improvement gradually, with benefits accruing over time. Indeed, benefits in terms of yield increase may not be realised in many cases during the early stages of evaluating the impact of conservation

agriculture practises. Understanding the dynamics of change and the interactions between physical, chemical, and biological processes is essential for developing better soil-water and nutrient management strategies (Abrol and Sangar, 2006). As a result, conservation agriculture research must have a longer time horizon.

3.6 Implications and Sustainability Uses:

Conservation agriculture entails a significant departure from traditional farming practises. Policy analysis is required to understand how CA technologies integrate with other technologies, as well as how policy instruments and institutional arrangements encourage or discourage CA (Raina et al., 2005). CA provides a means of halting and reversing the downward spiral of resource depletion by decreasing factor productivity, lowering cultivation costs, and making agriculture more resource-efficient, competitive, and sustainable.

While R&D efforts over the last decade have aided in increasing farmer acceptance of zero tillage for wheat in rice-wheat cropping systems, this has raised a number of institutional, technological, and policy issues that must be addressed if CA practises are to be adopted on a large scale in the region on a sustained basis.

A. CA technologies affect the plant growing microenvironment significantly. Changes in moisture regimes, root environment, the appearance of novel diseases, and a shift in the insect-pest situation are just a few examples. Plant types that are suitable for the new environment and meet specific mechanisation needs may differ. Complementary crop development programmes aimed at generating cultivars better suited to new systems are required. Farmers' participation in research appears promise for finding and producing crop types that are suited to a specific environment or place.

B. Support for the adaptation and validation of CA technologies in local environments: Adaptive research is necessary to match CA concepts and practises to local situations. This should be done in partnership with local communities and other stakeholders. Crop species, crop and cover crop selection and management, rotations, soil cover maintenance, and CA equipment should all be considered. In India, resource-poor and small-holder farmers lack economic access to new seeds, herbicides, and sowing machinery, among other things (Sharma et al., 2012). This necessitates a policy framework that makes crucial inputs readily available.

C. There is a need for generating a good resource database with agencies involved complementing each other’s work. Besides resources, systematic monitoring of the socio-economic, environmental and institutional changes should become an integral part of the major projects on CA.

D. Credit and subsidies: Another critical factor in the successful implementation of CA is the availability of financing to farmers to purchase equipment, machinery, and inputs at affordable interest rates from banks and credit agencies. At the same time, the government should provide a subsidy for farmers to purchase such equipment. For example, the Chinese government has recently undertaken a number of regulatory and economic measures to promote CA practises in the Yellow River Basin, including a subsidy on CA machinery and effective farmer training (Yan et al., 2009). This resulted in a significant increase in CA area. Presently, over 80% of the area under maize production in Shanxi, Shandong, and Henan provinces is dependent on no-till seeder.

E. Promote payments for environmental services (PES) and fines for faulty practices: Adopters of CA improve the environment through carbon sequestration, prevention of soil erosion or the encouragement of groundwater recharge. It provides ecosystem services, thus, farmers could be rewarded for such services, which have a great impact on the quality of life for all.
F. Scaling up conservation agriculture practises: Attempts to adapt CA concepts and technological components to the region's different agro-ecological, socio-economic, and farming systems began a few decades ago. More support from stakeholders, especially policymakers and decision-makers at the local, national, and regional levels, will facilitate CA expansion and let farmers to reap additional benefits from the technology. For more than a decade, substantial CA research has been undertaken in India, primarily at the Indian Agricultural Research Institute. Unfortunately, its reach among farmers is extremely restricted. There is a need to consider the challenges encountered during implementation and design a strategy that involves all parties involved. The majority of cases where reforms in favour of CA have happened have had limited success. According to FAO (2001), this is due in part to unfavorable policy conditions. One of the causes for the slow adoption of technology among farmers was the majority of farmers' previous inclination or mindset towards tillage (Hobbs and Govaerts, 2010).
G. CA allows for diverse cropping systems in various agro-ecoregions. Developing, upgrading, and standardizing equipment for planting, fertilizer placement, and harvesting while ensuring minimal soil disturbance in residue management for varied edaphic situations will be critical to CA's success. Bullock hauled equipment will be more useful for small landholders in various scenarios, such as in steep stretches. Ensuring quality and availability of equipment through appropriate incentives will be important. In these situations, the subsidy support from national or local government to firms for developing low cost machines will help in the promotion of CA technologies.

Conservation agriculture technologies are the future of sustainable agriculture. There are potential benefits of conservation agriculture across different agro-eco-regions and farmer’s groups.

The benefits range from nano-level (improving soil properties) to micro-level (saving inputs, reducing cost of production, increasing farm income), and macro-level by reducing poverty, improving food security, alleviating global warming.

There is a need for a global movement for promoting conservation agriculture. In India, the concept of conservation agriculture may be integrated with various government programs by sensitizing policy advisors, professionals and financial institutions.

The benefits of conservation agriculture need to be effectively communicated to all the stakeholders for its widespread adoption by the farming community. Failing that the sustainability of agriculture would be under threat and adversely affect natural resources and agricultural production. The most affected would be the under privileged and poor farmers in unfavorable and marginal areas. So it can be concluded that conservation agriculture is most need for Indian agricultural land for longer utilization and effective crop production

3.7 Conclusion:

Conservation agriculture represents a new paradigm for agricultural research and development that differs from the traditional one, which was primarily focused on meeting specific food grain production targets in India.

A paradigm shift has become necessary in light of widespread resource degradation issues that have accompanied previous strategies to boost production with little regard for resource integrity. Integrating productivity, resource conservation, soil quality, and environmental concerns is now critical to long-term productivity growth. In terms of knowledge base, developing and promoting CA systems will be extremely difficult.

The traditional approach to agricultural research and development in India has been replaced by a new approach that promotes conservation agriculture. It is becoming increasingly important to incorporate issues of productivity, resource conservation, soil quality, and the environment into continuous productivity increases.

It will be difficult to develop and promote CA systems without a solid knowledge base. Conservation agriculture provides a chance to prevent and reverse the downward spiral of resource degradation by lowering cultivation costs and increasing resource use efficiency, competitiveness, and sustainability in agriculture. The new mission must emphasize resource conservation while increasing output. Despite the obvious productivity, economic, environmental, and social benefits of CA, adoption does not occur on its own. Individual farmers have valid reasons not to implement CA in their specific farm situation.

The obstacles range in origin from intellectual, social, financial, biophysical and technical, infrastructural, to policy issues. Knowing the bottlenecks and problems allows for the development of strategies to overcome them. Crisis and emergency situations, which appear to be becoming more common in a climate change scenario, as well as political pressures for more sustainable use of natural resources and environmental protection on the one hand, and improving and eventually attaining food security on the other, provide opportunities to harness these pressures for supporting the adoption and spread of CA and assisting in overcoming existing adoption barriers.

As a result, the growing challenges confronting the world, ranging from the recent sudden global crisis caused by soaring food prices, high energy and input costs, rising environmental concerns, and climate change issues, provide policymakers with justification to implement supportive policies and institutional services, even including direct payments to farmers for environmental services from agricultural land use, which could be linked to the introduction of sustainable farming methods such as CA.

In this way the actual global challenges are providing at the same time opportunities to accelerate the adoption process of CA and to shorten the initial slow uptake phase. Conservation agriculture could decrease soil detachment and increase water infiltration that implies a decrease of water runoff; consequently, soil erosion would be reduced. Effects of conservation agriculture on reducing erosion were mainly caused by crop residues retained on the soil surface.

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4. Soil Health Management Under Conservation Agriculture

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Abstract:

Soil health is a key issue in agro ecosystems. Conservation agriculture (CA) aims to conserve, improve, and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs. CA can be defined as the minimal soil disturbance (no-till) and permanent soil cover (mulch) combined with rotations can be considered as an effective strategy against soil degradation and consequent improvement of soil health and quality. This chapter has made an effort to compile scientific data on how conservation agricultural practices are influencing soil health improvement. Ultimately, it is evident that CA practices positively impact soil microorganisms and microbial processes ascribed to changes in the quantity and quality of plant residues that enter the soil, their spatial distribution, change in the provision of nutrients, and physical alterations. The microbiological activity of the soil is improved by agricultural practices that offer a greater crop diversity, a decrease in mechanical soil disturbance, and/or an increase in organic amendment inputs that are characteristics to CA systems. It is necessary to develop new technologies and tools to guarantee soil's long-term productivity and environmental sustainability in preserving and improving soil health.

Keywords:

Conservation agriculture, Soil health, Soil quality, Long term productivity, Environmental sustainability

4.1 Introduction:

Soil is a natural body comprised of solids (minerals and organic matter), liquid and gases that occurs on land surface occupies space and is characterized by one or both of the following: horizons or layers that are distinguishable from the initial material as a result of additions, losses, transfers and transformations of energy and matter or the ability to support rooted plants in a natural environment. The upper limit of soil is the boundary between soil and air, shallow water live plants or plant materials that that have not begun to decompose, while lower boundary that separates soil from the non-soil underneath is most difficult to define. Soil Consists of the horizons near the earth surface that in contrast to the underlying parent material have been altered by the interaction of climate, relief and living organists over time.

The soil is a living, four-dimensional natural entity containing solids, water (or ice) and air. Most soils are outside and are open systems, but soils also occur in shallow lakes and underneath pavement. A soil can have any colour, any age, be very shallow or deep, and consists mostly of a structured mixture of sand, silt and clay (inorganics), rocks and organic material (dead and alive).

The soil has one or more genetic horizons, is an intrinsic part of the landscape, and changes over time. Soil are distributed across the earth mostly in a systematic manner. Soils store and transform energy and matter. The soil often supports vegetation, carries all terrestrial life, and produces most of our food. It is an integral part of the natural world interacting with the climate, lithosphere and hydrosphere. Soils are often studied in combination with land-use, climate, geomorphology or the hydrology of an area.Soil acts as an interface between environment and agriculture and thus it’s health and quality has a key role in determining environmental quality and agricultural sustainability which jointly determine plant, animal, and human health. Figure 4.1 shows the main functions exerted by soil.

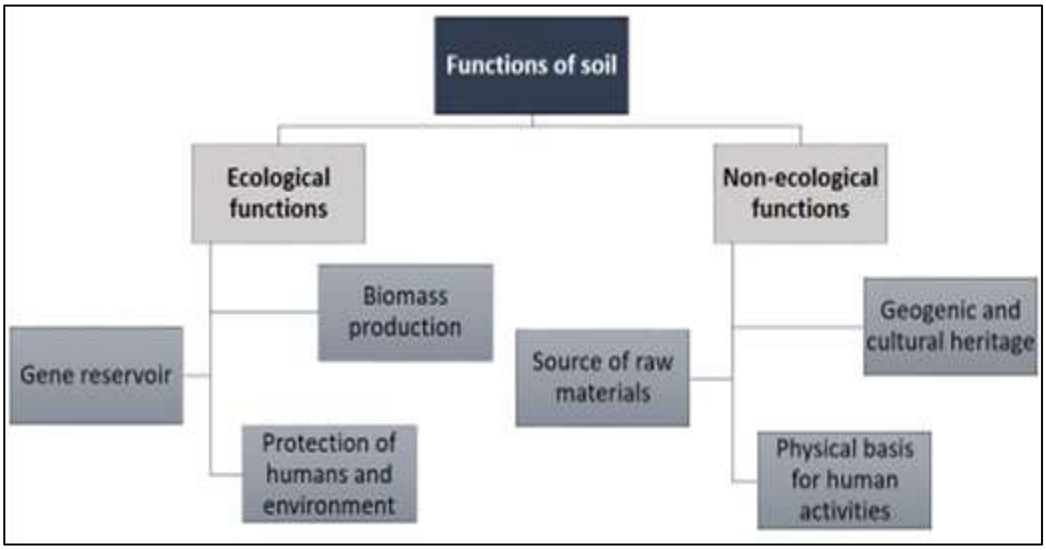


Figure 4.1: Functions of Soil (Blum, 2005)

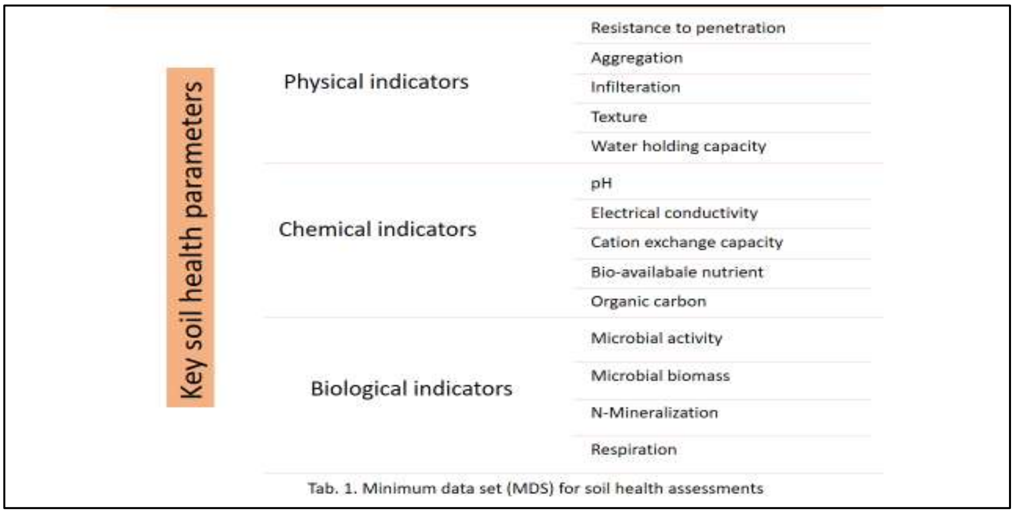
4.2 Soil Health:

Defining and evaluating the soil quality and health is essential to comprehend soil as a critically important component of biosphere for the production of food and fiber, ecosystems functioning and to maintain local, regional, and global environmental quality. Concepts such as soil health and soil quality has been receiving increasing political and scientific interest in recent times. Soil health has been broadly defined as the capacity of a living soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health. The terms soil health and soil quality are often used interchangeably. The potential ability of the soil to sustain biological productivity, improve environmental quality, and promote plant and animal health is referred to as its soil health, while soil quality concerns the capacity of a specific kind of soil to sustain a particular use, such as crop production. There exists an equilibrium between soil function for productivity, environmental quality, and plant and animal health for optimal soil health. The most important criteria for selecting indicators of soil quality and health are their usefulness in defining ecosystem processes and integrating physical, chemical, and biological properties; their sensitivity to management and climatic variations; and their accessibility and utility to agricultural experts, producers, conservationists, and policy makers. Six essential characteristics which are depicted below were considered by [1] as indicators of a healthy soil.

Figure 4.2: Characteristics of Soil Health (Wang and Hooks, 2011)

Apart from these conceptual definitions, operational definitions establish a series of key indicators to evaluate soil health, which can be divided into physical, chemical and biological properties. It is impractical to measure soil health in the field or in a lab; instead, it can only be determined through the measurement of soil indicators. These factors can be measured in the soil and have an impact on ecosystem services and soil function.

No single indicator will give an idea of soil health clearly, so it's necessary to adopt an integrative approach by establishing a minimum data set (MDS) including physical, chemical, and biological parameters of the soil in order to get a more valid idea on soil health. Major criteria adopted while choosing a MDS include, easiness to measure, rapidity, sensitiveness to management, relevance to soil ecosystem functions and informative for management.



Key soil health parameters		
	Physical indicators	Resistance to penetration
		Aggregation
		Infilteration
		Texture
		Water holding capacity
	Chemical indicators	pH
		Electrical conductivity
		Cation exchange capacity
		Bio-availabale nutrient
		Organic carbon
	Biological indicators	Microbial activity
		Microbial biomass
		N-Mineralization
		Respiration

Tab. 1. Minimum data set (MDS) for soil health assessments

Figure 4.3: Key Soil Health Parameters (Wang and Hooks, 2011)

4.3 Conservation Agriculture (CA):

The Food and Agriculture Organization (FAO) defines CA as an agro ecosystem management system to ensure food security and improve profits while preserving environmental resources. Conservation agriculture (CA) aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs. It contributes to environmental conservation as well as to enhanced and sustained agricultural production. It can also be referred to as resource efficient or resource effective agriculture [2]. A constant or semi-permanent organic soil cover is maintained by conservation agriculture, according to the FAO. This could be dead mulch or a living plant, which physically shield the soil from the sun, rain, wind or other climatic disturbances as well as to provide food for the soil biota. The tillage process and soil nutrient balancing are taken over by the soil microorganisms and soil fauna, where mechanical ploughing interferes with this process. Direct sowing and zero or minimum tillage are crucial components of CA. To prevent disease and pest issues, a diverse crop rotation is also essential.

Adoption of crop rotation to control pest and diseases and practicing zero or minimum tillage along with direct seeding are important elements of CA [2]. Currently, more than 2 billion people struggle with critical micronutrient deficiencies, almost 800 million people lack access to enough food, and roughly 60% of people in developing countries suffer food insecurity.

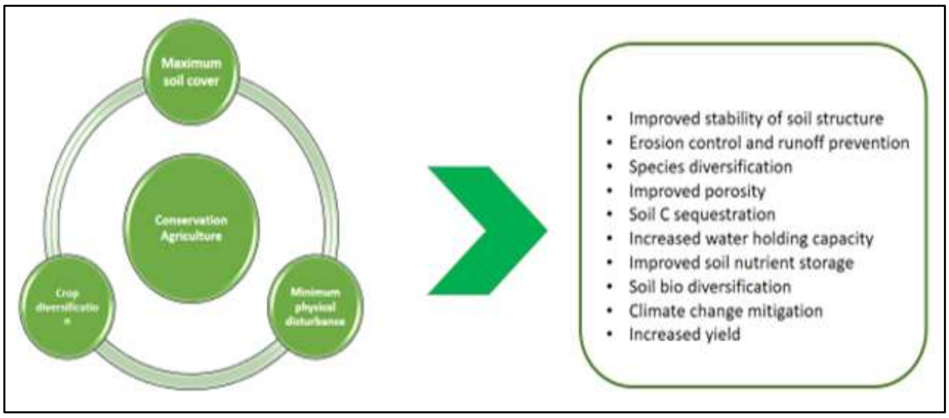


Figure 4.4: Benefits of Conservation Agriculture on Soils

The three primary principals followed in conservation agriculture which are, minimum mechanical disturbance, permanent soil organic cover with crop residues and species diversification (crop rotations, sequences, and associations), can be considered as a classical approach to define CA. The new sustainable agricultural intensification plan developed by the FAO is centered on CA. The fact that CA is more affordable in terms of both money and effort is one of its key benefits, which makes it popular with farmers. Some of the benefits of CA are summarized in fig.3.

4.4 Soil Health Management Under Conservation Agriculture (CA):

Global estimates indicate that 45% of the arable land is affected by degradation. Agricultural, industrial, and commercial pollution, urban expansion, overgrazing, long-term climatic changes, unsustainable agricultural practices viz., conventional tillage, continuous cropping with insufficient inorganic and organic fertilizers inputs and reduced organic matter addition in soil can be considered as the major factors leading to land degradation. Many practices can be adopted to prevent land degradation, which include afforestation, proper management of grazing land, control on mining activities and sustainable agricultural practices. Simple acts such as leaving vegetation on soil to allow nutrients to return into the earth, planting of shelter belts, promotion of crop diversification, agroforestry practices etc. helps in reversing soil degradation in particular.

Conservation agriculture which is defined as the minimal soil disturbance (no-till) and permanent soil cover (mulch) combined with rotations can be considered as an effective strategy against soil degradation and consequent improvement of soil health and quality. CA measures have been proven effective in terms of maintaining major soil functions viz. C cycling and transformation, nutrient cycling, and soil structure maintenance etc.

Contrarily, there is an almost general believe that certain practices of conventional agriculture to increase agricultural production have negative effects on the health of the soil. The total effect of CA systems on soil health is site-specific and depend on climatic conditions. It also depends upon the amount of time operating under a CA system and types of practices involved like types of cover crops, intensity of the crop rotation, etc. Influence of CA on soil health can be broadly classified under three categories:

4.4.1 Influence of CA On Soil Physical Properties:

A. Soil Structure:

Soil structural development can be enhanced by management systems that reduce soil disturbances, increase organic matter inputs, increase plant cover, and improve soil fertility. In this sense, one of the major negative impacts of conventional long-term tillage is the deterioration of the soil structure due to the reduction in soil organic matter. Numerous studies have reported an improvement in the stability of soil aggregates due to the application of CA practices [3].

Higher aggregate stability under CA practices can be summed up in following heads: (i) the retention of organic residue on the soil surface protects soil aggregates from raindrop impact and avoids soil compaction; (ii) organic matter decomposition increases the aggregate formation in soil ; (iii) least soil disturbance in CA enhances fungal populations and the persistence of root networks promote aggregate stability ; and (iv) reduced soil disturbance in CA systems causes a more stable soil structure than in CT systems. These CA-induced improvements in soil structure promote other favourable impacts on the soil, such as higher water infiltration through the soil profile, greater erosion protection, increased water-holding capacity, improved habitats for microbial activity, and so on.

B. Bulk Density:

The bulk density is one of the most common physical parameters to assess the impact of tillage and crop residue on agricultural soils, as it is an indicator of the soil’s compaction and reflects the soil’s ability to function in terms of structural support, water and solute movement, and soil aeration. The effect of conservation tillage systems (minimum/reduced tillage and no tillage) on the apparent density of the soil is not immediate; it is necessary that a few years elapse from the conversion from CT to reduce it. Some studies have shown that, the deposition of crop residues and soil organic carbon (SOC) on the soil surface in the first few centimetres of NT resulted in a reduced bulk density. Under no-tillage systems, the amount of residue may not always be sufficient to control the increase in bulk density. In these circumstances, the wastes can be shredded, increasing the covered area and reducing soil hardening. In conservation tillage, crop residue assimilation into the soil plays a critical role in lowering bulk density. In this sense, attributed that lowering of bulk density in CA systems is due to the presence of higher amounts of organic matter, which tends to improve soil structure and increase porosity. At 0 to 15 cm depth, the greatest difference compared to CT occurs with 35 years of continuous zero tillage. The bulk density at depths of 15–30 cm decreased linearly over the years of NT. This decrease in bulk density is associated with an increase in total soil porosity.

C. Surface Seal and Soil Crust:

Bare soil in conventional systems leads to increased surface seal and crust formation due to the lack of protection against the impact of raindrops. The impact of rainfall causes the breakdown of soil aggregates and the release of finer particles, which are redistributed by the near-surface and fill the most superficial pores. This process causes sealing and surface waterproofing, decreasing water infiltration and, consequently, enhancing the runoff and soil loss.

The presence of crop residues in CA practices can help protect the surface of the soil from raindrop impact and prevent surface sealing. In structurally unstable soils or regions where crusting is a serious problem, the maintenance of adequate surface cover is paramount to avoid surface sealing and crust formation. Thus, a permanent soil surface cover by crop residues significantly reduces surface sealing. Various studies report on the preventive effect against surface sealing in CA exerted by crop residues on the soil surface, protecting the soil from the direct impact of raindrops.

D. Soil Compaction:

Soil compaction is a form of physical degradation that consists of the densification of the soil, which often results in the destruction of the soil structure; a reduction in biological activity, porosity, and permeability; an increased risk of erosion; a restriction on root development; and, consequently, decreased crop performance. On farmland, the traffic of heavy agricultural machinery is the main cause of soil compaction, and its magnitude increases with the number and intensity of tillage operations and when these are carried out in inappropriate soil moisture conditions.

The influence of the machinery is so important that “controlling in-field traffic” is considered a component of CA. Bed planting, which decreases compaction by limiting traffic to the furrow bottoms, or the application of nutrients during seedbed preparation or seeding to reduce machinery transit, are both recommended techniques. Tillage causes soil compaction and the creation of a plough pan in the subsoil over time. Crop rotation, cover crops, and crop residue addition can all help to alleviate soil compaction in CA systems.

E. Soil Moisture Content:

CA practices improve soil moisture availability, especially under low-rainfall conditions and could contribute to maintaining crop yield in a changing climate scenario. In this sense, several studies have reported a greater availability of water in CA systems with respect to CT.

Residue retention and cover crops in CA systems improve infiltration and reduce runoff rates and evaporation losses, as they protect soil from direct contact with solar radiation and act as a barrier to air flow, contributing to higher soil moisture. In irrigated plantations, crop residues conserve soil moisture and delay irrigation timing, allowing farmers to save irrigation water.

F. Water Runoff and Soil Loss:

Conventional agriculture promotes runoff and soil loss by causing soil compaction, crusting, and surface sealing, and by decreasing porosity. In contrast, CA is associated with a decreased soil erosion. Cover crops and their residues also moderate the velocity of agricultural runoff along the slope, enhancing infiltration and minimising soil erosion.

According to [4] conservation methods reduce surface runoff and erosion by 67 and 80%, respectively, when compared to conventional approaches; cover crops are the most effective at reducing erosion and runoff.

4.4.2 Influence of CA On Soil Chemical Properties:

A. Soil Organic Carbon:

SOM is a keystone indicator of soil quality because it is linked to other physical, chemical, and biological soil quality indicators, playing a crucial role in soil fertility and sustainability. It increases soil aggregate stability and water retention and provides a reservoir of essential nutrients for crops. Increased SOC has a positive influence on soil quality, which can improve soil resilience and contribute to climate change adaption.

The transition from conventional to conservation tillage increases SOC deposition in the soil surface layer. CA improves SOC stock through reducing SOC losses owing to oxidation and erosion, increasing organic carbon inputs to the soil (plant leftovers), or a combination of the two. In an intense cereal-based cropping system in India, long-term CA increased SOC concentration in the 0-5 cm soil layer.

In a study conducted in northern Italy, [5] discovered that CA systems resulted in much higher SOC content and SOC stock in the medium term than traditional systems

B. Soil PH:

Conservation methods have a limited effect on soil pH in the topsoil layers. The effect of crop residues on soil pH is determined by the chemical composition of the residues as well as the soil parameters. Residues high in ash alkalinity and N, such as some legume residues, will have a greater effect on pH compared to residues with lower content, such as wheat.

The initial pH of the soil has a significant impact on the change in soil pH caused by crop residue incorporation because it affects the mineralization of N in the residue and the rate of decomposition of organic components. Many studies discovered that reduced tillage treatments increased acidity in topsoil layers compared to CT.

This rise in acidity is attributable to more soil organic matter accumulating on the soil surface in NT, which decomposes and causes acidity. When the soluble component of the residues flows across the soil profile and contributes to the alkalization of the subsurface layers, there is an increase in pH in the deeper layers.

C. Cation Exchange Capacity:

CA techniques enhance SOM content, which raises CEC by increasing the number of negative charges. Cover cropping practices which promotes organic matter addition has been shown to increase CEC. On the contrary there is chances for reduction of CEC in CA plots under conditions of high litter fall which lowers the soil pH and results in decrease of pH-dependent cation exchange sites.

D. Nutrient Availability:

CA techniques have a major impact on nutrients distribution and transformation in soil, and as a result, they can have a significant impact on soil nutrient dynamics. That is, CA systems that increase organic matter due to residue addition can increase nutrient reserves for plants by registering higher concentrations of nitrogen (N) phosphorus (P) potassium (K) calcium, magnesium, zinc, and manganese in the soil. The composition and management of agricultural leftovers have a substantial impact on soil plant nutrient availability. In the case of N, for example, the addition of legume residues with a low C/N ratio can result in N mineralization, whereas cereal residues with a high C/N ratio can result in N mineralization.

4.4.3 Influence of CA On Soil Biological Properties:

Soil biota, which represents one of the largest reservoirs of biodiversity on earth plays an important role in soil health and sustainable crop production by providing habitat for aboveground and underground biota, regulating climatic factors and water quality, controlling pollution, and supporting food production. CA increases biotic diversity in the soil as a result of the mulch and reduced soil disturbance. Surface mulch helps moderate soil temperatures and moisture, which is favourable for microbial activity. Parameters like the size and activity of the microbial population and soil enzymatic activities are used to gauge how soil microorganisms and biochemical properties respond to soil management techniques. The following are some key considerations for healthy soils: ’ Soil OM formation and the multitude of organisms involved – fauna and flora; ’ Healthy roots and the synergistic associations with biological organisms, e.g. rhizobia, mycorrhiza, and antifungal agents; ’ Soil microbes protect their territory and through microbial competition maintain a balance that stabilizes the population; ’ Some microbes help roots control disease – antifungal agents; ’ Healthy soils have more microbes than unhealthy soils; ’ Mulching helps promote more diversity of microbes through temperature and moisture moderation.

A. Microbial Activity:

Soil microbial biomass (SMB) is commonly used to evaluate soil microbial activity, as it’s a very sensitive parameter to changes in soil microbial activity. So it can be used as an indicator to change in soil management practices. Reduced physical disturbance to soil, increased SOM, favorable water and thermal environments, and a wider array of substrates are all factors that CA employs to produce the most favorable conditions for microorganisms. Release of root exudates and secretions from roots of crops in rotation or intercropping system supports the microbial growth and enhance their activity.

This will enhance the biomass bounded to microbial body and there is an increase in microbial biomass carbon (MBC) in soil under intercropping system compared to monocropped area. A more diverse soil bacterial community can be observed in soils under conservation tillage than soils under conventional tillage practices. Soil tillage is the agronomic practice that most influences soil bacterial diversity, with a greater functional and taxonomic diversity of bacteria in agricultural soils with minimal tillage compared to conventional tillage. Greater microbial diversity has been found in soils with a cereal based cropping system, which indicates the influence of crop system on microbial activity.

The higher C: N ration of cereal straw stimulated the microbial community to break down the organic substrate and promote microbial activity. Exudates released by plants and roots stimulate and maintain particular rhizo-bacterial communities that improve nitrogen fixation, nutrient cycling, pathogen bio-control, plant disease resilience, and plant growth stimulation.

B. Soil Enzymatic Activities:

The microbial enzymatic activities of the soil serve as an indicator of the potential of the soil to decompose organic C and mineralize nutrients (P and N), and thereby nutrients available for plants. Soil enzymatic functions are greatly influenced by the cropping system and the degree of soil disturbance. The main enzymes used to determine soil health are β-glucosidase, N-acetyl glucosaminidase, and acid phosphatase, which are responsible for mediating C, N, and P cycling in the soil, respectively. [6]

Minimum tillage promotes soil enzymatic activities viz., β-glucosidase, soil urease, dehydrogenase, and total phosphate activities activity due to the augmentation in microbial biomass, more substrate availability, and reduced soil disturbance. Soil enzyme activity were dramatically boosted in a conservation agriculture fields compared to conventionally cultivation plots. When compared to CT, CA methods like zero-tilled flatbed and permanent bed significantly boosts dehydrogenase, alkaline phosphatase, and urease activities resulted from the adoption of minimum tillage which improves -glucosidase activity due to increased microbial biomass, increased substrate availability, and decreased soil disturbance. Ultimately, it is evident that CA practices positively impact soil microorganisms and microbial processes ascribed to changes in the quantity and quality of plant residues that enter the soil, their spatial distribution, changes in the provision of nutrients, and physical alterations.

C. Earthworms:

Earthworms are one of the most significant soil macro faunal groups, and their influence on soil qualities and the availability of resources for other creatures have earned them the moniker "ecosystem engineers". Soil tillage harms earthworms physically and alters their environment, altering the community structure and relative abundance of earthworms. Consequently, the species that live in the topsoil are particularly vulnerable to the effects of ploughing. CA techniques have been observed to be beneficial to earthworms. The rise in earthworm density under no-till systems is due to the combination of several impacts, including reduced injuries, less exposure to predators at the soil surface, reduced microclimate variations, and improved organic matter availability. Agricultural residues left on the soil surface and little soil disturbance improve soil structure, serve as a food source, and lower the soil temperature, allowing earthworm populations to grow. Furthermore, decreasing soil tillage intensity increased functional diversity and the number of anecic earthworms.

D. Soil Respiration:

Soil respiration includes microorganisms oxidising organic materials and rhizosphere respiration. It is a measure of the soil microbial community's metabolic activity. It is one of the most extensively utilised soil biological markers in assessing soil quality. Soil management influences soil microclimate and biotic variables (soil organic carbon, aboveground biomass, root biomass, and plant residues) that influence soil respiration indirectly. Many research studies have reported the effect of conservation agricultural methods on soil microbial respiration, although there are no clear trends, and [7] found no significant differences in soil respiration between conventional tillage and conservation agricultural approaches. This could be because tillage appears to impact the temporal distribution of CO2 emissions from the soil more than the total amount. The microbiological activity of the soil is improved by agricultural practices that offer a greater crop diversity, a decrease in mechanical soil disturbance, and/or an increase in organic amendment inputs that are characteristics to CA systems.

4.4 Conclusions:

This chapter has made an effort to compile scientific data on how conservation agricultural practices are influencing soil health improvement. In the coming years, crop production will need to use natural resources more effectively in order to create more food on a smaller amount of land while also having little negative environmental impact. Assuring soil's long-term productivity and environmental sustainability is the primary challenge in preserving and improving soil health. As discussed earlier in this chapter, CA systems can be used to improve soil health, reduce erosion, rebuild soil organic matter, support beneficial soil life and encourage the sustainability and multi functionality of agro ecosystems, thereby reducing the socioeconomic and environmental offsets resulting from soil degradation.

However, the promotion of CA technologies is still subject to a number of obstacles, including the lack of suitable seeders, particularly for small and marginal farmers, use of crop residues for livestock feed and fuel, burning of crop residues, the lack of skilled labour, lack of technical and financial support from governments and other related organizations, and more over lack of awareness among farming community. So it is urgent to create a framework of policy and marketing plans to foster CA and its principles. Some of the ways which we can adopt to promote CA practices among farming community include:

Identification of site specific or locally adaptable crop rotation and management practices to deal with agronomic challenges Identification and removal of social, cultural, technological and institutional barriers along with promotion of research studies and improvement in research efficiency of extension services, Availability and supply of machinery and balanced plant nutrition.

Rather than solely depending on conservation agricultural practices, it’s necessary to develop new technologies and tools to guarantee soil's long-term productivity and environmental sustainability in preserving and improving soil health.

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5. Robotics in Agriclture

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Abstract:

Agriculture is the foundation of society as it provides the food, feed, and fibre on which all humans rely to survive. Precision agriculture is utilized to supply adequate treatments at the right place and right time in favour to achieve low-input, high-efficiency, and for a long time agricultural production. Automation and robots have developed as critical technologies in precision agriculture, with the goal of reducing environmental impact and increasing agricultural productivity. Automation and robots in precision agriculture are mostly used for accurate agricultural management by utilizing modern technologies. A large amount of study has been conducted in recent decades on the applications of mobile robots for agricultural tasks such as planting, inspection, spraying, and harvesting. To minimize system mistakes during future deployment, the designing process of an efficient autonomous agricultural robotic system must examine all possibilities and problems in various types of agricultural operations. An autonomous system with many simple axis manipulators can be faster and more efficient than the currently available professional, high-priced manipulators.

5.1 Introduction:

In the management and production of agriculture, robotics is becoming increasingly important. In order to run farms effectively, agriculture needs time-saving and autonomous technologies. Although traditional farm machinery is crop and topographical dependant, researchers are currently concentrating on many farming operational aspects to build autonomous agricultural vehicles. The primary purposes for which agricultural robots have been studied and created to date include harvesting, chemical spraying, picking fruit, and crop monitoring. Due to their use of unmanned sensing and machinery systems, robots like these can replace human labour in many situations.

The robots are capable of multitasking, have keen sensory perception, are reliable in their operations, and are adaptable to unusual operating circumstances. Several precision farming tools were combined with a model structure design for the study on agricultural robotic systems. A few prototypes with the names CROPS, ISAAC2 and Michigan Hortibot, Australia's AgBot, Finland's Demeter, India's Agribot, and many others were created by the European Union. Several localization methods, including vision, GPS, laser, and sensor-based navigation control systems, are used in the construction of agricultural robots.

The current trend in agriculture is towards automation in order to increase production through the use of equipment and technology.

The design focuses on implementing three distinct verticals, including sensor modules, frameworks (for applications) and mobile robot navigation. Mobile robots are being developed in these sectors by numerous nations, including the USA, European Unions, Denmark, Australia, Finland, and India, primarily to supply agricultural farming over commercial industries.

To operate robots in a single control space for farming, research teams have created a variety of specialised navigational methods, including odometer, vision-based, sensor-based, inertial, active beacon, GPS, map-based, and landmark navigation. This method is applied to tasks like preparing seed beds, placing seeds, reseeding, crop scouting, mapping weeds, robotic weed management, micro-spraying, robotic gantry, robotic irrigation, etc.

The majority of research on agricultural autonomous robotics has been done in controlled settings, such as when cherry tomatoes, cucumbers, mushrooms, and other fruits are picked by robots. Robots have been used in horticulture to harvest apples and citrus. Moreover, milking robots have received a lot of attention, especially in the Netherlands.

However, there are two difficulties with the development of these platforms: developing an electronic architecture to integrate the numerous electronic components and creating a physical structure suitable for the agricultural environment. An electronic architecture needs to be strong and dependable, quick and simple to maintain, modular and adaptable to allow for future expansions and the connection of new equipment.

5.2 Concepts and Components of Robots:

The idea of using robotics in agriculture must be compliant, that is, it must respond to unexpected and uncertain working environments better, be compatible with existing technology, and be more cost-effective than alternatives. The idea of using robotic technology to mimic or duplicate conventional agricultural methods has been tested in a number of agricultural unit operations, but there are currently no commercially available robots that can handle the complicated field conditions seen in agriculture. Sensors, end-effectors, a control system, a manipulator, and a power source make up the fundamental parts of a robotic system. End effectors are the final robotic components that are attached to the robotic arm or appendages.

They are used to handle, grab, or grasp objects in order to manipulate them. Robotic arms, also referred to as manipulators, are composed of finite, non-rigid parts called links. Joints connect the linkages to one another. Revolute, cylindrical, planar, spherical, spherical, screw, and prismatic joints are frequently employed in robotics. Roll, pitch, and yaw are used to perform the wrist or rotary moment in the x, y, and z axes.

Robot work volume is the three-dimensional area surrounding the robot where it can move its wrist to its maximum and minimum reach. The sensors are an essential part of measuring the environment and transforming the data into something that can be read.

The static and dynamic features of the sensors define them. In robotics, there are two different types of sensors: wheeled sensors and tactical sensors.

Whereas wheeled sensors are used to monitor the position or speed of the motor, tactical sensors are intended to sense physical touch and proximity. When developing a robotic system, choosing the power source is crucial. Care must be made to consider how the power source will affect the system's mechanism, packaging, weight, and size.

In robotics systems, generators, hybrids, batteries, solar cells, and fuel cells are the most often used power sources.

The control system acts to govern the behavior of all other subsystems; it needs information and knowledge about all the subsystems to be controlled, including their current and future stages.

There are two types of control systems: open and closed loop. It is crucial to have an effective control system to monitor and manage the robotic technology subsystems in order to complete a task with the specified aim.

5.2.1 Applications of AI in Agriculture Sector:

There appear to be four main categories in which the most common uses of AI in Indian agriculture may be found:

A. Crop and Soil Monitoring: Businesses are using sensors and various IoT-based technologies to keep an eye on the health of their crops and soil.

B. Predictive Agriculture Analytics: A number of AI and machine learning techniques are being used to forecast the best time to plant seeds, receive alerts regarding the dangers of pest assaults, and more.

C. Supply Chain Efficiencies: To create an effective and intelligent supply chain, businesses are employing real-time data analytics on data streams coming from many sources.

D. Agricultural Robots: Businesses are creating and programming autonomous robots to undertake crucial agricultural jobs, such harvesting crops more quickly and in greater quantities than human laborers.

5.3 Robotics and Automation Reasons:

- Labor issues are a key factor in the rise of automation and mechanization.
- Harvest crops at the right time to minimize crop losses.
- Knowledge and availability when required
- Is the cost of labor truly too high?
- Laborers' skill levels and expertise are frequently unavailable.
- Machines with sensors may be objectively monitored for product throughput.
- Consistency in output quality
- Low-cost labor competition for production

5.4 Production of Vegetables Using Robots:

- Greenhouses and nurseries
- Growing vegetables
- On-site observation
- Mechanical aids
- Machines and mechanization
- Harvesting and picking
- Sorting and grading
- Packing
- Accumulation

In the realm of agriculture, there are many different kinds of robots in use, and new technologies are always being created. Out of all of those, the following types of agricultural robots have gained popularity:

A. Iron Ox Lettuce Robot:

The robot employs a blockish frame to travel from one side to the other and is constructed to operate in glasshouses. Each factory is represented in three confines by the robot using a stereo camera that's installed on its arm. The gripper on the arm is made specifically to fit the capsules.

Figure 5.1: Iron Ox Lettuce Robot

B. Mit Robot Gardener:

The Massachusetts Institute of Technology scholars produce a mobile robot that can regulate the soil's humidity position and elect ripe fruit. Each factory has a network of detectors that cover the soil's moisture and signal the robot to bring water. Wireless communication exists between the robot and the factory detector.

Figure 5.2: MIT Robot Gardener

C. Hortibot:

The equipment that assists farmers with weeds is called HortiBot. The robot can recognize and get rid of up to 25 different types of weeds with an environmentally friendly wee-removing attachment.

Figure 5.3: Hortibot

D. Agbot II:

AgBot II is a robot created to assist farmers in making decisions on the application of fertilizers, insecticides, herbicides, and watering systems.

Figure 5.4: AgBot II

E. Hamster Bot:

The independent robot known as the Hamster Bot rolls over spreads without venturing them. A variety of detectors that measure soil temperature, composition, humidity, and factory health are mounted inside the ball.

Figure 5.5: Hamster Bot

F. Rowbot:

The robot Rowbot is made to serve in a range of settings. The junking of height restrictions caused by a crop that's expanding snappily is one exertion that involves moving between the rows of sludge. In order to apply fertiliser and gather information regarding the sludge, the robot can potentially work in groups.

Figure 5.6: Rowbot

G. Autonomous Robot Tractor:

This self-steering tractor is extremely accurate and capable of a wide range of manoeuvres. The tractor's direction change is a significant problem in an unsteady and unpredictable terrain. Both advanced computers and simple sensors are insufficient to solve the problems. This robot uses a programming that allows it to change its orientation in response to the terrain.

Figure 5.7: Autonomous Robot Tractor

H. Spray Robot:

The Spray robot is a different greenhouse tool created for autonomous spraying. The robot travels across the greenhouse on a 30 cm-wide pipe rail system. In addition to tomato, cucumber, pepper, and aubergine, it is indicated for use in rose, gerbera, anthurium, alstroemeria, and orchids.

Figure 5.8: Spray Robot

I. Trakur:

A robot called Trakur (fog) is used to spray insecticides in greenhouses. The robot employs a cable that produces an electromagnetic signal, algorithms, and GPS data for navigation.

Figure 5.9: Trakur

J. Vinbot:

This robot contains several sensors that might collect data and help winemakers determine the vineyard yield. The robot, known as VINBOT, uses a cloud network to gather and evaluate 3D data and vineyard pictures.

Figure 5.10: Vinbot

K. Bee Bot:

This little flying robot is used for pollination and is modelled after bees.

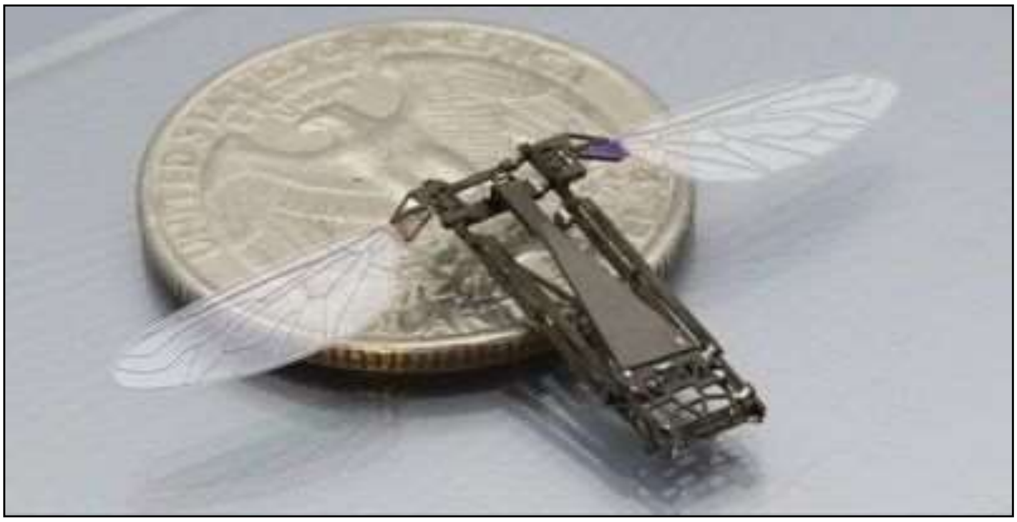

Figure 5.11: Bee Bot

L. Nursery Bot:

The Nursery Bot is the answer to moving potted plants automatically. The robot moves the plants to the desired area using wheels, gripper arms, trays, and sensors.

Figure 5.12: Nursery Bot

M. Ladybird:

Ladybird has methods and tools that enable it to carry out tasks on its own. The robot is employed for monitoring, mapping, categorization, and detection of various veggies.

Figure 5.13: Ladybird

N. Vine Robot:

The robot, which is just a prototype, controls the vines using cutting-edge sensors and artificial intelligence. Data on water quality, productivity, vegetable growth, or grape content are provided by the robot.

Figure 5.14: Ladybird

O. Insect Control Robot for Controlled Agriculture:

This is an autonomous insect control system able to move on a rail in greenhouses.

Figure 5.15: Ladybird

P. Gripper Inspired by Octopus:

This robot arm is moving the vegetables on a party tray back and forth somewhere in a lab. Each piece of broccoli can be wrapped in its blue fingers, which then lift it to a nearby chamber.

Figure 5.16: Ladybird

Q. Pro Packing Robot:

The fruit or vegetable cartons will be filled by this robot. A camera that has been configured to distinguish between the sorted items is part of the machinery.

Figure 5.17: Ladybird

5.6 Conclusion:

Future food security will be greatly maintained by robotics and automation in agriculture. Due to the advanced technology provided by the established system, farmers are now able to complete agricultural tasks quickly thanks to the use of robotics equipment. Because the development of robotic systems in agriculture is generally focused on mimicking the behavior of human labor in the completion of agricultural operations, operations like planting, inspection, spraying, and harvesting will be carried out efficiently with the least amount of operational costs and human labor.

The creation of a reliable and effective agricultural robotic system with the primary goal of producing a high level of agricultural output in order to preserve food security in the future may be accomplished in the future by designing a systematic autonomous agricultural robotic system.

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6. Crop Modelling of Adaptive and Mitigating Potential of Climate Smart Practices

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Abstract:

As the world population continues to rise, food production will have to be increased to meet and sustain the demands of our rapidly growing population. Not only will food production need to increase, but yields will need to be able to withstand climate changes which include increased temperatures and decreased rainfall patterns. By understanding and being able to predict crop production outcomes under various climatic situations and management approaches, farmers will be better equipped with adaptation strategies to maximize crop growth as sustainably as possible. Crop modelling tools offer a way to evaluate potential adaptations in climate and can help form the basis of decision-support systems for farmers.

Crop models are a formal way to present quantitative knowledge about how a crop grows in interaction with its environment. Using weather data and other data about the crop environment, these models can simulate crop development, growth, yield, water, and nutrient uptake. Crop models are sets of mathematical equations that represent processes within a predefined plant system as well as the interactions between crops and the environment. Considering the complexity of agricultural systems and the existing gaps in present knowledge, it seems impossible to express entire processes of a crop system in mathematical terms provided that agricultural models are still simplified versions of reality (Wallach et al., 2014). The ultimate purpose of developing crop models is to get a precise estimation of the economic yield. However, depending on the availability of information and data at the interested scale, crop models are developed at different levels of complexity (Jones et al., 2017).

Therefore, they may range from multivariate regression, so-called empirical models based on monthly weather variables intended to predict crop yields at regional scale (Paswan and Ara Begum, 2013), to process-based ones, so-called mechanistic models of plant growth, developed for getting insight into the crop physiological interactions (Janssen et al., 2017). Since 1970, several mathematical models at different levels of sophistication have been developed for simulation of growth, development, and yield of cultivated crops. These models are extensively used for different purposes such as crop management, yield gap analysis, crop-pest interactions, and climate change impact studies (Jin et al., 2018; Jones et al., 2017; Ritchie and Alagarswamy, 2002; Van Ittersum et al., 2013). Crop models are used for an increasingly broad range of applications, with a commensurate proliferation of methods. Careful framing of research questions and development of targeted and appropriate methods are therefore increasingly important.

Keywords:

Crop Models, Adaptation, Mitigation, Stakeholders.

6.1 Introduction:

Crop modelling in agriculture uses quantitative measurements of ecophysiological processes to predict plant growth and development based on environmental conditions and crop management inputs. These models simulate a crop’s response (growth or yield, for example) to the environment, management, water, weather, and soil parameters, as they interact over the course of a growing season. These tools mimic the growth and development of crops to mathematically represent the various components within the cropping system. The concept of crop modelling dates back to the 1960s when researchers modelled agricultural systems by combining both physical and biological principles. Crop models rely on measurable inputs (by sensors, machines, or hand measurement) to determine whatever output is of interest (plant growth, crop yield, soil nitrogen, crop staging, etc.).

Figure 6.1: Crop Modelling

Crop models are mathematical algorithms that capture the quantitative information of agronomy and physiology experiments in a way that can explain and predict crop growth and development. Crop models are a formal way to present quantitative knowledge about how a crop grows in interaction with its environment. Using weather data and other data about the crop environment, these models can simulate crop development, growth, yield, water, and nutrient uptake.

The data used in crop models include daily weather data, such as solar radiation, maximum and minimum temperatures, rainfall, as well as soil characteristics, initial soil conditions, cultivar characteristics, and crop management. Crop models are mathematical algorithms that capture the quantitative information of agronomy and physiology experiments in a way that can explain and predict crop growth and development.

They can simulate many seasons, locations, treatments, and scenarios in a few minutes. Crop models contribute to agriculture in many ways. They help explore the dynamics between the atmosphere, the crop, and the soil, assist in crop agronomy, pest management, breeding, and natural resource management, and assess the impact of climate change.

6.2 Modelling for Crop Improvement:

Crop models can also be used as a guide for breeding programmes or as a means to envision a crop idiotype (Boote ***et al.***, 1996). While simulation models can be used to predict appropriate trait phenotypes and selection protocols in breeding programmes to achieve ideotypes (Boote ***et al.***, 1996), for a true integration of crop models and breeding, the inheritance of model parameters is required (Yin ***et al.***, 2003). One objective that can be pursued in a breeding programme is to optimize plant carbon allocation among plant components (i.e. leaf, stem, rhizome and root), which requires at least (1) phenotypic and genotypic data, and (2) a crop model that can capture the impact of different carbon allocation schemes on growth and biomass production.

This approach can be used to study the effects of genotypes with different biomass participating schemes. However, there is clearly a balance between the support and nutrient acquisition provided by rhizomes and roots and the benefit of partitioning more biomass to above-ground organs that can be harvested. One factor that is likely to have a major impact on carbon allocation is the manipulation of flowering time (Sticklen, 2007). By reducing the energy invested in reproductive structures, the proportion of biomass available for harvest can be increased (Ragauskas ***et al.***, 2006) and optimized to develop cultivars adapted to particular regions.

For example, an improved carbon allocation scheme can result in reduced leaf area by increasing the number of stems and/or their thickness. In addition, maintaining leaf area index at optimum values (Hay and Porter, 2006) also has the potential of reducing crop transpiration and thus improve water use efficiency which can be especially important for biomass production in dry environments (Richards ***et al.***, 2002). This reduction in leaf area index will be most beneficial if it does not impact on the timing of canopy closure and maximum light interception. It should also be considered that flowering is an important component in triggering senescence processes which, in perineal crops, initiate translocation of nutrients and carbohydrates to below-ground storage (Heaton ***et al.***, 2009).

If delayed flowering prevents this from happening, the nutrient use efficiency will decrease, impacting the sustainability of the cropping system, since synthetic fertilizers need to be added and the excess N in the exported biomass needs to removed or treated (Beale and Long, 1997).

A gap between the potential and practical realization of adaptation exists adaptation strategies need to be both climate-informed and locally relevant to be viable. Place-based approaches study local and contemporary dynamics of the agricultural system, whereas climate impact modelling simulates climate-crop interactions across temporal and spatial scales. Crop modelling studies have projected a 7–15% mean yield change with adaptation compared to a non-adaptation baseline. Climate change adaptation and mitigation strategies and the impacts on the global food system and socio-economic development can be simulated over long-term predictions.

While this long-standing approach may remain an essential three further key components:

- Working with stakeholders to identify the timing of risks. What are the key vulnerabilities of food systems and what does crop-climate modelling tell us about when those systems are at risk?
- Use of multiple methods that critically assess the use of climate model output and avoid any presumption that analyses should begin and end with gridded output.
- Increasing transparency and inter-comparability in risk assessments.

Adaptation can be understood as the process of adjusting to the current and future effects of climate change. Mitigation means making the impacts of climate change less severe by preventing or reducing the emission of greenhouse gases (GHG) into the atmosphere. The adaptation strategies include the application of organic fertilizers, changing of planting dates and growing of short duration crop varieties. The application of organic fertilizers increases crop yields by improving soil moisture content and supply of nutrients to crops (Below et al. 2020). The mitigation actions are planning and zoning, floodplain protection, property acquisition and relocation, or public outreach projects. Examples of preparedness actions are installing disaster warning systems, purchasing radio communications equipment, or conducting emergency response training.

6.3 Crop Modelling of Adaptive and Mitigating Potential of Climate Smart Practices

6.3.1 The Role of Crop Models in Assessing Risk and Adaptation:

Crop models have a long history, during which their focus and application have altered in response to societal needs. They have contributed to decision support and risk assessment and have resulted in conceptual and practical advances in publicly-funded agricultural development work. The last decade has seen an increase in the use of crop-climate ensembles targeted at informing adaptation. Food systems risks can be defined narrowly as the potential for reduced food production (e.g. Li et al., 2009), or broadly as the risk to food security.

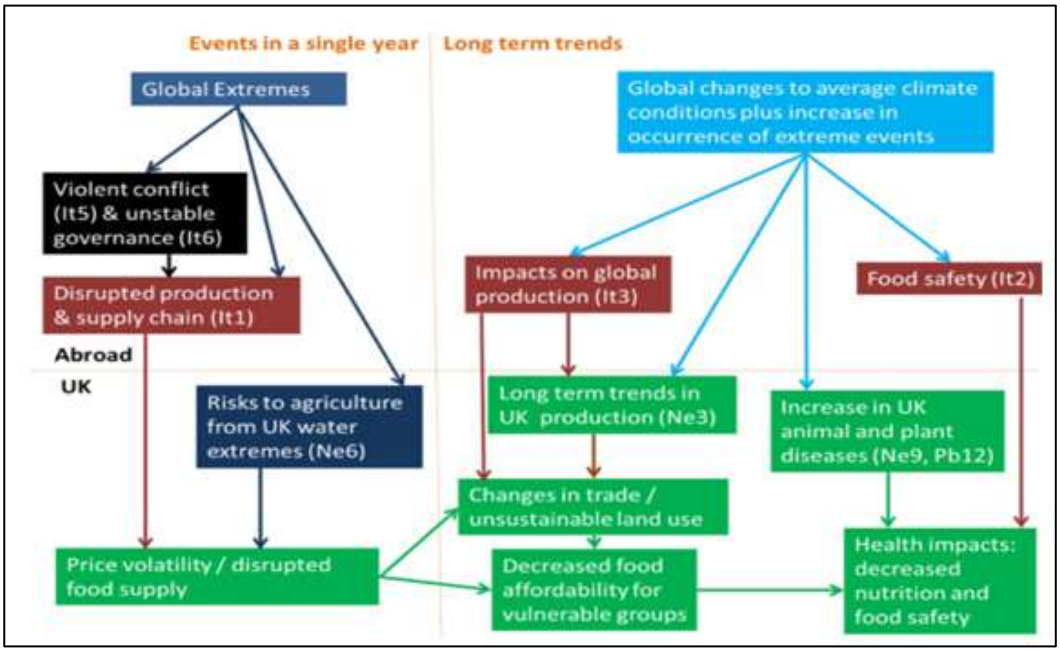

Figure 6.2: Improving The Use of Crop Models for Risk Assessment and Adaptation.

Even more broadly, food systems have many interactions with other systems, e.g. the energy system (Homer-Dixon et al., 2015). Crop models will have a greater or lesser role in the analysis, depending on the nature of the risks being assessed. Integrated assessment of risks from climate change is a relatively recent focus for crop modelling.

6.3.2 Towards Improved Framing of Risks Posed by Climate Change to Food Production Systems:

A. Risk, Uncertainty and Livelihood:

Risk and uncertainty are concepts that apply where the range of future possibilities is largely known (Stirling, 2010). The difference between them lies in whether or not probabilities can be calculated (Wynne, 1992). This distinction is often a matter of (expert) opinion rather than provable fact, so that the same crop-climate ensemble can be presented as an assessment of risk or as an assessment of impacts expressed using uncertainty ranges. True assessment of risk implies a knowledge of the consequences of an event, since risk is the product of two factors: the probability that an adverse event will occur and the consequences of that adverse event (Jones, 2001).

B. Frameworks for Interconnected Risks:

Interactions between sectors (e.g. agriculture, forestry, water) are important in determining climate change impacts (Harrison et al., 2016, Elliott et al., 2014, Piontek et al., 2014). The interactions that lead to climate change risks go beyond those amongst ecosystem-based sectors and into governance, society, health and economics, to name but a few areas. Key issues that emerged in that assessment are the fundamental interconnectedness of both climatic and non-climatic risks and the transmission of risks across international boundaries (e.g. transnational transmission of risks to crops from ozone Hollaway et al., 2011).

Thus, the relevance of crop modelling goes well beyond an understanding of food production, or even food security, and there is a concomitant breadth required in the systems boundaries used in crop modelling studies (Campbell et al., 2016, Waha et al., 2012), especially where broad system boundaries are used.

Integrated assessment models (IAMs) may be expected to deliver frameworks for interconnected risks; however, the use of crop models within IAMs is at a relatively early stage (Ewert et al., 2015). Further, IAMs may not be the best tool to assess the range of trade-offs and synergies that are important to food systems. The complexity of the inter-related set of climate change and food security risks and responses has led to them being labelled a "wicked problem" requiring a range of approaches (Vermeulen et al., 2013). Food security targets are not solely a matter of increasing yield, but also of improving food access, quality and diversity.

There may be direct yield trade-offs involved in actions and activities that contribute towards food security (Campbell et al., 2016). The integration of local knowledge and the input of social scientists within interdisciplinary modelling research can contribute to the identification and outlining of realistic scenarios of socio-technical change, crop-climate indices, or of model output priorities (i.e. not solely yield Herrero et al., 2015, Campbell et al., 2016).

The insights gained may inform the design of models and modelling studies that go beyond conventional projections of yield and yield response and are designed to analyse trade-offs (Wessolek and Asseng, 2006), determine least regrets options, or inform multi-criteria analyses (Hallegatte, 2009, Challinor et al., 2010).

C. Joint Adaptation and Mitigation Frameworks:

Much of the current focus on assessing the risks of climate change is focused on the stringent 1.5–2 °C limit on global warming agreed at the international climate negotiations in Paris in 2015 (COP21). In order to be consistent with a 2 °C target, emissions across all sectors need to decrease by over 80% by 2050 (Edenhofer et al., 2012), with even greater reductions required for a 1.5 °C target. The agriculture, forestry and other land use sector is responsible for 24% of all human greenhouse gas (GHG) emissions (Smith et al., 2014), so is a critical sector for delivering the Paris Agreement. More than even before, it is clear that agricultural systems require changes that address both adaptation and mitigation.

Both sustainable intensification and climate-smart agriculture (Lipper et al., 2014) seek to address the challenge of joint adaptation and mitigation challenge. Climate-smart agriculture targets the simultaneous achievement of increasing agricultural production, adapting to climatic change, and mitigating this change through reduced agriculture-related emissions. Understanding and addressing the trade-offs and synergies between these objectives is therefore a research priority for the climate-crop modelling community

(Campbell et al., 2016), which is particularly well placed to contribute given its capabilities to simulate regional and global scale change. How might the crop-climate modelling community develop joint adaptation and mitigation frameworks? One approach would be to calculate, or at least estimate, the emissions associated with modelled adaptation options.

Tian et al. (this issue) exemplify this approach by quantifying the non-CO2 greenhouse gas emissions associated with different paddy rice management strategies and examining yield emissions trade-offs. Composite measures, such as yield emission efficiency, might also be used to assess how climate-smart specific adaptation options are. A set of recent studies exemplify different existing frameworks for the joint assessment of adaptation, productivity and mitigation outcomes for different types of agricultural interventions, technologies and practices (e.g. Shirsath et al., 2017; Shikuku et al. 2017; Notenbaert et al., 2017).

D. Risk Frameworks Need to Incorporate Multiple Perspectives:

In addition to being a technically challenging issue, understanding risk and uncertainty requires cognisance of the multiple perspectives and interpretations that exist (Wesselink et al., 2014). The frameworks used to conceptualise uncertainty determine the potential for crop-climate modelling to distinguish risks. A range of interpretations on these related topics exists not just between different groups (scientists, politicians, public), but also within them. Even experts within the same project can disagree on the meaning and adequacy of reported uncertainty ranges, based on their assessment of whether or not all risks are known and whether or not the known risks are adequately quantified (Wesselink et al., 2014).

Systematic assessment might seem to be a way to ensure objectivity. However, herein lies the thorny issue at the heart of uncertainty analysis: attempts to be systematic, for example by quantifying parametric uncertainty by using ranges of values, can result in ranges that are not informative, and even unrealistic (Challinor et al., 2007). The range of all simulated events is an attempt to capture all possible events, yet the overlap is not only partial; models and model ensembles are collections of methodological choices and assumptions that may not explore the full range of possibilities (Whitfield, 2013). Equally, the range of model results may extend beyond the realms of possibility (Spiegel halter and Riesch, 2011).

Hence risk assessment with models should not be reduced to the process of equating multiple model outputs with a probability distribution.

6.3.3 Developing and Running Crop Models:

A. Good Practice in Crop Modelling Underpins Accurate Risk Quantification:

The results of using a risk framework will only be as good as the models and methods used within that framework. A model needs to be skilful if its assessment of risk is to be correct. We turn now to the technical challenges of running crop models. For a long time, it has been recognised that studies using crop models need to satisfy certain criteria in order to contribute to the literature in a valuable way (e.g. Sinclair and Seligman, 2000). A more recent review found significant issues with the way that crop models are described and used for assessing climate change impacts (White et al., 2011).

The supplementary information also presents the full list of our criteria for application of crop modelling to impacts, adaptation and risk assessment. The crop model used, and the processes simulated, should be of appropriate complexity given the evidence from available data and the spatial scale of the simulations. This helps to avoid over tuning during the calibration process, especially if a broad array of observed data is used (e.g. yield, LAI) across a broad range of observed values. Different models were developed to address different questions. High complexity is warranted where yield-determining processes are demonstrably complex. Field scale models are often used at spatial scales greater than those at which they were developed for, implying challenges to aggregation and parameterization. The model(s) used should be evaluated using historical observed data. A broad range of data (not just yields) over a broad range of environments should be sought and used in evaluating crop models, and error checking of the data is important. Attention to interannual variability is particularly important (see e.g. Hoffmann et al., this issue, and Müller et al. (2017)). The simulations carried out should be documented in sufficient detail to demonstrate the extent of good practice, and to ensure reproducibility of the work carried out.

B. Crop Model Improvement Supports Accurate Risk Quantification:

With improved measurements and availability of reference data, crop models are continually being improved by more faithfully representing the processes they simulate and by identifying new processes and interactions. As long as this process does not result in unwarranted complexity (Section 3.1), this often improves skill (Maiorano et al., 2017). Several researchers have made a case for seeking consensus amongst models and for the inclusion of N dynamics responses to elevated CO2 (Bannayan et al., 2005, Boote et al., 2013, Yin, 2013, Li et al., 2014). Few models (e.g. Reyenga et al., 1999, Børgesen and Olesen, 2011, Asseng et al., 2014) capture this response, yet it remains key for realistic simulation of source-sink relationships, yield quality (through protein content), sink-strength related photosynthetic acclimation to elevated CO2, fertilizer use, and greenhouse gas emissions from agricultural practices (Muller et al., 2014, Vanuytrecht et al., 2011).

Particularly sensitive and/or high frequency processes are another area needing improvement, since they can be especially difficult to simulate. Sensitivity studies from the AgMIP-wheat and AgMIP-rice pilot showed that uncertainty in simulated yield increased with increasing temperatures (Li et al., 2015, Asseng et al., 2013, Asseng et al., 2014). For both crops the large spread between models could be partly attributed to how phenology was simulated, i.e. the choice of cardinal temperatures, the choice of thermal time accumulation function and, for wheat, the inclusion of accelerated leaf senescence with high temperatures (Asseng et al., 2011). Similar results have been shown for potato (Fleisher et al., 2016) and for maize (Wang et al., 2015), even though this was not a general finding of the AgMIP-maize model intercomparison (Bassu et al., 2014). Furthermore, the increased uncertainty between models was due to how models dealt with an increased frequency of high-temperature events around and after anthesis and its simulated impact on crop growth.

A third area for crop model improvement is the potential need to account for microclimate, which requires simulations of canopy temperature. Recent studies have demonstrated the importance of microclimate when predicting heat sterility in rice (Julia and Dingkuhn, 2013). For wheat, canopy microclimate studies indicate that temperatures can be several degrees warmer or cooler depending on whether evaporative cooling is present (Kumar and Tripathi, 1991; Asseng et al., 2011).

However, recognition of importance does not necessarily transfer into increased model skill. A study comparing nine wheat models that use three different approaches to simulate canopy temperature found only minor improvements when simulated canopy temperature was used for heat stress effects and no improvements when canopy temperature was additionally used for various other processes (Webber et al., 2017).

6.3.4 Crop-Climate Resembles:

A. Forming A Crop-Climate Ensemble:

a. Model and Bias Correction Choices:

The first task in implementing a risk assessment framework is to choose crop and climate models to work with. Climate model ensembles are usually chosen by the impacts community based on availability and so are to a large extent ensemble of opportunity. Similarly, crop modelling groups may have in-house crop models that they favour, often for good reasons such as confidence in their sound use of the model. However, explicit justification of model choice is often missing: White et al. (2011) found that only 18% of 221 studies reviewed thoroughly justified their choice of crop model. Justification for use of a particular crop model in an ensemble can come entirely from a-priori reasoning – i.e. demonstration that the model is fit for purpose.

However, in the context of an ensemble a second criterion presents itself: to what extent will that model contribute to the correct capturing of the underlying distribution of probabilities.

b. Use of Ensemble Mean and Spread:

Ensemble mean or medians can serve as a best-estimate for the impact of climate change. Recent MIPs in crop modelling also find that the median compares better to reference data than most or even any individual model (Asseng et al., 2013, Fleischer et al., 2016, Martre et al., 2015, Bassu et al., 2014, Li et al., 2014). This result is in line with what the climate modelling community found in their model intercomparison work, which showed that the superior performance of model ensembles is a result not only of error compensation, but also greater consistency (Hagedorn et al., 2005) and robustness (Knutti and Sedlacek, 2013).

B. Skill-Based and Spread-Based Selection of Resemble Members:

Two categories of selection criteria for ensemble members can be identified: i. skill-based approaches, whereby appropriate model (s) are chosen for a targeted study, and ii: spread-based approaches, which focus on capturing the underlying distribution of possible futures using ensembles. McSweeney and Jones (2016) offer the fraction of the full range of future projections captured by a subset as a useful spread based climate model selection metric.

Skill-based approaches use model evaluation statistics, whilst spread-based approaches focus on the assessment and use of ensemble ranges. Purely skill-based approaches, on the other hand, may tend to underestimate the full range of future realisations. Although looking at cryosphere rather than agricultural climate impacts, Wiltshire (2014) offer an interesting combination of the skill and spread- based approaches by choosing models which are shown to best represent key features of the Indian Summer Monsoon and sample either end of the spread of precipitation projections. A more complex combination of the two approaches is commended in Lutz et al. (2016): model selection follows a three step protocol: first, splitting the envelope of projections into four portions based upon a combination of temperature and rainfall and selecting one model from each portion (for example one model from the cold and dry portion); second, sampling of extremes; and finally filtering the remaining models based on skill in representing the annual cycle of temperature and precipitation. Work across crop and climate modelling community can lead to improved treatments of uncertainty (Wesselink et al., 2014, EQUIP, 2014, Challinor et al., 2013). Despite the progress made with existing methods, new methods are needed for objectively determining the criteria for inclusion of models within a given multi-model study.

Wallach et al. (2016) provide a valuable discussion of model selection approaches and identify a broad range of lessons for crop modellers based on methods in ensemble climate modelling. Objective criteria for model selection and weighting of ensemble members are amongst the suggestions made in that paper for improving ensemble crop modelling.

C. Scale-Dependency of Model Choice and Ensemble Member Selection:

Choice of parameterisations (and by extension, models) that are appropriate for the spatial scale of a study is critical, since measured and modelled responses to the atmosphere can differ across scale (Challinor and Wheeler, 2008).

However, in more than half of studies, models are applied at scales other than those for which they were originally designed (Ramirez-Villegas et al., 2015) – specifically, field-scale models are used above field scale in roughly 50% of the cases. Hoffmann et al. (2015), Hoffmann et al. (2016) and Zhao et al. (2015) studied the effect of using aggregated, low-resolution climate or soil input in field-scale models applied at regional scales. The extent to which model output is biased by aggregation depends upon the crop model, environmental conditions and spatial variability of weather and soil (Hoffmann et al., 2016).

Skill-based crop model selection is likely to be particularly important and possibly much easier at smaller spatial scales, where the specifics of the agro ecological system being studied become increasingly important (Challinor et al., 2014a). Models often perform better in some regions than in others. This may be simply because of variation in the strength of relationships between yield and climate (see e.g. Watson et al., 2014, Watson and Challinor, 2013). However, model structure and complexity, and data and calibration issues, are also likely to play a role. The precise cause of variation in skill is difficult, if not impossible, to determine. At larger spatial scales, it is often more difficult to assess model skill, owing to scarce and uncertain reference data and aggregation issues (Porwollik et al., 2017, Müller et al., 2017). Here, spread-based crop model selection is likely to be more common.

6.3.5 Modelling Adaptation:

A. Limitations of Current Methods:

Risk assessments will not be accurate unless they account for the autonomous adaptation that occurs in changing climates. A significant portion of the crop modelling literature has focused on assessing adaptation options: out of 91 published studies on climate change impacts used for the IPCC AR5 (Challinor et al., 2014b, Porter et al., 2014) about a third (33) also quantified adaptation.

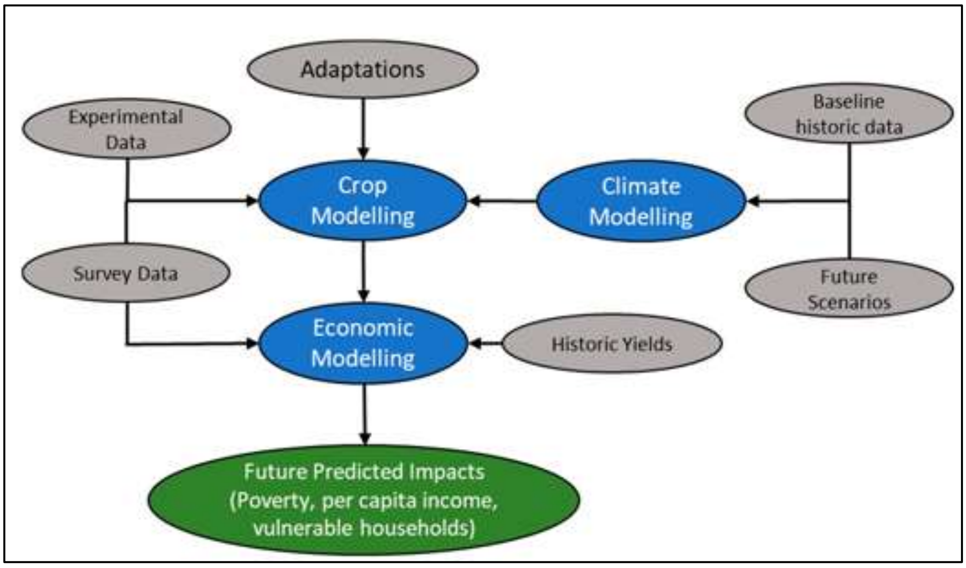

Figure 6.3: Modelling Adaptation

However, only four adaptation strategies were used in those studies, namely, changes in planting date, irrigation, crop cultivar and fertilizer. Adaptation studies therefore fail to represent the broad scope that adaptation has in the real world. Notably, little attention has been paid to changes in farm composition, including crop diversification and intercropping, which are typical of smallholding systems across the tropics (Claessens et al., 2012), as well as to long-term transformations (Rippke et al., 2016, Weindl et al., 2015). Modelled adaptations also ignore interactions within the system, e.g. changes in soil organic matter contents in mixed crop-livestock systems (Thornton and Herrero, 2015). Modelling studies also fail to represent farmers as agents who are continuously making decisions about the objectives or management of the system in the context of interacting biophysical and socio-economic drivers (Quinn et al., 2011, Below et al., 2012). As a result, framing of adaptation has skewed evidence towards a few practices and systems that can be simulated with confidence, rather than covering what is relevant in specific socioeconomic or environmental contexts. Even if the full range of adaptation options could be modelled, significant problems in quantifying adaptation benefits remain. It has been hypothesised that relative yield changes provide essentially unbiased estimates of future climate impacts that can then be applied to any technological pathway (Nelson et al., 2014, Valin et al., 2014, Springmann et al., 2016).

However, any changes to agronomic management that neglect the evolution of a system under a given socioeconomic pathway are unlikely to reflect the true response of the system, since they will neglect the interactions between adaptation and technological change. Similarly, crop production systems that will evolve due to technological progress and altered resource access will likely respond differently to climate change than the current systems that are typically represented in the models (Glotter and Elliott 2016). Improvement is therefore needed in the way adaptation is calculated and in the assumptions on future technologies, e.g. by employing scenarios. Modelling studies tend to compare a future with adaptation against a historical baseline, instead of comparing a climate change development pathway with its corresponding non-climate change counterfactual (Lobell, 2014). This leads to a systematic under-estimation of future crop yields.

Thus, crop modelling studies typically, but not always (e.g. Ewert et al., 2005), fail to account for the technological development (often agricultural intensification) that occurs regardless of adaptation (Liu et al., 2013, Garnett et al., 2013, Tittonell and Giller, 2013). A second point for improvement regarding how adaptation benefits are quantified relates to the comparative advantage of an adaptation option under a future climate with respect to the implementation of the same option under the current climate conditions.

Figure Diagram showing how crop-climate modelling studies should calculate both impacts and adaptation. A1 and A2 represent a farming system under current climate with and without adaptation (respectively), whereas B1, B2, and B3 represent the farming system of A1 but under future climate with neither adaptation nor technological progress accounted for (B1), only technological progress accounted for (B2), and with both adaptation and technological progress accounted for (B3). Based on Lobell (2014).

B. Recommendations for Simulating Adaptation:

Current good practice in adaptation studies involves inclusion of autonomous adaptation, since this avoids over-estimation of impacts. Less common, but equally important, is comparison of the effect of any future adaptations to their historical counterparts. As outlined above, adaptation tends to be over-estimated when comparing a non-adapted historical period with an adapted future period. Future directions for modelling adaptation include:

- New methods are needed in order to permit a broader range of adaptations options to be assessed. Model limitations currently preclude a comprehensive assessment of adaptation, skewing evidence towards a few practices that can be simulated with confidence, rather than covering what is really relevant in specific socio-economic or environmental contexts. Generally, the absence of explicitly representing management as a response to variable conditions (e.g. Hutchings et al. 2012, Waha et al., 2012, van Bussel et al. 2015) in future projections make simulations of adaptation difficlt. In addition, Beveridge et al. (submitted) present some promising ways of making crop modelling adaptation studies both more locally relevant and climate-informed.
- New methods are also needed to compute adaptation benefits, since crop modelling studies typically do not usually account for technological development (but see Glotter and Elliott, 2016), thereby underestimating the effectiveness of adaptation.

- Improved simulation of adaptation through better representation of processes. Ongoing crop model improvement is important. Many areas need attention, for example sensitivity of climate impacts to nitrogen treatments and inclusion of the response of nitrogen dynamics to elevated CO2 (Vanuytrecht and Thorburn, 2017). More generally, research needs to address the lack of consensus on the nature and magnitude of essential processes to be captured in crop models and assess the variation in essential processes with environmental conditions (Fronzek et al., this issue, provide a good example).

6.3.6 Towards Targeted Use of Models:

Ongoing work to improve crop models their use in ensembles is clearly important. However, we argue that innovative approaches to impact and risk assessments will also be needed to address the challenges faced by crop-climate modelling. The Paris Agreement has brought into sharp focus the need to address adaptation and mitigation jointly.

It has reignited scientific interest in sub-two-degree global mean temperature targets and prompted a need for risk assessments that can differentiate between 1.5 and 2.0 degrees of global warming. Detecting systematic differences in crop yields at 1.5 vs 2.0 degrees of warming is currently difficult because the range of model results stemming from methodological choices and spatial variability is large (Schleussner et al., 2016; and Fig. 3 below).

However, this approach is of little use unless the various perspectives can be addressed satisfactorily within a single framework or methodology in order to robustly address a key question and/or decision. We now present three areas of progress and potential in this kind of targeted use of models.

A. Working with Stakeholders to Identify the Timing of Risks:

The current decade has seen an increasing focus in climate science on identifying the timing of changes in climate (Joshi et al., 2011). This contrasts with the more traditional framing that asks “what will happen at a given time in the future?” Given the large uncertainties that exist, the result of these traditional assessments can often lack utility (Challinor et al., 2007).

The more recent focus on timing of risks means that uncertainty is expressed using time intervals, rather than ranges of temperature or crop yield. As a result, these new methods can answer the question “for a given important change in climate, or subsequent impact, when are changes likely to be seen?” By comparing the pace of climate change with the pace of autonomous adaptation, these new methods are generating information on the timing of risks to food production systems (Vermeulen et al., 2013, Rippke et al., 2016).

With the shift in methods towards timing, the focus of adaptation studies can now be ‘by when do key adaptations need to be in place?’ This approach helps in moving from analysis to action (Campbell et al., 2016). In some cases, the indications are that food systems are not keeping pace with climate change, as is the case for maize breeding systems in Africa, where the warming that occurs between breeding and final seed usage will result in an unintentionally shorter crop duration (Challinor et al., 2016).

Others indicate that more long-term transformations of agricultural systems are needed as land becomes unsuitable for current crops (Rippke et al., 2016). These are exactly the kind of issues that risk assessments need to address. With the focus on timing of adaptation comes increasing stakeholder relevance. Furthermore, stakeholders are often needed for robust research results, particularly where understanding of decision-making processes and priorities is required (Lorenz et al., 2015). The MACSUR project has identified agreements on goals with a wide range of stakeholders as a main challenge for European risk assessment (Köchy et al., 2017).

Participatory stakeholder approaches to modelling have taken a variety of innovative forms (Whitfield and Reed, 2012). Vandewindekens et al. (this issue) describe a method of stakeholder input informing a semi-quantitative modelling approach.

These participatory approaches have been shown to bring about benefits of improved contextual calibration and decision-making relevance as well as subsequent trust in, and action on, the emergent evidence bases produced by the research (Chaudhury et al., 2013, Reed, 2008, Prell et al., 2013). In summary, engagement with stakeholders is critical if the research is to have a practical risk management or adaptation outcome.

B. Thinking Outside the Grid Box:

Long-standing approaches to crop-climate modelling ask "what is the change in yield due to climate change in this location and how might cropping systems adapt?" We argue here that it is important to ask different and more useful questions of our modelling studies, using a wide range of methods and information sources. This includes recognising the potential value of interpreting climate model data both with and without using a crop model. Downscaling is often cited as a method for making crop-climate model output more relevant to stakeholders. However, climate model outputs are not primarily maps, since they do not contain geographic features in the way in which we are accustomed to reading them. Rather, they are information with applicability at spatial scales that depend upon the climate itself, which are usually greater than the domain of that grid cell (Hewitson and Crane, 1996).

Crop modelling studies either use the grid on which the input climate simulations were generated, or they downscale those data to a more relevant spatial scale. A range of downscaling methods exist, each with its pros and cons (Wilby and Wigley, 1997). Downscaling is often combined with bias correction, whereby the output of climate models is corrected towards observations.

Use of native (i.e. non-downscaled) or downscaled climate model grids is a reasonable way of determining impacts and conducting risk analysis. However, it may not be the best way in some situations. As climate models increase their resolution we might expect increases in skill (Challinor et al., 2009), but even this is not a simple or guaranteed process (Garcia-Carreras et al., 2015). Additionally, impact models have their own spatial scale issues that make comprehensive global assessments difficult, and regional-scale information important (Challinor et al., 2014). Whilst downscaling techniques are regularly applied when field-scale models are used (Vanuytrecht et al., 2016, Vanuytrecht et al., 2014), they nonetheless potentially add bias and are a source of uncertainty.

“Thinking outside the grid box” is a broad term that tries to capture the need to critically assess the use of climate model output and avoid the presumption that analyses should begin and end with gridded output. This is not a matter of further processing or aggregating grid box data, but rather of recognising the inherent limitations of it and extracting the maximum information content from the data.

Approaches used include non-spatial representations of impacts, as is common in many studies (e.g. quantification of incidence of crop failure rates, Parkes et al., 2015); analysis of collected gridcell data (e.g. Challinor et al., 2010), as opposed to being overly explicit geographically; and use of crop-climate indices (Trnka et al., 2011). In particular, the term conveys targeted analyses that employ a range of linked methods and have relatively broad systems boundaries. Challinor et al. (2016) present an example of this approach, by using data on the breeding and dissemination of new crop varieties; crop-climate indices, with uncertainty analysis to identify the time at which a climate change signal emerges from current observed variability; and ‘traditional’ crop modelling. These methods were used to target crop breeding applications by calculating the spatial and temporal scale of robust crop-climate signals.

C. Increasing Transparency and Inter-Comparability in Risk Assessments:

The various choices (calibrating, running and evaluating models; designing ensembles) faced by a crop modeller when contributing to a risk assessment always result in some limitations. Different choices have different limitations. The purpose of a framework is not only to minimise the limitations, but also to highlight the limitations. However, frameworks are often implicit and justification of modelling choices is often missing from crop-climate studies (White et al., 2011), which makes it difficult to compare different studies directly.

The identification of consensus views can be supported by clear critical evaluation of methodologies and model projections. Ruiz-Ramos et al. use an ex post plausibility check in ensemble wheat modelling, which usefully goes some way towards increasing robustness. However, comparability across risk assessment is only possible when some common methods or protocols are used (see e.g. Liu et al., 2016). Systematic assessments of the response of models to carbon dioxide, temperature, water and nitrogen have been suggested as a way to clearly understand and document model performance (Ruane et al., 2014, Rosenzweig et al., 2013b). The response of the model to changes in key input variables should match what is seen in observations, and a systematic comparison method would aid this assessment.

6.4 Conclusion:

Crop modelling in agriculture has the potential to provide valuable insights and solutions for agricultural professionals. With improved Agronomic data collection, predictive modelling using multiple datasets will allow researchers and farmers to better understand the parameters and management practices that are most influential on crop growth. Being able to explore potential outcomes over time, given changes in climate or other inputs, opens up a whole new perspective as we work to improve efficiency and reduce environmental footprints.

The challenge of producing locally relevant and climate-informed adaptation strategies for agriculture is complex. Adaptive decisions transcend spatial and temporal scales and interact with social, economic and environmental systems. Cross-disciplinary approaches can build our capacity to identify and understand critical factors that drive and limit agricultural adaptation at the local scale. They can also be used to assess the potential impact of an identified adaptive strategy across spatial and temporal scales, including under future climate change scenarios, which is of particular relevance to policy decisions. There are practical steps needed for successful iterative working between crop-climate modelling and place-based communities. Crop-climate modelling research needs to better address adaptation in climate change studies.

A collective action towards building consistent and accessible datasets on management and adaptation is also a pre-requisite to incorporating more adaptation processes into crop-climate modelling studies. Building trust between researcher and stakeholder will be essential for successful iterative research and assessment of locally relevant adaptation. Participatory and iterative modelling, as commonly used in place-based approaches, is a potential tool to do this, by aiding communication, developing a shared understanding and set of definitions between researchers from different backgrounds and stakeholders and improving impact and uptake of adaptation science.

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7. Site Specific Nutrient Management as Climate Smart Practice

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7.1 Introduction:

Site Specific Nutrient Management (SSNM) is a strategy to fertiliser management that strives to enhance crop production while reducing the negative impacts on the environment. Based on the unique requirements of the crops and the soil's properties, it entails the use of a mix of soil testing, crop monitoring, and nutrient management techniques to identify the right type, rate, timing, and placement of fertilizers. By ensuring that nutrients are delivered to crops only when they are required and in the appropriate proportions, this strategy lowers the possibility of nutrient losses due to leaching, volatilization, and runoff. By lowering greenhouse gas emissions and increasing the capacity of agricultural soils to store carbon, SSNM can help to mitigate the effects of climate change on agriculture. Farmers can minimize N2O emissions and the amount of fertiliser lost to the environment by applying fertilizers precisely and strategically depending on the unique requirements of the crops and soil conditions. The soil's organic matter content is improved by SSNM. This method offers a foundation for rice nutrient best management techniques and allows rice farmers to customize nutrient management to their own field conditions. It is an advanced knowledge base that emphasizes double and triple monocultures of rice (FAO, 2011). A Mekong Delta study revealed that employing SSNM increased grain yield by roughly 0.5 tonnes per hectare (Hach and Tan, 2007). Nitrous oxide (N2O) emissions from agriculture account for about 70–90% of total emissions (cgiar.org). It is a dynamical system that aids in optimizing crop production by matching the natural spatial and temporal requirements of plants through the use of the proper amount, source, rate of application, timing, and method. Prescriptive and corrective SSNM are two different types. Nutrient addition in prescriptive type is based on soil testing, crop, and climate considerations. Curative type refers to field management, and some examples include nutrient experts, leaf color charts, and SPAD metres for measuring chlorophyll. By delivering nutrients at the best rate and time, SSNM achieves excellent nutrient use efficiency without intentionally aiming to decrease or increase fertiliser consumption. Effective N management can lessen other environmental problems such eutrophication, acidification, air quality, and human health while assisting in adaptation and mitigation. By lowering total N application and/or timing applications to crop demands, SSNM minimizes N2O emissions and prevents N losses through volatilization, leaching, and runoff.

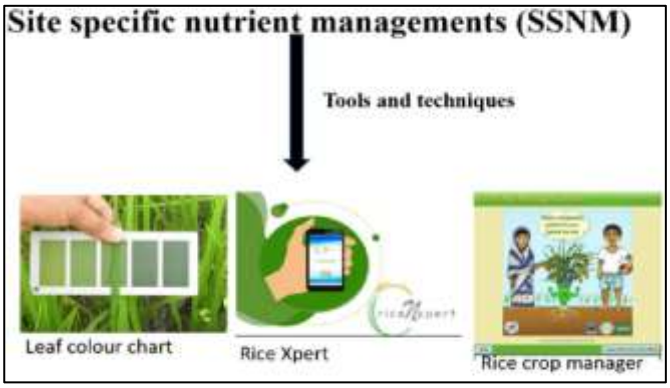

Figure 7.1: Some Prominent SSNM Tools for CRA

SSNM helps in improving NUE as it provides an approach for feeding crops like rice, maize, wheat, etc. with nutrients as and when needed. For efficient and effective SSNM, use of soil and plant nutrient status sensing devices, remote sensing, GIS, decision support systems, stimulation models for variable application of nutrients play an important role. It aims to:

A. Provide a locally-adapted nutrient best management practice tailored to field and season specific needs for a crop
B. Increase yield
C. Increase fertilizer use efficiency
D. Improve profitability
E. Improve marketable crop quality
F. Improve environment stewardship

Figure 7.2: Site-Specific Nutrient Management.

7.2 Important Features of SSNM:

Use of SSNM helps in optimizing the use of existing indigenous nutrient sources like crop residue, organic matter, etc. Application of nutrients (like N, P and K) is tailored according to site and season specific demands of the crop. Use of tools such as leaf color chart ensures that nitrogen supply is at right time and in amount required by crop which helps in reducing fertilizer waste. For determining the dose of phosphorus and potassium, nitrogen omission plot method is used. Hence ensuring that supply of P and K is in ratio required for maintain crop growth especially in rice. For zinc, sulphur and micronutrient application local randomization methods are followed. Economic combinations of available fertilizer sources. Integration of other crop management practices like use quality seeds, maintain optimum plant density, integrated pest management and good water management.

7.3 Plant Analysis Based SSNM:

It is considered that the nutrient status of the crop is the best indicator of soil nutrient supplies as well as nutrient demand of the crops. Thus the approach of plant based SSNM is built around it. Five key steps for developing field-specific fertilizer NPK recommendations have been developed:

A. **Selection of The Yield Goal:** A yield goal exceeding 70-80 % of the variety-specific potential yield (Ymax) has to be chosen. Ymax is defined as the maximum possible economical yield limited only by climatic conditions of the site, where there are no other factors limiting crop growth. The logic behind selection of the yield goal to this level of potential yield is because the nutrient use efficiency at a very high level near Ymax decreases.

B. **Assessment of Crop Nutrient Requirement:** The nutrient uptake requirements of a crop depend on the yield goal and its potential yield. In SSNM, nutrient requirements are estimated with the help of quantitative evaluation of fertility of tropical soils (OUEFTS) model. Nutrient requirements for a particular yield goal of a crop variety may be smaller in a high yielding season than in a low yielding one.

C. **Estimation of Indigenous Nutrient Supplies:** Indigenous nutrient supply (INS) is defined as the total amount of a particular nutrient that is available to the crop from the soil during the cropping cycle, when other nutrients are no-limiting. The INS is derived from soil, incorporated crop residues, irrigation water and BNF.

D. **Computation of Fertilizer Nutrient Rates:** Field-specific fertilizer N, P & K recommendations are calculated on the basis of of above steps (1-3) and the expected fertilizer recovery efficiency (RE- kg of fertilizer nutrient taken up by the crop per kg of the applied nutrient). Studies indicated RE values of 40-60 % for N, 20-30 % for P, 40-50 % for K in rice under normal growing conditions.

E. **Dynamic Adjustment of N Rates:** Whereas, fertilizer P and K are applied basally (at the time of sowing), the N rates and application schedules can be further adjusted as per the crop demand by using chlorophyll meter (SPAD), Green seeker and Leaf Color Chart (LCC). Recent on-farm studies in India have revealed a significant SPAD/LCC based N management schedules in rice and wheat in terms of yield grain, N use efficiency and economic returns over the conventionally recommended N application involving 2-3 splits during crop growth. SPAD based N application resulted in a saving of 55 kg N/ha as compared to Soil Test Crop Response (STCR) based N application.

7.3.1 Soil-Cum-Plant Based SSNM:

In this case, nutrient availability in the soil, plant nutrient demands for a higher target yield (not less than 80 % of potential yield), and recovery efficiency of applied nutrients are considered for developing fertilizer use schedule to achieve maximum economic yield of a crop variety. To assure desired crop growth, not limited by hidden or apparent hunger of nutrients, soil is analyzed for all macro and micronutrients well before sowing/planting. Total nutrient requirement for the targeted yield and RE are estimated with the help of documented information available for similar crop growing environments.

7.3.2 Site Specific Nutrient Management for Precision Agriculture:

SSNM is a component of site-specific crop management or precision agriculture." Precision agriculture can be defined as the application of principles and technologies to manage spatial and temporal variability associated with all aspects of agricultural production for the purpose of improving crop performance and environmental quality" (Pierce and Nowak, 1999).

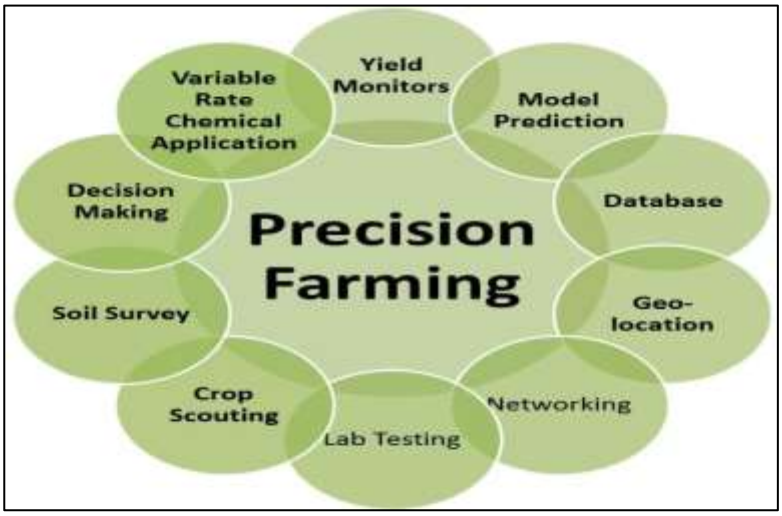

Figure 7.3: Precision Farming

A. Components of Precision Farming:

- Remote sensing
- Geographic information system (GIS)
- Differential global positioning system (DGPS)
- Variable rate applicator

Nutrient management in precision agriculture is governed by 4 R's: Right product, right time, right place and right time. Precision management is important for nutrient application because:

- Nutrient variability within a filed can be very high, affecting optimum fertilizer rates
- Yield potential and grain quality can also vary greatly within the same field, affecting fertilizer requirements
- Increasing fertilizer use efficiency will become more important with increasing fertilizer costs and environmental concerns.

For this purpose, various technology tools like: GPS, GIS, remote sensing, variable rate technology, laser, LCC, green seeker, chlorophyll meter or soil plant analysis development meter, etc. are being used. Computer or mobile phone-based tools are being increasingly used to facilitate improved nutrient management practices in farmers' fields, especially in geographies where blanket fertilizer recommendations prevail. Nutrient Expert® and Crop Manager are examples of decision-support systems developed for SSNM in cereal production systems. Nutrient Expert® is an interactive, computer-based decision-support tool that enables small holder farmers to rapidly implement SSNM in their individual fields with or without soil test data. While Crop Manager is a computer and mobile based application that provides small-scale rice, rice-wheat, maize farmers with site and season-specific recommendations for fertilizer application.

B. Problems in Adoption of SSNM:

- Fragmented land holding
- Lack of continuously monitoring the health and availability of the natural resources.
- Climatic aberrations
- Operational constraints
- Absence of a long standing and uniform agricultural policy
- Lack of success stories
- Lack of local technique expertise
- Land ownership, infrastructure and institutional constraints

C. Probable Strategies for Adopting SSNM:

- Farmer's co-operatives
- Pilot projects
- Agricultural input suppliers, extension advisors and consultant play important role in the spread of the technology
- Combined effort of Researchers and Government
- Public agencies should consider supplying free data such as remotely sensed imagery to the universities and research institutes involved in precision farming research.

D. Conclusion:

SSNM is gaining popularity with the passage of time obviously due to its in-built advantages over other contemporary approaches. With an increase in understanding of SSNM, decision support tools on fertilizer, best management practices will be developed for different crops and farming situation.

7.4 Importance of SSNM:

In order to meet all objectives of sustainable agriculture (increased food and fibre, profitability, efficiency of input use and an appropriate concern for the environment), a balance of adequate levels of nutrients is the key component.

Over the past four decades' crop management in India has been driven by increasing use of external inputs. Food grain production were more than doubled from about 98 million tonnes (MT) during 1969-2007 to a record 212 MT in 2001-2002, while fertilizer nutrient use increased by nearly 12 times from 1.95 MT to more than 23 MT in 2007-08 (Rao, 2009) [5].

Notwithstanding these impressive developments, food grain demand is estimated to increase about 300 MT yr-1 by 2025 for which country would require 45 MT of nutrients (ICAR, 2008) [2]. With almost no opportunity to increase the area under cultivation over 142 million hectares, much of the desired increase in food grain production has to be attained through yield enhancement in per unit area, in particular that of major staple food crops like rice, wheat and maize, which incidentally responded considerably to the introduction of green revolution technologies to contributing to more than 80% of total food grain production (Johnston et al. 2009).

Nutrient differences which exist within fields, and making adjustments in nutrient application to match these location or soil differences by using some form of field diagnostic, such as intensive soil sampling, soil sensing, aerial imagery, yield mapping etc. is known as Site specific nutrient management (SSNM).

Site-specific management allows for fine-tuning crop management systems along with 4R Nutrient Stewardship the right source, rate, time and place of nutrient use.

7.5 Elements of SSNM:

Site-specific management technology relies on the interaction of three broad and fundamental elements to be successful in its implementation. They are categorized in terms of information, technology and management.

A. Information:

In field variability, spatially or temporally, soil related properties, crop characteristics, weed and insect pest population and harvest data are important databases that need to be developed to realize the potential of site-specific management technology. Out of these, crop yield monitoring is the most mature component and logical starting point. Several years of yield data may be required to make a good decision.

Establishment of soil related characteristics within field, through regular soil sampling, is another database that is extremely important. Decision therefore, has to be made on what property to sample, how to sample and how often to sample so that interpretation from database can be made with greater confidence.

B. Technology:

The recent development in microprocessor and other electronic technologies for monitoring yields and sensing soil related variables are new tools available to make site specific farming a success. geographical positioning system (GPS) can be used to identify the locations where the data are taken. Some GPS users demand accuracy in identifying field location and differential global positioning systems (DGPS) is one of the improved GPS system that reduce position errors. Remote sensing technique can also be utilized to detect soil related variables, pest incidence and water stress.

The basic idea of site specific farming is not only to measure field variability, but also to be able to apply inputs at varying rates almost instantaneously, “real time”, according to the needs. Variable rate application machinery is a type of field implements that could be used to handle field application of inputs such as seed, fertilizer and pesticides at the desired location in the field, at the right amount, at the right time and for the right reasons. The application of variable rate technology (VRT) can be accomplished either as a map based VRA or a sensor based VRA. However, different types of sensors are now available (or under development) that can monitor crop yield, soil properties, and crop condition that can be used to controlled field operations.

C. Management:

Site specific farming makes farm planning both easier and more complex. The ability to combine information generated and the existing technology into a comprehensive and operational system is the third key area in the precision farming.

7.5 Basic Steps in SSNM:

Assessment of soil and crop variability, managing the variability and its evaluation are three basic steps in site specific nutrient management. The available technologies enable us in understanding the variability and by giving site specific agronomic recommendations we can manage the variability that make precision farming viable and final evaluation must be an integral part of any precision farming system.

A. Assessing Variability:

Assessing the variability is the critical first steps in precision farming. Quantifying the variability of the factors and processes and determining when and where different combinations are responsible for the spatial and temporal variation in crop yield is the challenge for the precision farming. we need both the space and time statistics to apply the precision farming techniques.

B. Managing Variability:

Once variation is adequately assessed, farmers must match agronomic inputs to know conditions employing management recommendations. Those are site specific and accurate use applications control equipment.

The potential for improved precision in soil fertility management combined with increased precision in application control make precise soil fertility management as attractive, but largely unproven alternative to uniform field management.

C. Evaluation:

There are three important issues regarding precision farming evaluation: economics, environment and technology transfer. The most important fact regarding the analysis of profitability of precision farming is that the value comes from the application of the data and not from the use of the technology. Potential improvements in environmental quality are often cited as a reason for using precision farming.

SSNM has successfully been tried in India using different approaches and demonstrated a potential not only to increase crop yields and farmer profits but also has shown increasing evidence of environmental friendliness owing to its balances and crop-need nutrient application (Satyanarayana et al., 2011).

7.6 Dissemination Tools for SSNM:

The widespread dissemination of improved nutrient management practices requires transforming the principles of SSNM into locally adapted tools that enable extension workers, crop advisors, and farmers to rapidly adopt and implement best management practices for specific fields and growing conditions. Computer-based decision support tools are the options to address this novel cause. IPNI South Asia program in collaboration with its International staff in South East Asia, International Rice Research Institute (IRRI) and the fertiliser industry is working to consolidate the complex and knowledge intensive SSNM information into simple decision support tools enabling farmers to rapidly implement SSNM. These tools include ‘Nutrient Expert’ developed by staff of IPNI South East Asia program, ‘Nutrient Manager’, a delivery system developed by IRRI, GIS based fertility maps, an initiative by IPNI South Asia program and other computer based decision tools.

7.7 SSNM for Potassium:

In many regions of India, recommendations for potassium for any given crop or cropping system were based on predefined K rates for sizable areas of production, ignoring the variability of soil fertility both at the spatial and temporal dimensions. Despite the fact that the majority of Indian soils were thought to be fertile and rich in potassium, recent studies revealed a falling tendency in most of the states. Heavy crop removal and minimal K additions by farmers led to widespread potassium depletion, which in turn caused K deficiency to arise in soils and crops. Over time, this caused a shift in fertility from high to medium or medium to low K status. Furthermore, due to variations in climate, crop-growing circumstances, and crop and soil management strategies, the crop requirements for K nutrition vary substantially among fields, seasons, and years. The International Plant Nutrition Institute (IPNI) in India has conducted research that conclusively demonstrates that fertiliser K recommendations are insufficient for current yield targets. As a result, the soil test K level, which was previously thought to be adequate, turns out to be insufficient to balance the high rates of N and P being applied (Tiwari, 2005).

There is a need for site-specific potassium management that takes into account the crop's unique needs for additional potassium and replaces the present and generalist fertiliser recommendations that were devised decades ago. In order to maintain the balance between K mining and a productivity target, Chatterjee and Sanyal (2007) described a method for site-specific K recommendations based on the results of soil tests. The K rates were computed by computing a factor with respect to available and non-exchangeable pools of K.

7.8 Models for SSNM:

The International Rice Research Institute (IRRI) has created a plant-based SSNM method that is now available for maize and wheat. This strategy concentrated on regulating spatial variation in native NPK supply that is peculiar to a given field, temporal variation in plant N status that occurs during a growing season, and medium-term variations in soil P and K supply that are caused by actual nutrient balance. In order to forecast soil nutrient availability and plant uptake in absolute terms in Asia's high-yielding irrigated rice systems, the method required a data management option. The link between grain production and nutrient accumulation as a function of climatic yield potential and the supply of the three macronutrients was described by a modified QUEFTS model (Janssen *et al*., 1990; Witt *et al*., 1999). An accessible manual for managing rice's nutrient content was written in 2002 using the scientific concepts of SSNM. Following an update (Fairhurst *et al*., 2007) and translation into the regional language of the region, this well-known guidebook, which offers recommendations on optimal rates of N, P, and K adjusted to field specific yield levels and indigenous supply of nutrients, was published.to regional language of Hindi (http://tinyurl.com/6lp8zj).

7.9 Nutrient Expert as A Decision Support Tool:

Figure 7.4: The user interface of the Nutrient Expert for Hybrid Maize software

Many Asian nations have begun to replace general fertiliser recommendations for large regions of rice, maize, or wheat with more site-specific recommendations tailored to local requirements. A transition from conventional on-station research to on-farm creation and evaluation of novel methods was made in conjunction with this approach. The complexity of the factors determining nutrient requirements continues to be a major problem for local extension organizations. Based on the site-specific nutrient management (SSNM) concepts outlined by Witt *et al*. (2009). The Nutrient Expert for Hybrid Maize (Fig. 4) is a computer-based decision support tool designed to help local experts quickly generate fertiliser instructions for tropical hybrid maize as described by Witt *et al.* (2009). With the use of this programme, scientists and extension specialists can create unique nutrient management techniques for assessment.

The Nutrient Expert for Hybrid Maize can assist a farmer in increasing yield and profit by offering advice on setting realistic production goals for his region and outlining the fertiliser management tactics necessary to meet those goals. Only information that a farmer or local expert may readily offer is needed for this software.

This Informational Set Consists of:

- The farmer's current planting density;
- The present yield and nutrient management strategy;
- The characteristics of the growing environment or an estimate of the achievable yield (if known)
- Indicators of soil fertility (such as soil color and texture, past usage of organic inputs, or projections of yield responses to N, P, and K fertiliser) (if known)
- Crop residue management, usage of organic inputs, and nutrient carryover from previous crop are used to adjust fertiliser P and K requirements as needed

The user will receive instructions on fertiliser management (and more) that are specific to his area (i.e., the environment for maize) and locally accessible fertiliser supplies after responding to a series of short questions.

The software also provides a straightforward profit analysis that contrasts the costs and advantages of the farmer's existing practice versus the suggested improved alternative approach. Moreover, Nutrient Expert for Hybrid Maize was created with the intention of being used as a learning tool.

It offers instant summary tables and graphs, quick guidance, and a great deal of freedom while browsing the software's modules. The guidelines offered by this software are in keeping with the scientific foundations of Site-Specific Nutrient Management (SSNM), and the following SSNM objectives served as the development of this software's guiding principles:

- Apply sufficient amounts of fertilizer N, P, K, and other nutrients to reduce nutrient-related restrictions and produce high output. Use local nutrient sources that are available on-farm.
- Reach high profitability in the short and medium terms
- Prevent the crop from consuming excessive amounts of nutrients
- Reduce soil fertility loss The Nutrient Expert for Hybrid Maize (Fig. 4) offers assistance with developing the best planting density for a particular site, assessing current nutrient management techniques, choosing a meaningful yield goal based on achievable yields, and estimating the NPK fertilizer rates necessary to achieve the chosen yield goal.
- Incorporating fertilizer sources and NPK rates
- Create a fertilizer application strategy (appropriate rate, appropriate source, appropriate place, and appropriate time); and
- Assess the predicted or actual impact of current and better practices.

7.10 Nutrient Manager:

Figure 7.5: Nutrient Manager for Rice

A user-friendly, interactive computer-based decision tool called Nutrient Manager (Fig. 5) was created in 2008 by the International Rice Research Institute (Buresh, 2008). Via a series of simple questions and answers, the tool is designed to gather the data essential for decision-making on nutrient management. This decision-making tool comprises of roughly 10-15 multiple-choice questions that a farmer or extension agent may readily respond to in about 15 minutes. To help farmers fertilize their fields at the proper time and amount, a fertiliser guideline with fertiliser requirements per crop growth stage is offered based on the replies to the questions. The rice-specific Nutrient Manager software can recommend fertiliser for a variety of rice cultivation techniques, such as transplanted vs. direct seeded rice, hybrids vs. varieties, and rice with a range of growth options, including short, medium, and long durations.

This feature makes the software available to a broad range of rice farmers. In addition to taking into account the residual fertility, final recommendations on the rate and timing of fertiliser application were made after subtracting and balancing the nutrient contributions from organic sources, sediment, and irrigation water inputs. The programme also enables farmers to choose the fertiliser mixtures they like from the local fertiliser sources to satisfy the crop's nutritional needs. A computerized version of Nutrient Management for Rice in the Philippines was created by IRRI and partners in the Philippines in 2010.

Extension personnel and farmers can use it online or via a mobile device. The web site for released internet applications of Nutrient Manager is: www.irri.org/nmrice. Because to its balanced and crop-need-based nutrient administration, SSNM has been successfully tested in India utilizing a variety of methods, demonstrating the ability to not only boost crop yields and farmer income but also to show increasing evidence of environmental friendliness.

Based on the SSNM principles, the new nutrient decision support tool NE for wheat suggests a balanced application of nutrients depending on the crop's needs. Those involved in the development of wheat in India, including those from the government research and extension system, commercial businesses, the International Maize and Wheat Improvement Center (CIMMYT), and the International Plant Nutrition Institute, collaborated to create the tool (IPNI).

Contrary to current approaches, it enables crop consultants to quickly generate fertiliser recommendations tailored to particular fields in order to increase wheat farmers' yields and economic advantages. Specifically, for the South Asian IGPR, SSNM-NE is a newly created precision nutrient management technique that is directed by DSS software and improves crop yields, environmental quality, and overall agricultural sustainability.

A. The Recommendations Made by This Software Are:

- There were no significant water restrictions (such as droughts) during the growing season, any issues with micronutrients and acidity are carefully handled,
- Utilization of high-yielding wheat cultivars;
- Absence of significant damage from pests and diseases;
- Appropriate use of fertiliser.

B. The Software Also Needs Some Readily Available Data, Including:

- Current farmers' yield;
- Farmers' fertilization practices;
- Attainable yield of a location;
- Managing residues in the current wheat crop;
- Credits or adjustments for nutrients from organic inputs;
- Nutrient carryover from previous crop; and
- Outcome of omission plot trial (if available)
- Calculating the predicted levels of N, P, and K in the farmer's field using data on the soil type, soil color, organic matter content, soil analytical information (if available), and soils with a history of P fixation.

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8. Concept and Practices Under Conservation Agriculture

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Abstract:

In order to prevent soil and environmental degradation while maintaining crop production, conservation agriculture (CA) is characterised by low soil disturbance, diversified crop rotations, and the surface crop residue retention. To get around the traditional use of tillage operations, CA includes modifying a number of standard farming practises as well as farmer's mindset. It was discovered that land preparation costs 25-30% more than other operations, which can only be lowered by implementing high conservation tillage practices such as zero tillage, minimum tillage, happy seeders, laser levellers, and so on. Despite the fact that CA adoption is rising across the board, in some places it is either minimal or nonexistent. Although CA adoption has advantages for both agriculture and the environment, there is a lack of knowledge regarding the interactions and effects of key CA components, which affect yield and prevent CA adoption. Conservation agriculture crop can be increased food security, climatic resilence, soil nutrion, income and energy reduction. Farmers are facing the problem of labour shortage and drudgery of farming these can be minimized by conservation tillage practice.

8.1 Introduction:

The concept of conservation agriculture is relatively using of new and modern cultivation practices. Traditional agricultural methods encourage significant soil tillage, crop residue burning, and external inputs. Due to erosion, compaction, and loss of organic matter, these practises degrade the soil. More than 70–75 percent of farmers in India are small-scale landowners who continue to use conventional farming methods and play a significant role in the nation's overall food supply. However, many people find farming difficult, frequently using only the most basic tools and equipment. The majority of farmers pay little attention to long-term resource management and rarely have the money for inputs like high-quality seeds, fertiliser, large machinery, and herbicides for chemical weed control.

The goals of conservation agriculture are to (i) produce at high and sustained levels, (ii) maximise profitability, and (iii) protect the environment. Additionally, it says that improving natural biological processes above and below the soil surface is the foundation of conservation agriculture.

These offer a variety of technological and management alternatives that go beyond zero-tillage. Practically all types of crops, including cereals, horticulture, and plantation crops, can benefit from conservation agricultural practises. These are more common in maize, soybean, rice, and wheat, though. The potential of conservation agriculture practises for various soil types and agro-ecological systems is enormous.

A. What is Conservation Agriculture?

CA is a farming method that can restore degraded soils while preventing the loss of arable land. It improves biodiversity and natural biological processes above and below the ground, which help boost the efficiency with which water and nutrients are used and help sustainably raise crop yield.

Is it a method of farming that enhances, conserves, and makes sure that natural resources are used effectively? It tries to assist farmers in making a profit while maintaining output levels and protecting the environment.

B. Why Conservation Agriculture?

- Because the needs of the constantly growing human and livestock populations cannot be addressed by traditional farming practises.
- Land degradation can be stopped and reversed by conservation efforts, and conservation agriculture enhances productivity while minimising land degradation and boosting food security.

8.2 Principles of Conservation Agriculture:

8.2.1 Permanent Organic Soil Cover:

In conservation agriculture, a permanent soil cover is essential to prevent the soil from suffering negative effects from exposure to rain and sunlight, to maintain a constant food supply for soil micro- and macroorganisms, and to alter the soil's microclimate for the growth of soil organisms and plant roots.

According to Ghosh et al. (2010), this enhances soil aggregation, carbon sequestration, soil biological activity, and biodiversity. Biomass from crop residues, stubbles, and cover crops is used to create soil cover.

According to FAO (2014), crop residues should cover at least 30% of the total farmed area. There are three groups based on the amount of land surface cover: greater than 90%, greater than 61%, and between 30% and 60%.

8.2.2 Diversified Crop Rotations:

A diverse crop rotation is necessary to feed the soil microorganisms and to enable the crops to use nutrients that have been leached into the soil from various soil layers. Rotating deeply rooted crops with shallowly rooted ones will help.

Additionally, a variety of crops in rotation results in a variety of soil fauna and flora. Legumes have an important role in crop rotations because they help biological nitrogen fixation, reduce pest infestation by disrupting the life cycles of the pests, and increase biodiversity (Kassam and Friedrich, 2009; Dumanski et al., 2006).

8.2.3 Minimum Mechanical Soil Disturbance:

In general, soil biological processes are anticipated to result in extremely stable soil aggregates as well as pores with a range of sizes that allow for adequate air infiltration and water infiltration.

The biological soil structuring activities disappear with mechanical soil disturbance caused by tillage or other farming techniques.

In order to maintain the ideal composition of respiration gases in the root zone, moderate soil organic matter oxidation, appropriate porosity for soil water movement, retention, and release, and to prevent the re-exposure and germination of weed seeds, minimal soil disturbance is required (Kassam and Friedrich, 2009).

A. Difference Between Conventional Agriculture and Conservation Agriculture:

Table 8.1: Difference Between Conventional Agriculture and Conservation Agriculture

Conventional Agriculture	Conservation Agriculture
Excessive tillage and soil erosion	No till/ drastically reduced tillage
Crop residue burning or incorporation	Surface retention of residues
Use of ex-situ FYM/ compost	Use of in-situ organic/ compost
Free use of farm machinery	Controlled use or low use of farm machinery
Incorporation of green manure	Surface drying of green manure
Crop based management	Cropping system-based management
Single crop or sole crop is grown	Intercropping/ relay cropping
Uneven field levels	Precision laser land levelling

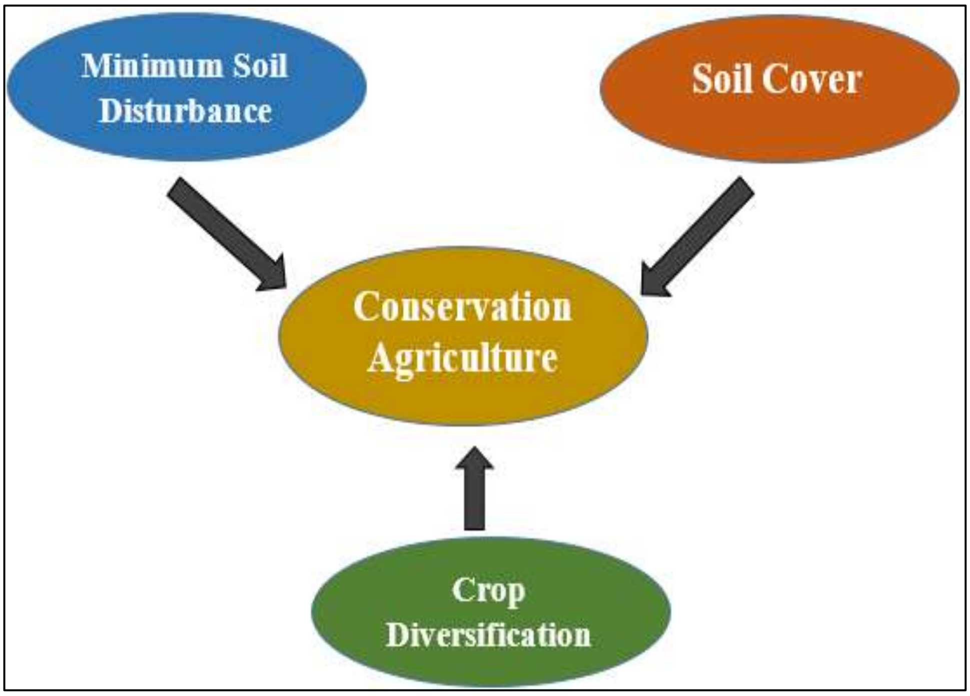

Figure 8.1: Conservation Agriculture

B. Agronomic Interventions Following Conservation Agriculture Principles for Improving Crop Yields

- Conservation tillage
- Permanent soil cover
- Diversified crop rotations
- Soil and water conservation practices
- No burning of residues
- Direct sowing

8.3 Conservation Tillage Practices Include:

A. Zero Tillage: Primary tillage is completely avoided and secondary tillage restricted to seed bed preparation in the row zone only.

B. Minimum Tillage:

- Reducing tillage to the minimum necessary for ensuring a good seedbed.
- It involves soil disturbance, to lesser extent. Keeps 30-50% crop residue on soilsurface

C. Stubble Mulch Tillage: Soil is protected all the times by growing crop or crop residue left on the soil surfacebetween two crops.

D. Ridge Tillage:

- Ridge-tillage cultivator removes weeds, loosens the soil and builds up the ridge at a time.
- seeds are placed in the center of the ridge.

E. Weed Control: In CA systems, weed control is seen as a severe issue, and successful weed control is essential to system success. In order to reduce the energy reserves in the various storage organs or roots of weeds, many tillage activities are necessary to control perennial weeds.

8.4 Status of Conservation Agriculture and Its Extent of Adoption in India:

According to Farooq and Siddique (2014), farmers in India are estimated to be using no-till techniques on about 1.5 million acres of land for crops such maize, millets, sorghum, pigeon pea, cotton, and chickpea as well as in rainfed upland areas. The area under conservation agriculture in the rice-wheat and rice-maize cropping systems has significantly risen over the past ten years. Through the combined efforts of various State Agriculture Universities and Indian Council of Agricultural Research (ICAR) institutes, conservation agriculture practises have undergone significant testing. The Rice-Wheat Consortium, which was part of the CGIAR system, supported the adaptation, promotion, and development of these practises. As a result, farmers in the IGP belt (Haryana, Punjab, and Western Uttar Pradesh), which covers about 2 M hectares, are quickly adopting these technologies. According to research from IARI (2012), farmers in the northwest are also adopting conservation agriculture practises such furrow irrigation raised-bed planting, laser assisted field levelling, unpuddled mechanical transplanting of rice, and residue management practises. Intercropping systems like maize + potato + onion + red beets or sugarcane + chickpea + Indian mustard are also gaining popularity among farmers in western Uttar Pradesh (Gupta and Seth, 2007Zero-tilled (ZT) wheat has been widely used in the rice-wheat cropping (RW) systems in the northwestern IGP, and recently, its use has also begun to rise in the eastern IGP (Malik et al., 2005). According to Smart Indian Agriculture (2015), under the direction of the ICAR Directorate of Weed Research, conservation agricultural technologies have recently been successfully tested on farmer farms in Madhya Pradesh's district of Jabalpur. According to their findings, conservation agriculture is the fastest-growing farming method in this area, and the black cotton soils of central India are among the best ones for it. The long-term study on various conservation agriculture-based systems, started under AICRP weed management, has produced encouraging results for maize-sunflower in Tamil Nadu, pearl millet-mustard in Gujarat, and rice-chickpea-green gramme in Karnataka, pointing towards the potential for extending the advantages of conservation agriculture to central and south India (DWR, 2014).

8.5 Conservation Agriculture Benefits:

- Improvement of soil quality, i.e. soil physical, chemical and biological conditions.
- In order to reduce pollution from greenhouse gasses and to allow growth processes greater resistance to climate-related aberration, enhancing sequestrationof soil in C and building up organic matter is a realistic approach.

- Lessening of the occurrence of weeds.
- Increasing of nutrient and water use efficiency.
- Increasing of production and productivity (4% – 10%).
- Sowing can be done early.
- Greenhouse gas emission reduction and enhanced environmental sustainability.
- Preventing seed residues from combustion decreases fertilizer depletion and contamination of the atmosphere, which eliminates significant health harm.
- Opportunities to diversify and increase crops, such as sugar cane systems, mustard, chickpea, pigeon pea etc.
- Enhance the efficacy of resources use by decomposing residues, improving the structural conditions of soil, increasing recycling and access to plant nutrients.
- To keep an eye on the grass and soil temperature, reduce evaporation, and promote agricultural growth by using surface leftovers as a polkway. The benefits of the ZT wheat technology are being tested and employed in various Indian agricultural methods, but there are substantial knowledge gaps in the use of CA-based technology, which suggests that such technologies need to be developed, improved, popularised, and extensively disseminated.
- Decrease in production cost.

8.5.1 Economic Benefits:

To monitor the temperature of the grass and soil, lower evaporation, and encourage agricultural growth by using surface waste as a polkway. However, there are significant knowledge gaps in the application of CA-based technology, which shows that such technologies need to be created, enhanced, popularised, and widely distributed. The advantages of the ZT wheat technology are being evaluated and applied in various Indian agricultural approaches. Erenstein and Laxmi (2008) claim that planting ZT-wheat in India after rice increases farmers' revenue from growing wheat (US$97/ha) as a result of the combined impacts of yield enhancement and cost-saving (Table 1). In a similar vein, Gupta and Seth (2007) found net gains from ZT-wheat in India of $150/ha.

8.5.2 Environmental Benefits:

Resources are used more skillfully in conservation agriculture than in traditional agriculture, making them available for other uses and preserving them for future generations. Increased crop diversification, improved soil biological processes, lower erosion and leaching, and reduced long-term usage of inorganic fertilisers and pesticides can all result in greater water and nutrient retention and efficiency.

Through increased water infiltration and less surface runoff, ground water supplies are refilled. As a result of less pesticide pollution and soil nutrient leaching and soil erosion, water quality is also improved (Bassi, 2000). ZT agriculture significantly minimises the need of fossil fuels, which lowers greenhouse gas emissions and maintains the biome's cleaner air. Additionally, conservation agriculture significantly reduces air, soil, and water pollution by using less agrochemicals. Given the potential for global warming, conventional tillage produces more greenhouse gas emissions than zero tillage under both wheat and rice cropping systems.

8.5.3 Benefits in Resource Conservation and Improvement:

According to studies by Dahiya et al. (2007), Verhulst et al. (2010), Jat et al. (2012), Saharawat et al. (2012), and others, conservation agriculture (CA) is a strategy for improving water use efficiency in a sustainable manner by increasing soil water infiltration and retention, reducing evaporation loss, improving nutrient availability, and reducing the prevalence of weeds like Phalaris minor in wheat. Crop growth and production are enhanced or maintained as a result of CA practises (Aulakh et al., 2012; Krishna and Veettil, 2014; Yadav et al., 2019). Its long-term benefits in promoting crop yield, increasing water and nutrient uptake, reducing soil erosion, and attenuating the consequences of climate change are of utmost significance. Let's do a methodical recall.

8.5.4 Soil Physical Health:

A crop must have the right soil conditions for it to grow and develop properly. Therefore, it is necessary to understand how conservation agriculture affects the physical quality of soil. Conventional tillage (CT), which involves frequent and intensive tillage operations, physically degrades soil structure, whereas decreased or no tillage preserves soil aggregation due to less soil disturbance and the intact presence of intact root fragments and mycorrhizal hyphae as binding agents. In contrast to Connecticut,

where there is no permanent crop residue, conservation agriculture protects the soil against wind, water, and rain drop erosion. Conservation agriculture maintains larger aggregates (Bhushan et al., 2007), higher mean weight diameter (Jat et al., 2009), and reduces the impact of many constraints related to soil physical health degradation, such as soil structure degradation, soil compactness, soil crusting, and decrease in soil organic matter (Dalal et al., 1996). By increasing soil organic carbon content, zero tillage improves soil aggregate stability (Chauhan et al., 2002).

8.5.5 Crop Productivity:

Due to a loss in agricultural output in the first few years after CA implementation, farmers are typically reluctant to implement it. However, numerous studies have found that CA either have no effect on crop productivity or have a favourable influence. Krishna and Veettil (2014) investigated the effects of implementing zero tillage on farms in Haryana and found that crop productivity increased by 5%. In the eastern and north-eastern regions of India, the adoption of conservation tillage, along with better plant nutrient management and 30% residue retention for three years, increased grain yield by 51.1–52.2% in comparison to farmer practises at the time (Yadav et al., 2019).

According to Das et al. (2014a), conventional tillage produced a larger yield of rice grains than minimum tillage. However, after four years, the soil quality and nutrient recycling increased and the yield stabilised with minimum tillage. According to Jat et al. (2013), wheat crop had significantly higher yield under no-till flat system during first year and non-significant difference in succeeding two years. Maize crop produced higher grain yield under permanent raised beds system as compared to no-till flat and conventional flat system. As a result, CA practises may be advantageous.

8.5.6 Water and Nutrient Use Efficiency:

Through its effects on mineralization, recycling of soil nutrients, moisture retention, and controlled evaporation, tillage, residue management, and crop rotation significantly influence the physical environment of the soil and the dynamics of water and nutrients in any soil. In the Indo-Gangetic plains of India, wheat is typically grown using zero tillage. Zero tillage can save 20 to 35 percent more irrigation water on wheat crops than conventional tillage (Mehla et al., 2000; Gupta et al., 2002). By using the remaining moisture from the paddy crop's harvest instead of pre-sowing irrigation, this practice helped save water for the wheat crop. Additionally, the practice enabled earlier wheat crop planting and harvesting, which further reduced the need for one or more irrigations in the late season.

The irrigation water productivity in the winter months was boosted by 39–138% over the conventional system in the eastern Indo-Gangetic plains by incorporating the CA components (Laik et al., 2014). on an experiment on a maize-wheat cropping system on sandy loam soil, Jat et al. (2013) found that permanent raised beds had a 16% greater water use efficiency than conventional tillage. Permanent raised beds and no-till flat treatments required less irrigation water, by 24.7% and 10.8%, respectively, than the conventional tillage treatment. In the cropping system for pigeon pea and wheat, the CA system had a greater water use efficiency than the CT system (Das et al., 2016). In the northwestern Indo-Gangetic plains, CA-based plots reduced evaporation by 23–37% compared to CT-based plots (Parihar et al., 2019). Here, the permanent raised bed plots had water productivity that was 14-35% and 30-36% higher than the zero-till and conventional-till plots, respectively.

8.5.7 Soil Erosion Control:

Without control, soil erosion results in the loss of fertile top soil, which reduces sustainability, while also causing water bodies downstream to become sedimented and atrophied. According to research on CA practices, runoff, which is otherwise responsible for transferring soil sediments and residual agrochemicals, is reduced (Kukal et al., 1991). This has an impact on both surface and ground water contamination. According to Kurothe et al. (2014), there was a 37.2% decrease in average soil loss when compared to conventional tillage. In comparison to conventional tillage, the runoff under ridge farming tillage, no tillage, and stubble mulch farming tillage was reduced by 69.4, 16.2, and 59.6 percent, respectively.

8.5.8 Climate Change Mitigation/Adaptation:

CA has the potential to help with adaptation and mitigation for extreme weather events that happen as a result of climate change. By using less fuel during reduced tillage operations and by enhancing soil organic carbon retention, CA can lower the release of atmospheric greenhouse gases (GHGs) and aid in mitigating climate change. By combining decreased tillage with enhanced plant nutrient management (IPNM) and 30% rice residue retention in wet season rice, 1.30 Mg C ha-1 was amassed with a sequestration rate of 427.9 kg ha-1 yr-1 in a rice-rice cropping system. According to reports, implementing CA with IPNM/INM and residue retention or incorporation had the ability to reduce CO2 emissions by about 1.6 Mg ha-1 yr-1 in paddy soil, which can help to mitigate climate change (Yadav et al., 2019).

Conservation agriculture on permanent bed systems, with crop residue retention in the maize-mustard-mung bean cropping system, and nitrogen treatment with neem coated urea, according to Jat et al. (2019b), can reduce carbon footprint and is therefore an environmentally secure and effective practise.

8.6 Management Practices Concentric to Conservation Agriculture:

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8.6.1 Conservation Tillage Practices:

Conservation tillage techniques include mulch tillage, ridge tillage, contour tillage, reduced or no tillage, and minimal tillage. There is no soil surface disturbance caused by tillage in no-tillage (NT). Only a small portion of the soil's surface is disturbed when seeds are sown. There is no secondary tillage work done in minimum or reduced tillage.

When using mulch tillage, the soil is tilled so that the residual crop wastes can cover the greatest possible area of the soil surface. Crops are planted either on top of or on either side of the ridges that are prepared during sowing in ridge tillage.

8.6.2 Residue Management Practices That Avoid Burning:

All residue management techniques that prevent its burning are beneficial to the environment and natural resources in one way or another. The management of crop wastes under Indian conditions may include mulching, conservation agriculture, composting, mulch tillage, biochar production, and animal feeding. Crop residues, whether left on the soil surface as mulch or incorporated as compost, biochar and farm yard manure (FYM) from animals, typically protect the soil surface from extremes of rainfall and temperature.

They also increase the activity of different soil macro and micro-organisms, which further aids in the formation of stable soil aggregates. Crop residues lessen soil aggregate dispersion and breakdown as well as surface compactness, surface sealing, and crusting.

According to Ruan et al. (2001), various bio-physical factors like soil type, topography, temperature, intensity and amount of rainfall, wind speed, amount and magnitude of soil surface cover by crop residues, and common cropping patterns all influence how much crop residue cover has a positive impact on a region. More land surface cover increases the preservation of soil physical qualities against natural and artificial disturbances, according to Blanco-Canqui et al. (2006). In a four-year study on permanent bed systems, Jat et al. (2019b) found that applying agricultural residue boosted productivity by 11.7% relative to a system without residue.

8.6.3 Crop Diversification Practices:

Beyond conservation tillage and residue management, crop rotation is a key element of conservation agriculture. The types and characteristics of the crops used during crop rotation define the degree and scope to which soil physical health may be altered. Proper crop rotation makes it easier for different micro- and macro-pores to form, which is necessary for the circulation of water, air, and nutrients into the soil and is good for crop root growth. According to Jat et al. (2019b), growing maize, mustard, and mungbeans in a permanent bed system of conservation agriculture had a benefit-cost ratio that was 11% higher, more net energy, and a 9% lower carbon footprint than growing maize, wheat, and mungbeans.

8.6.4 Nutrient and Water Management Practices:

Since CA influences different physical, chemical, and biological properties of soil, which in turn dictate the nutrients and water availability, it is necessary to improve nutrient and water management practises with respect to CA in order to gain maximum benefits and sustainability. According to Jat et al. (2019b), application of nitrogen using neem-coated urea in permanent beds with crop residue increased system production by 10.9% compared to non-coated prilled urea. In a study that lasted four years in a soybean-wheat cropping rotation in the northwestern part of the Indo-Gangetic plains with soil that had a loamy sand texture, low levels of organic carbon, and available phosphorus, Aulakh et al. (2012) found that soybean productivity could be increased under conservation agriculture as compared to conventional agriculture either by applying 25 kg of manure per hectare per year or by using a combination of both.

8.6.5 Weed Management Practices:

The main and most frequently mentioned barrier to farmers' adoption of CA is the shift in weed species and rise in weed density, which reduce agricultural output. Numerous experts claimed that although their degree of adoption is now relatively low, cover crops may be essential for weed management in CA systems. Alterations to planting methods, tillage patterns, and other management techniques can drastically alter the weed flora by altering the soil environment. Herbicide use has been a crucial part of managing weeds in CA systems, but more work needs to be done to combine it with non-chemical weed control methods.

8.7 Effect of CA On Crop Yields:

Concern over conventional agricultural practices, particularly soil tilling with a plough, disc, or hoe, is developing in many regions of the world due to the negative effects they have on the environment and the productivity of soils. This prompted both governments and farmers to find other methods of production that maintain the productivity and soil structure. When there is little or no tillage, the use of cover crops, extensive field rotations, and straw mulches is frequently an obvious and popular option to preserving grass (Knowler and Bradshaw, 2007). CA is a significant and inescapably detrimental departure from the current management for many active farmers. For farmers who aren't ready to accomplish this, reduced tillage options are a practical option.

The combination of decreased tillage (with the aim of no tillage) and other characteristics of CA practises led to the development of sustainable intensification conservation agriculture (CASI), with the goal of increasing cultivation schemes in a sustainable manner.

Over the past thirty years or so, the IGP has tested CASI technology, particularly in RW systems. In comparison to traditional labor-intensity (CT) approaches, the adoption of Zero Tillage (ZT) and residue preservation for wheat has been shown to increase yields, flexibility in resource usage, soil and water quality, and lower production costs (Islam et al., 2019). Permanent vegetative covering or flour cover, low ground disturbance (No/reduced tillage), and numerous crop rotations are the three main tenets on which CA is often based. Due to CA's positive impact on the preservation of land and water, human safety, and economic viability, it has been recognised as an environmentally benign technology and used internationally. Despite rising food security globally, there are worries regarding the effects of CA practises on crop output, particularly in underdeveloped nations (Zheng et al., 2014). The impact of CA on crop output may be complicated. For instance, CA can boost crop yields by boosting soil fertility by preserving soil and water and storing organic carbon in agricultural fields (Holland, 2004). In comparison, CA may also havedetrimental effects on crop yield by modifying soil physio-chemical and biological conditions, such as growing soil temperatures in high latitudes or low temperature seasons and aggravation of temperatures in agricultural areas. The true effect of CA on crop yields will mostly be calculated by different CA methods, national climatic conditions and crop systems (Liu *et al.,* 2010). Numerous crops grown around the world that are focused on conservation have shown increases in yield. For instance, Thierfelder et al. (2015) found that conventional labour produced more maize (Zea mays L.) than other methods in South Africa. Between conservation agricultural and laying plans, maize and other crop yields have been documented not only in African nations but also in North, Latin American, and Asian countries (Kassam et al. 2009; Faroooq et al. 2011). The main causes attributed to better yields include enhanced soil fertility over the long term and improved soil physical conditions (such as improved infiltration and retention of soil moisture). Increased farmers' experience was lacking, slow fertility rate increased, water stock in high rainfall periods was reduced on poorly drained soils, cultivation of delayed crops due to the occurrence of wet and cold soil fertilisation, residue management issues, and increasing weed competition (Linden et al. 2000; Faroooq et al. 2011; Thierfelder et al. 2015).

8.8 Predictions of Conservation Agriculture:

In order to refocus current farming and processing activities with lower pricing by choosing less risky pathways and options, Asian farmers and researchers will also need support. Therefore, continuing with business as usual doesn't seem like a realistic option for conventional farming practices. Sustainable improvements in food grain output and, thus, CA-based crop implementation strategies tailored to particular requirements, would also have to play a significant role in the majority of the ecological and socioeconomic context of Asian agriculture. The following opportunities for fostering CA in theIndian / Asian context:

- Production cost is Reduces
- Weed growing is reduced

- Water and nutrient saving
- Yields of crops increases
- Beneficial for the environment
- Diversification of crops
- Improves the resource use efficiency.

8.8.1 Limitations for Adoption of CA:

Moving farmers, engineers, extenders, and researchers away from land degradation and towards sustainable production techniques is important to bring about a change in farming attitudes (Derpsch 2001). CA is currently a route for sustainable agriculture. Therefore, the advancement of scientific research will be necessary for the growth of conservation agriculture. The widespread adoption of the CA is hampered by a few significant obstacles.

- Lack of seeds for small and medium - size growers, in particular.
- The high utilisation agricultural residues in cattle feed and energy.
- Crop residues burning.
- Failure to realize CA’s value for producers, extension officers and growers.
- Required trained and technical workers.

8.8.2 Bottlenecks for Adoption of Conservation Agriculture:

Apart from the many advantages of conservation agriculture, there are a number of issues that prevent it from being widely used, such as equipment and machinery, weed control, farmer mindset, and policy restrictions. The major obstacles in Indian farmers' adoption of CA are briefly discussed below.

8.9 Lack of Appropriate Machineries:

Although major efforts have been made to develop and market equipment for sowing wheat in no-till systems, it will need far more work to develop, standardise, and encourage high-quality equipment for a variety of crops and cropping patterns if the technology is to be successfully adopted. These would entail the creation of suitable equipment to manage crop residues and carry out simultaneous tasks like uniformly shredding of residues that are typically piled in the field after combine harvest, collection of part of residues for animal feed and application of fertilisers at the proper place and in the proper quantity along with seeding.

In this context, the Australian Centre for International Agricultural Research and Punjab Agricultural University, Ludhiana, have created a novel equipment named the "Happy Seeder." A 45 HP tractor is needed to operate the Happy Seeder machine. In a single operational pass of the field, it cuts, lifts and controls the standing stubble and loose straw by keeping it as surface mulch and sows the wheat crop. However, the machine's weight, the burden on the tractor, and the choking of the machine with a big stubble load are still the main operational restrictions. The development of a super straw system attachment for combines now ensures cutting and even distribution of heaped or anchored wastes in the field. Therefore, this might be a practical way to deal with the residue.

In the case of the Turbo Happy Seeder, the tractor's power demand must be greater than 50 HP. As most farmers own tractors with 40 or fewer horsepower, this presents another barrier to managing residue. In this situation, the farmer won't need to buy a new, high-powered tractor because the draught required for the Turbo Happy Seeder can be decreased by reducing the number of tines. Additionally, farmers are hesitant to buy these devices because they sit dormant for the majority of the year.

8.9.1 Infrastructural Constraints:

A few of the inputs that must be made widely accessible in the market in order to promote CA include herbicides, seeds for rotational and cover crops, and agricultural machinery for direct sowing, planting, and residue management. Many times, these equipment types diverge completely from those that are normally employed. This can be accomplished with improved input supply infrastructure and a proactive attitude on the part of the supply sector, including dealers and manufacturers.

8.9.2 Obnoxious/Stubborn/Resistant Weeds:

Infestation, distribution, diversity, growth style, and resistance levels of weeds have changed throughout California. Herbicide applications over an extended period of time can somewhat suppress weed infestation.

Since herbicidal applications are typically used to manage most weeds, their gradual reappearance over time is a severe issue. But over time, the majority of weeds develop resistance to pesticide use. Even pesticides are ineffective at controlling obnoxious weeds. The quality of crop yield and soil biodiversity may be threatened by the regular administration of herbicides to farms in California to suppress such weed species. Therefore, it may be necessary to redefine the CA and permit one-handed weeding at the proper stage of the crop. It will be the effective method to control weeds without much disturbance to the soil and at the same time save the fields from being overloaded with herbicidal residues.

8.10 Conclusion:

Conservation agriculture covers a wide range of topics, including maintaining agricultural productivity, guaranteeing food security, conserving natural resources including soil, nutrients, and water, and mitigating or adapting crops to climate change conditions. Numerous advantages of conservation agriculture include improved soil physical, chemical, and biological health; sustaining crop production through resource conservation and soil quality; cost, energy, and labour savings; improved water and nutrient use efficiency; reduced greenhouse gas emissions by carbon sequestration; reduced soil erosion and environmental pollution due to the elimination of the need to burn crop residues; and climate change mitigation. Different from the conventional system, CA's management techniques change depending on the soil, crop, and resource availability. Even Nevertheless, there aren't many barriers preventing its widespread implementation. Through the implementation of effective policy, the agricultural clients may easily access suitable farm equipment, particularly for residue management.

The requirements of small and medium farmers must be taken into consideration when developing the agricultural machinery for CA. In addition, the concept of one-handed weeding at the proper crop stage for managing noxious weeds needs to be introduced in order to redefine the phrase "conservation agriculture". In accordance with the conditions in the local area, more research is needed to improve these management practices.

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9. New and Innovative Technologies and Machinery in Conservation Agriculture

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Abstract:

The practice of conventional agriculture with the reliance on intensive farming practices has led to serious ill effects on soil, plant and ecosystem and thereby threatened the sustainability and stability of the systems. This led to the evolution of a more reliable and sustainable crop production system which is today known as conservation agriculture. A rising number of people are turning to conservation agriculture (CA) as a means of achieving the twin objectives of feeding a growing global population and protecting natural resources. Mechanisation is a crucial component of CA. A variety of CA machines, including the laser land leveller, no-till drill, Turbo Happy Seeder, multi-crop planters, and relay seeders, which are all suitable for the main cropping systems in India, have been developed and evaluated with satisfactory progress. However, smallholder farmers frequently find it challenging to make the necessary financial commitments. To offer mechanisation inputs a supply chain for equipment inputs must be established to ensure easy availability of innovative and new machineries.

Equipping and educating business owners who offer CA services can also be a practical approach. These entrepreneurs may sustain themselves by offering high-quality CA and other mechanised services on a fully costed basis with the suitable equipment, chosen for the demands of their local farmers, and the appropriate technical and business management training. This chapter inculcates the characterization of various machineries and implements which are suitable and inevitable for conservation agriculture.

9.1 Introduction:

Mechanization of agriculture has pushed the agriculture sector so far in terms of production. however, it has also led to severe repercussions. The mechanization process involved multiple cultivations of land (4-5 times), faulty agricultural operations, cultivation of single high value crops every season, which totally degraded the soil, environment and ultimately the health of planet. The crop residue burning had been a common phenomenon in many parts of India especially, north-eastern region. The crops which are harvested leave behind tonnes of residues on the fields. Large volumes of attached and loose crop residues are left on the fields when rice and wheat are harvested together. Contrary to rice straw, which is regarded as a poor feed due to its high silica content and has no other economic use, wheat straw is collected using a straw combine for use as fodder approximately 75% of the time.

The loose rice residues in the fields make it difficult to till the soil and plant the wheat crop that will follow. To prepare fields for the timely sowing of wheat, northwest India often burns rice residue in open areas. The process results in significant losses of plant nutrients, particularly N and S, and organic C, with significant ramifications for soil quality and human health [1]. Only by implementing conservation agriculture practises will soil degradation caused by ongoing use of large machinery and inefficient farming practises be reversed. Conservation agriculture (CA) supports long-term RW production systems by restoring soil nutrient stocks and organic matter through in-field crop residue retention [2].

The idea behind conservation agriculture (CA), which is focused on boosting natural and biological processes above and below the ground, is to produce agricultural crops while conserving resources. Through the long-term, judicious, and sustainable use of the resources at hand, CA seek to increase productivity and profitability [3]. Besides other good agricultural practices, CA is defined by three interconnected principles (Figure 9.1), including: (i) no or minimal mechanical soil disturbance (implemented by the practice of direct planting into untilled soil and no-till seeding or broadcasting of crop seeds and causing least soil disturbance from any agronomic operation, harvest operation or farm traffic); (ii) maintaining a continuous biomass soil mulch layer over the surface of the soil (accomplished through retaining atleast 30% agricultural biomass, root stocks, stubbles, cover crops, and other ex situ biomass sources); and (iii) Cropping systems with crops in rotations, sequences, associations, and/or sequences incorporating annual and perennial crops, as well as a balanced combination of legume and non-legume crops, are used to diversify crop species [4].

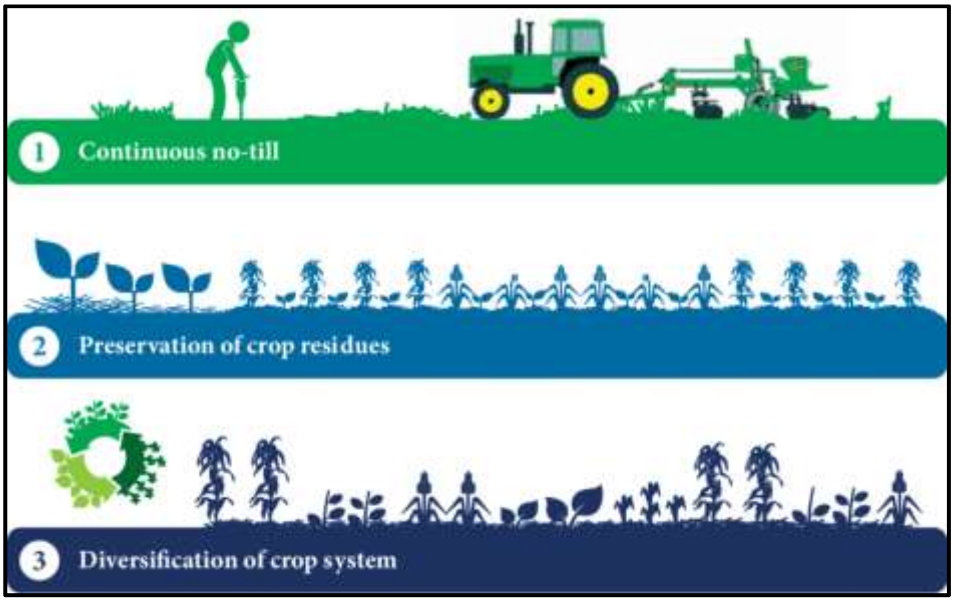

Figure 9.1: Key principles of Conservation Agriculture [5]

Another aspect which is nowadays emerging as a fourth principle is controlled traffic that reduces soil compaction. According to [6,7], CA is a potential technique for the long-term sustained production and efficient rational use of the available resources. According to [8,9], conservation agriculture-based management practises are realistic solutions for sustainable agriculture and efficient techniques to stop land degradation.

Around 180 Mha of cropland, or about 12.5% of all cropland worldwide, were used for CA in 2015–16, a significant increase of 74 Mha from 2008–09 [4]. Various cropping systems involve the late harvesting of the *kharif* season crops which delays the sowing of the succeeding *rabi* crops. In such scenarios, relay cropping has emerged as quite a viable option. Relay planting provides a fantastic chance to raise crop yield and farmer revenue in India's wheat-based systems. Due to the delay in sowing cotton, wheat yields in the cotton-wheat system are noticeably lower than those after rice and maize.

Therefore, new equipment is required for the timely sowing of wheat into the existing cotton crop. Similar to this, adding short-duration mungbeans to wheat-based agricultural systems can increase farmer profitability while also supplying protein to undernourished populations. Mungbean planting, on the other hand, is delayed after wheat harvest, which causes crop failure since the maturity time overlaps with the start of monsoon season. In order to accelerate sowing and ensure that the crop matures before the monsoon season, relay planting mungbean in standing wheat crops is helpful. More focus than ever is being placed on maize-wheat and rice-maize systems to diversify the RW system.

A variety of other crops and cropping sequences currently lack CA technology, despite advances in the development and promotion of machinery for direct seeding of wheat into combine harvested rice fields. The machineries that have been developed are generally high-power requiring and expensive which makes them unaffordable to the small and marginal farmers of the country. Since most Indian land holdings are between 1-2 ha, both large and smallholder farms require CA machinery. Major barriers to the use of CA machinery in India include a small proportion of land holdings, poor economic conditions of farmers, low seasonal usage of machines, uneven size and shape of fields, competition between machine and manpower, and farmers' attitudes towards zero-till planting of crops. Therefore, there is a need to develop need based, energy efficient, cost efficient machineries and technologies which could be feasible in long run.

9.2 CA Technologies and Machinery in India:

Conservation agriculture refers to the selective application of new, modern methods of farming. According to the [10]**,** conservation agriculture is a method for growing crops that produces high and consistent yields while preserving the environment by using less resources. The use of external inputs, such as agrochemicals and mineral or organic nutrients, is administered at a desired level, in a method and amount that does not interfere with the biological process, and interventions like mechanical soil tillage are restricted to the bare minimum. According to [11]**,** direct seeding or planting has been proven to have positive effects. It was found that only by adopting high conservation tillage techniques like zero tillage, happy seeding, laser field levelling, etc. land preparation costs could be lowered by 25–30%. Irrigation, pesticides, and herbicides may not be necessary for crop establishment if applied at the appropriate time and on the appropriate covering machinery. To enhance soil organic matter, as many residues as feasible are to be left behind, and they are to be distributed as uniformly as possible. The following goals may be accomplished by conservation agriculture: greater crop production, which in turn increases farmer income; climate resilience; food security; soil nutrition; and energy reduction. Conservation tillage practises can help farmers deal with the labour scarcity and hardship they are now experiencing.

A crucial input for CA is mechanisation, particularly power units, seeders, rippers, and sprayers. No-till planting and weed control equipment are the main mechanisation needs for smallholder CA [12]. The different machineries and technologies that may be used with conservation agricultural techniques include:

9.2.1 Machineries and Technologies for Sowing Management:

A. Laser Land Leveler:

a. Four-wheel tractor driven Laser leveler:

A laser-guided precision levelling technology called Laser Land Levelling is used to achieve very precise levelling with the desired grade on the field within 2 cm of its average micro-elevation. It makes use of a laser transmitter unit that continuously discharges a 360° rotating beam that is parallel to the necessary field plane (Figure 9.2.). This is received by a laser receiver (receiving unit) mounted on a mast on the scraping unit. A two-way hydraulic control valve automatically adjusts the scraper level in accordance with the signal's conversion into cut-and-fill level adjustment. By automatically handling the cutting and filling operation, laser levelling preserves the grade. To find the highs and lows in the field, a grid survey is carried out using grade rods. The high expense of purchasing a laser leveller prevents individual farmers from purchasing the machinery. Therefore, even for low-income small farmers, using LLL is economically viable and available through custom hiring services. According to the findings of several studies, laser land levelling (LLL) increased the application efficiency of irrigation systems, saving 20–25% of irrigation water. It increased rice, wheat, and sugarcane crop and water production by 15–25% and brought financial rewards to the farmers [13,14].

Figure 9.2: Laser land leveller

b. Two-wheel tractor driven Laser leveler:

For efficient field operation, a 50-horsepower tractor is necessary for the typical laser leveller. Additionally, in the eastern parts of the IGP, the small holding size and irregular shapes of the field make it difficult to use a 4-wheel tractor-driven laser leveller economically.

A laser leveller that can be placed into 2-wheeled tractor and is suitable for small-size holdings has been developed. The Borlaug Institute for South Asia (BISA), Ladhowal, Punjab, created a prototype of a 2WT-operated laser leveller for the region's small farmers.

B. Slit till Drill:

It is a tractor-powered machine (45-50 hp) that is used to sow seeds into the slits that are opened by the rotating slit disc that is mounted in front of the machine's furrow openers in only one operation in stubbles fields (Figure 9.3.). In the stubble fields of soybean, maize, and paddy, the machines prepare a 20 mm slit in the soil and insert seed and fertiliser into the prepared slits. In comparison to strip and roto till drill, it decreases moisture loss and draught force. In comparison to strip till drill machines, cost reduction through time and energy savings and environmental health optimisation through reducing soil compaction were less significant [15]**.**

Figure 9.3: Slit till drill.

C. No-Till (NT) Seeder for Anchored Stubble Conditions:

In India, the most common No-Till equipment is a 4WT-drawn seed drill, which plants wheat seeds straight into tilled soil in one operation. For ripping of anchored stubbles, the NT drill uses inverted T-type furrow openers rather than shovel type furrow openers. The coulter and seeding system draws the seed through the soil with a 4WT while the Inverted-T creates a small split in the soil. NT seeders typically have a 6-row, 1.2 m-wide seed-cum-fertilizer drill.

A tractor with 35 horsepower or more can drive it. It produces an efficient 0.35 to 0.40 hectares per hour. In compared to conventional tillage, NT seeding of wheat is advantageous in terms of economics, irrigation water savings, and enhanced timeliness of wheat sowing [16]. The greater wheat yields produced under the NT method are mostly attributable to earlier planting. However, because loose residue frequently obstructs the placing of seeds, wheat sowing with an NT drill can only be implemented after the removal or burning of loose rice residue from the fields. Farmers typically burn the loose leftovers on their fields as a result, which is not a sustainable method.

D. No-Till Drill for Seeding into Crop Residues:

Direct drilling of wheat or any other crop into loose rice residue poses challenges because (i) straw builds up in the seed drill's furrow openers and (ii) heavy residue conditions necessitate frequent lifting of the implement, which affects seed depth and ultimately crop establishment. So, for no-till seeding into crop residues, drills that can cut through loose straw, enter the soil, and properly depth the seeds are needed. The development of Turbo Happy Seeder (THS) for seeding into rice residues began in 2002 at PAU Ludhiana with support from ACIAR. The first edition of Happy Seeder was produced and suggested in 2007 [17,18]. By making a number of additional adjustments, the most recent Happy Seeder (also known as THS) was enhanced and tested by PAU, Ludhiana, for direct seeding wheat into large amounts of rice residue in 2012 [19]. In the THS, wheat is sown using a zero-till drill and a rotor for handling paddy residues. By leaving the seeded rows uncovered and readily visible, the THS allows for precise alignment of subsequent sowing passes. With a 45 horsepower tractor, this PTO-driven equipment can cover 0.3 to 0.4 hectares per hour (Figure 9.4)

Figure 9.4: Turbo Happy Seeder.

The THS method of sowing wheat into rice residue offers several advantages for the environment and the economy. Significant air pollution can be decreased, soil nutrients can be recycled, and soil organic matter can grow by not burning the rice residue [20]. THS performed successfully in farmer farms throughout Punjab, increasing wheat yields by an average of 3.2%. Previous research on farmer fields and on-station [21] shown that happy seeder seeded wheat produced yields that were comparable to or greater than those of conventional practise. Increases in wheat production for the Turbo Happy Seeder may be attributable to enhanced soil thermal regime with surface residue retention and increased soil water availability as a result of decreased soil evaporation [22]. Mid-March saw a 10–20% improvement in grain production in the THS-sown wheat plots compared to farmers' fields due to the lower canopy temperature [23]. When compared to CT, the THS may save up to 83% of the energy needed for wheat planting, and it also uses less fuel, which lowers CO2 emissions. Due to the existence of sufficient residual soil moisture in the rice fields, pre-sowing irrigation was not necessary in the majority of the studies for early sowing of wheat utilising THS. Thus, the use of happy seeder technology may be able to save 75–100 mm of irrigation water.

When irrigation scheduling was based on soil moisture potential, residue mulch reduced soil moisture loss through evaporation by around 40 mm and may therefore save one irrigation in wheat. In the IGP, THS is currently widely employed for direct planting of wheat into paddy fields. The addition of triple action straw management rotors and energy-efficient blades in THS further decreased the operational power consumption by 20–25% and increased the field capacity by 15%. Wheat, dry seeded rice (DSR), moong beans, and maize may all be sown in rice residue using THS.

E. Turbo Happy Seeder for Seeding Mungbean and Maize Fodder:

Typically, 25% of the residual wheat straw is burned by farmers, and the remaining 75% is gathered using straw combines in the area after combine harvesting. After making a little change to the seeding mechanism, the Turbo Happy Seeder may also be used to directly sow summer mungbean or maize for fodder right after the harvest of wheat, generating extra revenue for the farmers (Figure 9.5.). Thus, CA interventions not only boost farmers' income but also open the door for the addition of a legume crop to the RW cropping system [24,25].

Figure 9.5: Turbo Happy Seeder for Seeding Mungbean and Maize Fodder

F. Low Powered Tractor Operated Turbo Happy Seeder:

Nowadays, efforts are concentrated on growing CA among South Asian smallholder growers. The creation of smaller versions of Turbo Happy Seeders that require low powered 4-Wheeled Tractors and 2-Wheeld Tractors when human and animal labour becomes less readily accessible is an example of innovation in CA planters for smallholder farmers in eastern IGP of India and Bangladesh (Figure 9.6.). With 5 seeding rows, the low-hp 4 wheeled tractor operated THS can directly seed wheat into rice residue for smallholder farmers. By taking out the tiller attachment, it is possible to put the smaller THS on the 2-wheeled tractors.

Despite the fact that 2 wheeled tractors require more maintenance and have more operating complexity (and related expenses), the manufacturers supplied a better level of training support. Up to four rows of zero tillage can be planted with the THS machine mounted to the back of a 2 wheeled tractor.

Figure 9.6: Low Powered Tractor Drawn Turbo Happy Seeder

G. No-Till Planter for Direct Seeding of Rice:

Due to a lack of workers for traditional Puddled Transplanted Rice, DSR cultivation is becoming more and more popular in India, particularly in the northwest. According to [26] this approach greatly lowers the cost of producing rice. Farmers were utilising either ineffective seed drills or a very high seeding rate for manual seeding in the lack of proper DSR seeding equipment, which results in low yields. The use of a DSR planter with inclined plates that was created in India is currently being encouraged among farmers in NW India. The seed box, inclined rotary metering plates, seed cups, seed metering strip, seed delivery pipe, and seed boot make up the planter's seed metering and delivery system. The DSR planter maintains the appropriate plant to plant and row to row (20 cm) distances without mechanically harming the seeds while employing a seed rate of 15-20 kg ha^{-1} at a depth of 2-3 cm. The planter has a 1.8 m operating width and a 0.4 ha/h field capacity. For various crops, there are several tilted seed metering plates. Currently, the gadget costs around Rs. 75,000. The DSR planter is likewise becoming more and more well-liked in the eastern IGP. A Luck seed drill with a spraying attachment for DSR has also been developed by PAU, Ludhiana. The drill had nine furrow openers, an inclined plate seed metering system with notched cells, a tank, a hydraulic pump, and nozzles positioned on a boom. The weedicide is sprayed while the drill plants the rice seeds (Figure 9.7). Thus, manpower may be saved, and weeds can be better controlled with timely spraying.

Figure 9.7: No-till Planter for DSR

H. Machinery for Permanent Raised Bed Planting System:

The resource conservation technique of raised bed planting, a type of controlled traffic, was first used for wheat in India in the middle of the 1990s. The possibility of no-till planting of crops with the related benefits of CA is added by permanent raised beds (PRBs) with stubble retention.

The PRB planting method offers additional chances to lessen the negative effects of excessive water use on crop productivity besides providing other advantages, such as the ability to mechanically manage weeds [27,28], a 25–30% reduction in irrigation water use, and decreases in lodging and seeding rates.

The size of the bed ranges from 50 to 120 cm depending on the kind of soil and cropping strategy used (such as row spacing) with 37.5 cm broad furrows. For farmers that produce crops on PRBs, bed planters have been created that simply rearrange the beds before planting the following crop and keep all or part of the crop leftovers on the surface.

The PRB planter includes a bed shaper and double disc furrow openers (Figure 9.8). In comparison to other types of openers, the double disc furrow openers provide a small slit for the planting of seed and fertiliser as well as for controlling corn residue. In the maize-wheat system, the PRB planting aids in strong crop stand, improved production, and resource use efficiency [29].

Figure 9.8: Inclined plate planter with double disc furrow openers sowing wheat on PRBs (left) and earthing up/weeding in PRBs in wheat (right).

When fertiliser is applied on the soil surface (or broadcasted) under CA, more nutrients are lost, which results in inefficient nutrient utilisation and environmental degradation. In order to ensure that crop roots can absorb the necessary nutrients during the growth season and consequently boost the nutrient usage efficiency, fertiliser placement is vital [30]. Using 4WT with narrow tyres, the no-till planters may also be used to apply fertiliser at the proper depth to standing crops of wheat, direct-seeded rice, and maize (Figure 9.9). The standing crop under CA or a permanent raised bed system can have the nutrient placed at a depth of 5 to 10 cm near the root zone.

Fertilizer drilling increased wheat grain yield (670 kg/ha) and profitability (7700 rupees/ha). The two-wheeled tractor-driven bed planters are used to construct raised beds for the planting of various crops, such as maize, wheat, and rice, on PRBs.

Figure 9.9: No-Till Planters for Fertilizer Placement

I. Two-Wheel Tractor Self -Propelled Relay Planter:

The Cereal Systems Initiative for South Asia (CSISA) and CIMMYT team created a self-propelled relay seeder for two wheeled tractors in cooperation with PAU Ludhiana and Amar Agro Industries, Ludhiana, Punjab. Relay wheat sowing enhanced cotton productivity by 11–14% by allowing for an extra picking, which was made feasible by the crop's approximately 30-day prolonged growth season.

Relay planting resulted in a 25% increase in wheat production when compared to conventional sowing [31]. When compared to conventional till wheat after cotton, the self-propelled walk behind type relay seeder increased wheat yield by 12-41%. It is manually operated and only has a small field capacity (0.6 hectares per day).

J. Hand Jab Planter:

It is a manually operated equipment for seeding under no-tilled residue retained soils. A predetermined quantity of seeds and fertilizer is inserted into the soil by jab planters. The jab-planter is set on a wooden frame with two points and contains two compartments: one for seeds and one for fertiliser (Figure 9.10). Seed and fertilisers fall into the planting hole once the operator pushes the tips into the ground and opens them.

They frequently have two tips so that fertiliser may be applied together with the seed. The flow of seeds and fertiliser may both be altered. The handles are pulled apart after the point is pushed into the ground with the tip closed, releasing seed and fertiliser into the seeding hole. The seed and fertiliser points are refilled at the end.

Figure 9.10: Hand Jab Planter

K. Multi Crop Raised Bed Planter:

Multi-crop raised bed planters can be used for minimum tillage planting on permanent beds (Figure 9.11). Although significant soil disturbance occurs during the initial bed formation, once established, regular bed reshaping only causes minor soil disturbance. On the two raised beds made by ridgers, it is used to sow bold grains like maize, groundnut, peas, cotton, and sunflower. It is possible to swap out the planting discs for various crops without removing the main shaft of the seed hopper. It is suitable for small holder farms and operated with 12-16 hp two-wheeled tractor. Depending on the situation fertilizers can also be applied. A roller is available to correctly shape the raised bed and cover the seeds [32]. The effective field capacity of this multi-crop planter is between range of 0.11 to 0.20 ha h^{-1}. Bed planting increases wheat production by 05–10% compared to flat sowing, saves 25–30% on seed and fertiliser and irrigation water by 30-35%.

Figure 9.11: Multi Crop Raised Bed Planter

L. CRIDA Precision Planter:

The ICAR-CRIDA precision planter (zero till planter with herbicide and fertiliser applicator) features seed, fertiliser boxes, a seed measuring system, seed and fertiliser delivery tubes, and seed depth control wheels in addition to the herbicide tank (Figure 9.12.). It is powered by tractors with 35 hp. Inverted T type openers are used to properly place seeds and fertilisers in narrow furrows unlike wide furrows in conventional planters. This aids in seed placement at the proper depth and seed coverage. Improved seed-soil contact and seed coverage aid in crop establishment and germination [33].

Figure 9.12: CRIDA- Precision Planter Cum Herbicide Applicator

M. Sugarcane Residue Management Using Stubble Shaving Off-Barring Root Pruning and Fertilizer Drilling Machine (Sorf):

NIASM, Baramati developed this drill machine, which is three-point hitch linkage-operated and powered by tractors with 50–65 horsepower (Figure 9.13). The machine is ideal to carry out a number of additional activities, such as stubble shaving, covering garbage with loose soil, off-barring, and root trimming for sugarcane ratoon crop in a single pass, in addition to drilling fertilisers (upto 0.15-0.25 m soil depth depending on height of raised beds).

In a nutshell, the equipment consists of a power transmission unit, two vertical discs for off-barring, a central horizontal rotating disc attachment with fixed peripheral blades for stubble shaving, and mechanisms for placing fertiliser and root pruning. Old roots of the sugarcane ratoon crop can also be pruned using off-barring and root pruning.

It is a simple, inexpensive, efficient, and environmentally friendly agricultural equipment with a variety of uses, including stubble shaving, covering rubbish with loose dirt, root trimming, and applying fertiliser to a sugarcane ratoon crop [34].

Figure 9.13: SORF Machine Developed By NIASM, Baramati

N. Rippers

The extension of area under CA might have been an interim solution through the use of ox-drawn CA equipment. The reduced tillage principles also apply to ripping as they do to permanent basins. A groove in the soil is made by a ripper where seeds are sown and fertilisers are added (Figure 9.14).

The ripping lines, which are typically 75–90 cm apart, should be in the same location each year and the surrounding soil should not be disturbed. The nutrients and moisture gathered only benefit the crops in the lines. During the dry season, rip lines are opened up (these are often relatively shallow and no deeper than 10 cm) with a chisel-tined ripper to break the plough pan [35].

Figure 9.14: Rippers for Conservation Agriculture

9.2.2 Nutrient Management Technologies and Equipment:

One of the most important and inevitable part of crop production is nutrient management which is a very crucial issue in conservation agriculture. The availability of nutrients is also impacted by conservation agriculture, notably the availability of mineral N, with stubble retention resulting in increased immobilisation and a shortage of crop N early in the growing season. The stubble load, meteorological factors, and natural soil N fertility all have a role in how much immobilisation affects early N supply. However, with larger stubble loads, the ideal N rate tends to be greater under stubble retention due to immobilisation. Stubble loading of 1-3 t/ha are unlikely to change the optimal N fertiliser rate. Therefore, optimization of nutrients to fulfil the crops needs and increase in nutrient use efficiency require to be resolved with new and different approaches.

A. Site Specific Nutrient Management:

In SSNM approach, the plant's need for fertilizer N, P or K and micronutrients is determined from the gap between crop demand for sufficient nutrient to achieve a yield target and the supply of nutrients from indigenous sources, including soil, crop, residues, manures, and irrigation water (Figure 9.15). Management of nutrients (N, P, K) is done according to field- and season-specific conditions [36].

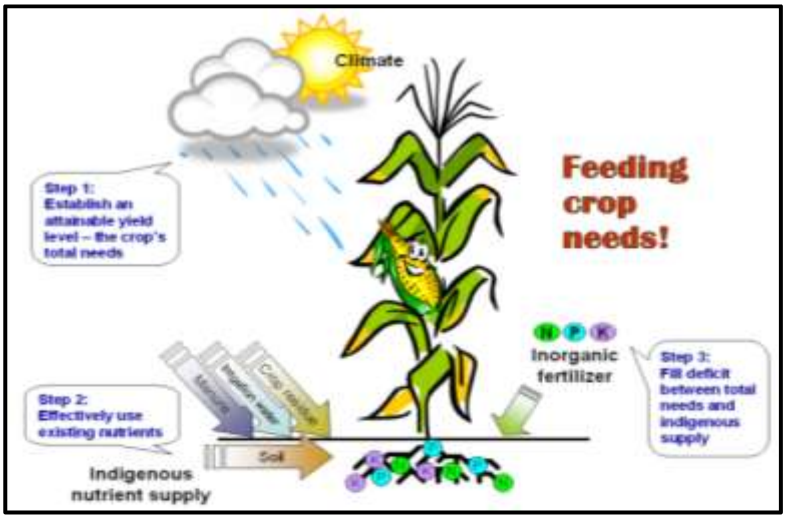

Figure 9.15: Site Specific Nutrient Management Source: Seap.Ipni.Net

B. Leaf Color Chart:

Leaf colour chart is an easy to use and inexpensive tool to manage N fertilizer more efficiently in rice. It is a plant health indicator, developed in Japan (Furuya, 1987) which consists of six colour shades form light yellowish to dark green (Figure 9.16). The colour strips are fabricated with veins resembling rice leaves. The leaf colour below critical value suggests the application of fertilizer. Around 25% N requirement can be cut with the use of LCC.

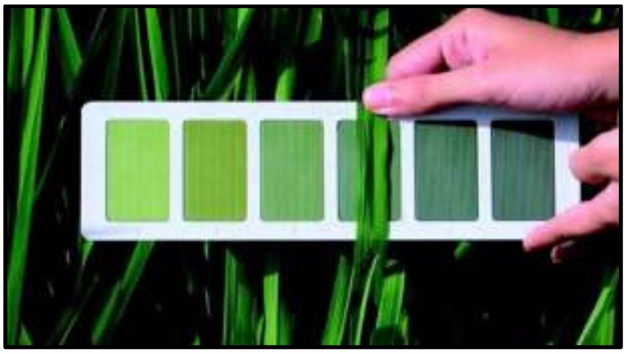

Figure 9.16: Leaf Color Chart For Real Time N Management

C. Green Seeker:

A variable rate application and mapping tool called Green Seeker (GS) is made for usage all through the growing season. It is an optical sensor-based nitrogen management tool that provides useful data to determine NDVI and Red to infra-red ratios (Figure 9.17). Here, the normalised difference vegetative index (NDVI), a measurement of crop vigour, serves as the foundation for N recommendation rates. According to [37], the findings of GS sensor-based N management produced equivalent (in rice) to greater yields (in wheat) with lower N rates which in turn increased NUE.

$$\boldsymbol{NDVI = \frac{NIR - RED}{NIR + RED}}$$

Figure 9.17: Green Seeker

D. Spad (Soil Plant Analysis Development) Meter:

Because chlorophyll molecules hold the bulk of the leaf's nitrogen, the two components of leaves can be correlated. Therefore, monitoring leaf greenness throughout the growing season with a chlorophyll metre like the SPAD metre can detect any possible N deficit early enough to remedy it without affecting yields [38] (Figure 9.18). In comparison to farmers' practises in China, the SPAD meter-based SSNM boosted partial factor productivity of N in rice by 48% [39].

Figure 9.18: Soil Plant Analysis Development Meter

E. Nutrient Expert:

A recently created decision support system (DSS) called Nutrient Expert® allows maize and wheat farmers to quickly adopt SSNM for each of their particular fields by combining the results of on-farm research into an easy delivery mechanism. The International Plant Nutrition Institute (IPNI) and the International Maize and Wheat Improvement Centre (CIMMYT) jointly developed and validated the Nutrient Expert (NE) DSS for wheat, a user-friendly, interactive computer-based decision tool that can quickly recommend nutrients for a farmer's field whether or not soil test results are available.

The tool calculates the potential yield for a farmer's field based on the growing conditions, calculates the nutrient balance in the cropping system based on yield and fertilizer/manure used in the previous crop, and combines this data with soil characteristics to predict expected N, P, and K response in the concerned field to produce a location-specific nutrient recommendation for wheat [40].

9.2.3 Cover Crop and Weed Management Equipment:

The major reason behind the success of conservation agricultural practices is the control of weeds through herbicides. The herbicidal weed control is the most prominent way of weed management under CA farms. However, the heavy usage of herbicides leads to weed flora shift (the dominance of perennial weeds in the field), herbicide resistance etc. In this context the exploration of other innovative measures needs to be addressed.

There have been several cultural methods which can be used in conservation agriculture practices such as stale seedbed technique, cover crops, mulching, crop diversification and many more [41]. Mechanical weeding is typically more cost-effective than manual labour because it involves the use of tillage tools like harrows, weeders, and cultivators that are propelled by animals or an engine. These tools rely on burying and uprooting weeds that have grown between crop rows and are large enough to move without significantly harming the crops. Thus, there can be some tools and machineries which can help in the successful weed management under CA.

A. Knife rollers: Prior to direct drilling, it is convenient to manage cover crops, residues, and weeds with knife rollers. Knife rollers are cylinders with blades that crimp vegetation without actually cutting it, and in many situations, this is enough to kill the plants (Figure 9.19). Knife rolling may be done using tractor power and animal traction as holdings are bigger. It can be a useful management strategy for some weeds as well as for cover crops [42].

Figure 9.19: Knife Roller

B. Star weeder: It contains V-shaped serrated blades that a person may manually use to perform weeding operations on any dry land crop. 0.024 ha/h is the field capacity (Figure 9.20).

Figure 9.20: Star Weeder

C. SWI weeder: It is a manually driven weeder that is frequently used in SWI (System of Wheat Intensification) fields in all sorts of soil regions for weeding and intercultural operations. 0.0160 ha/h is the field capacity of this tool (Figure 9.21).

Figure 9.21: SWI Weeder

D. Herbicide protector box: For the effective and efficient use of herbicide in the field, the Water Technology Centre, IARI, New Delhi, has created a Herbicide Protector box (Figure 9.22.). This box-like structure may be positioned in the space between rows of crops. As the box is being pulled between rows, the herbicide may be sprayed. To obtain the proper swath and reduce herbicide drifting, the height of the nozzle must be kept at half the height of the herbicide box. By maintaining the nozzle within the box, it is necessary to guarantee that the herbicide is sprayed inside the container. For improving herbicide application efficiency, a flat fan nozzle is suggested. Herbicide protector boxes cost about Rs 1500 [43].

Figure 9.22: Herbicide Protector Box

E. Allelopathy: To effectively manage weeds under CA, crop allelopathy against them may be used. Alfalfa, barley, black mustard, buckwheat, rice, sorghum, sunflower, and wheat are among the crops that may effectively reduce weeds by the release of allelochemical substances from living plant parts or from decaying residues. The development of sustainable CA systems may greatly benefit from the application of allelopathic features from crops or cultivars that exhibit significant weed inhibitory properties in conjunction with conventional weed control techniques. For instance, sunflower leftovers mixed into field soil had a strong inhibitory effect on the overall quantity and biomass of weeds developing in a wheat field [44].

Similar practises for managing weeds in California include mulching allelopathic plant residues and using specific allelopathic crops in crop rotations, intercropping, or as cover crops. Depending on environmental and management circumstances, these various allelopathic application methods may operate as natural weed controlling agents to varied degrees of effectiveness [45]. Thus, allelopathy presents a practical choice for weed management in CA.

F. Site specific weed management: Site specific weed management is the use of concepts and technology to control the spatial and temporal variability related to the quantity and make-up of weeds in an agricultural field [46]. This idea is supported by three facts: Because of the following factors: (i) weed populations are frequently dispersed irregularly within crop fields; (ii) geospatial technologies (such as GPS and GIS) have made it possible to detect and map weeds; and (iii) new smart sprayers, robots, and mechanical cultivators (Figure 9.23. a,b,c,d) have made it possible to carefully tailor weed management to fit the unique characteristics of each field [47].

Figure 9.23: Smart robots and mechanical implements for SSWM a. Quadrocopter UAV b. Terrasentia weeding robot c. Ecorobotix d. Weed Seeker

9.3 Water Management Technologies and Machineries:

Agriculture is one among the major sectors which utilizes water resource in enormous amounts and which is also considered as one of the major causes of soil and water pollution. The leaching of chemicals, pollutants, pathogens and organic matter from the soil through run-off is the most important cause of water pollution. On the other hand, CA reduces the leaching of these chemicals through runoff from the soil surface. It not only increases the infiltration capacity of soil but also reduces the amount of water used and lost through evaporation [48]. The farming practices coming under CA which enhances the water use efficiency are described briefly.

9.3.1 Direct Seeded Rice:

For manpower and water savings, direct seeded rice is an alternative to puddled transplanting. If the weeds are managed with careful herbicide application, it is a labour-, fuel-, time-, and water-saving method that produces rice with a yield comparable to puddled transplanted rice [49]. It minimises the total demand for the puddled transplanted rice by avoiding the water needed for puddling.

The quality of the rice is not impacted by direct seeding, which is an option in highland, medium, lowland, deep water, and irrigated regions among other ecologies (Figure 9.24). Direct seeded rice uses fertilizer and water more effectively, improving soil health and conserving 35–40% of water. This method may be used for water management in conservation agriculture [50].

Figure 9.24: Direct Seeded Rice

9.3.2 System of Rice Intensification:

System of Rice Intensification (SRI) aims to boost the output of rice grown by farmers. It is a low water, time-consuming technique that employs younger seedlings spaced individually and usually weeded by hand using specific equipment. Henri de Laulanié developed it in Madagascar in 1983. Rice yields are boosted by 20–50% or more, depending on present yield levels. increased income as a result of greater grain quality, higher yield, and less water usage. Water needs are decreased, often by 25–50%, because SRI fields are not kept permanently submerged (Figure 9.25).

Although commercial inputs can be utilised with SRI methods, the system does not call for the acquisition of new types of seed, chemical fertiliser, or agrochemical inputs. SRI farming practises are more affordable for low-income farmers since they don't need them to borrow money or incur debt, in contrast to many other breakthroughs. Costs of production are often decreased, typically by 10% to 20%, however this number fluctuates depending on how intensively farmers are already using inputs [51]. Farmers' net income increases more than their increased yield due to higher output and decreased costs. SRI is a more resilient system since it keeps producing under adverse situations including pest and disease pressure, drought, and climate change.

Figure 9.25: SRI System of Rice Cultivation

9.3.3 Micro-Irrigation Systems:

The micro-irrigation systems such as sprinkler and drip irrigation systems can also be used under conservation agricultural practices to improve the water use efficiency of crops. The use of saline and alkaline water along with good quality water can be easily done which enhance the water productivity in these systems.

9.3.4 Harvest Management Using Combine Harvesters:

The 'combine' harvests wheat and rice in a width equal to the width of its cutter bar and scatters straw from straw walkers in the middle of the harvested area. It equally slices and spreads the loose straw that comes from the harvester straw walkers. It can be attached at the back of a self-propelled combine harvester with a cutter bar length of 4.27 metres and a 110 hp engine [52]. Straw from the combine harvester's straw walkers is fed into the unit from one side and expelled out the housing's outlet. To evenly distribute the leftovers across the breadth of the combine harvester, the chopped material is blasted off tangentially and deflected with the aid of a deflector (Figure 9.26).

Figure 9.26: Combine harvesters for rice and wheat harvesting

9.5 Conclusions:

The problems and bottlenecks of conventional agriculture can be addressed and reduced by conservation agricultural practices. The mechanization is the basis of conservation agricultural practices. The development of suitable machineries to handle the on-farm residues, for seeding the crops in standing stubbles, efficient nutrient management, weed management, water and harvest management under conservation agriculture has aided in its adoption for sustainable long-term productivity. There is still a need for low-cost, precise CA machinery for various agronomic operations (such as fertiliser placement, weed and pest management, etc.) that are appropriate for various soils and cropping systems, both in irrigated and rainfed systems, despite the fact that several CA machines have been developed in India for various crops and cropping systems. A continuous process involves the creation of new machine designs, the improvement of the current CA machines, and their adaptation to regional variations in soil, climate, and crop production systems.

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10. Nanotechnology in Agriculture Against Climate Change

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Abstract:

Global agricultural production is facing substantial losses due to climate change-related phenomena's such cold, drought and salinity, which lead to tissue damage and that ultimately causes yield penalties. Ensuring food security is highly challenging in the developing countries by overcoming these climate change related phenomena. The development of novel and sustainable 'green' technologies is therefore becoming increasingly important. Nanotechnology provides invaluable opportunities to variety of industrial sectors. Recent focus has been driven to the development and optimization of nanomaterials for application in the agricultural sector towards improving growth, protection and overall performance of plants based on the small size, high surface to volume ratio and unique optical properties of nanomaterials. The present chapter provides a description and application of advanced nanoparticles and polymers at seed and plant level, covering biological, technical and socio-economical aspects of this promising approach. This technology offers an attractive alternative to established approaches in agriculture such as conventional breeding, genetic modification, fortification of agri-products and precision management of inputs with key advantages, representing a characteristic example of integrative plant physiology where multiple disciplines such as analytical chemistry, materials science and agriculture join hands to develop exciting new tools for modern agriculture against climate change.

Keywords:

Nanoparticles, Seed coatings, Nanomaterials, Biotechnology, Abiotic stress and Priming.

10.1 Introduction:

Agriculture is one of the most important sectors in world economy as it provides food and raw materials for variety of industries. The limit of natural resources such as arable land, soil, water and the growth of global population claim for agricultural progress must be efficient, viable and sustainable. Demographics will radically change over the coming future. World population is expected to increase and surpass 9.7 billion by 2050 and 11 billion by the year 2100 (United Nations, 2019). Projected growth in the world's population is likely to be concentrated in African and South Asian countries. Based on these, Food and Agricultural Organization (FAO) estimated that agriculture in 2050 should be able to produce food more than double to meet global demand (FAO, 2019). However, in most of the parts on the globe, further expansion of cultivable land is much limited. Especially in sub-Saharan Africa, Northern Africa and parts of Central Asia potential land expansion is constrained by water shortage and lack of infrastructure. Furthermore, in all these regions, agricultural land expansion could lead to further deforestation, which would destabilize ecosystem and its sustainability, because of the impact on greenhouse gas emissions and biodiversity loss and all these reversible accelerates climate change. Crop intensification can be a best alternative to land expansion. Although, by adopting this practice, soil does not have enough time to rejuvenate its fertility and productivity, thus leading to nutrient deficiencies and land degradation (Abhilash et al., 2016). In addition to the aforementioned issues, the changing climate poses a significant danger to agriculture and food security (Dubey et al., 2016). Changes in water availability, increasing frequency and intensity of extreme weather events, changes in rain and drought patterns, and increases in temperature and levels of carbon dioxide in the atmosphere all have a significant influence on the growth of agriculture (Zandalinas et al., 2018). One of the new ecological effects of climate change is undoubtedly the difficulties posed by abiotic stress on plant growth and development (Bellard et al., 2012). All research on abiotic environmental stressors or factors that can stress out a variety of species is included in the field of plant abiotic stress (He et al., 2018). These stressors include excessive sodium ions that cause salinity, extremely hot and low temperatures, light, radiation, and a lack of or surplus of water and vital nutrients. Combinations of these stresses commonly occur in the field, producing special consequences that cannot be predicted from the stressors alone (Suzuki et al., 2014), leading to unexpected physiological interactions. Different approaches are being used today to improve stress tolerance. Crop cultivars with varied stress-tolerant features have been bred during the past several decades with a lot of effort. This procedure has been conducted using two basic strategies. One involves breeding conventionally using methods like broad hybridization and mutation breeding. Despite their value to agriculture, these techniques are time-consuming and frequently produce unpredictably (Hu and Xiong, 2014). Another approach is to modify the genetic makeup of the plant by adding exogenous genes or altering the rate at which endogenous genes are expressed in order to increase stress tolerance (Hu and Xiong, 2014). In order to find and characterise the routes to build stress-tolerant agricultural plants, it is crucial to understand the molecular processes by which plants receive and transmit stress signals to cellular machinery to initiate adaptive responses (Kollist et al., 2019). Globally, the cultivation of genetically modified plants is restricted because this practise is now prohibited in many nations. While many nations continue to worry about detrimental effects on the environment, farmland, and biodiversity, parties to the Cartagena Protocol on Biosafety (Secretariat of the Convention on Biological Diversity, 2000) have the right to restrict or completely ban cultivation in their territories.

Priming is a fascinating alternate strategy for helping plants withstand environmental challenges. Through the efficient induction of already established defence pathways, chemical priming exhibits great promise for improving plant tolerance to these abiotic stresses without the need for genetic modifications. In comparison to unprimed plants, plants that have been pre-treated (or "primed") with specific natural or synthetic compounds respond better to less-than-ideal conditions (such as drought, heat, salinity, or heavy metals; Savvides et al., 2016).

Through the regulation of reactive oxygen species (ROS) accumulation, redox signalling, and gene expression that contributes to an enhanced stress response, priming enhances plant defence mechanisms by improving perception and/or amplification of signals (Balmer et al., 2015). Amino acids, phytohormones, metabolites with hormonal activity like polyamines, melatonin (Antoniou et al., 2017), reactive oxygen–nitrogen–sulfur species (Antoniou et al., 2016), fungicides (Filippou et al., 2016), as well as synthetic hybrid donors like NOSH aspirin (Antoniou et al., 2020). The concurrent use of nanotechnology and its tools beside with chemical priming will lowers the environmental burden (Khan et al., 2019). Nanoparticles, which range in size from 1 to 100 nm in at least one dimension (depicted in the **Figure 10.1** have a wide range of unique physicochemical characteristics. Due to their high surface energy and high surface-to-volume ratio, they exhibit higher reactivity, solubility, and biochemical activity (Dubchak et al., 2010). Various physical, chemical, and biological processes can produce nanoparticles, which have a variety of effects on plants by promoting their growth, productivity, and development (Singh et al., 2016b). Additionally, nanoparticles are crucial for shielding plants from a variety of abiotic stressors. In addition to protecting the photosynthetic machinery and enhancing photosynthesis by suppressing oxidative and osmotic stress, they have been demonstrated to scavenge ROS (Rico et al., 2013). Titanium oxide (TiO2), cerium dioxide (CeO2), zinc oxide (ZnO) and several other nanomaterials have all been put to the test in recent years to see whether they may help plants grow faster and handle stress better. It's interesting to note that some substances, especially when used at greater concentrations, might cause poisoning symptoms (Begum and Fugetsu, 2012; Gohari et al., 2020a). Due to oxidative stress brought on by nanoparticle exposure, crop yields, root and shoot length, and germination rate all suffer (Barhoumi et al., 2015).

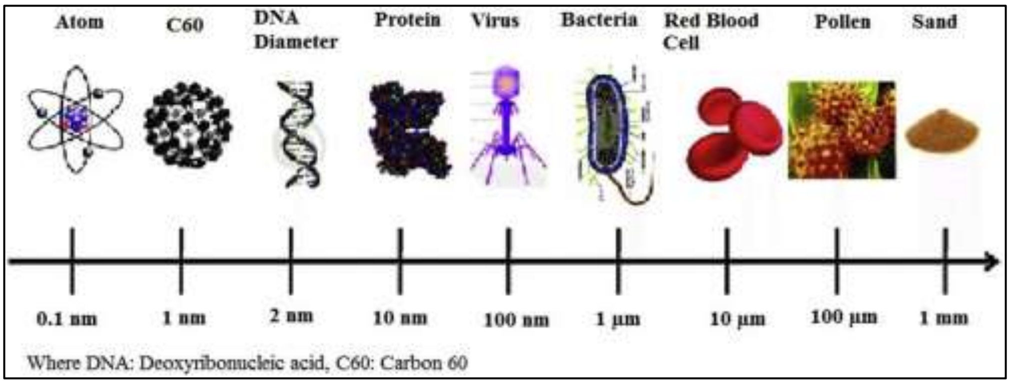

Figure 10.1: A pictorial exhibition of things in the "nano" (<100 nm) and "micro" (>100 nm) size ranges (DNA: Deoxyribonucleic acid, C60: Carbon 60).

Biological materials can also be used to create nanomaterials, in addition to chemical ones. Plant extracts can be used to biologically synthesise certain metallic nanoparticles since most plants contain sugars, enzymes, and phytochemicals such flavonoids, latex, phenolics, terpenoids, alcohols, amines, and hormones, among other things. In addition to producing products with well-defined size and form and reducing soil contamination, these substances act as stabilisers during eco-friendly nanoparticle synthesis methods (Dubchak et al., 2010; Singh et al., 2016a).

The use of nanomaterials to improved crop production and sustainable agriculture is still in its infancy. We anticipate that as our knowledge of nanotechnology grows, we will be able to take full use of its potential benefits. To construct "green" technology without harming the environment, it is vital to have a fundamental knowledge of how nanoparticles and sophisticated polymers interact with plants at the cellular and molecular level.

The parts that follow give a current account of the technical, biological, and socioeconomic aspects of contemporary nanotechnologies utilised in agricultural practises, with an emphasis on nanoparticles and sophisticated polymers used as seed coating agents.

10.2 Nanoparticles and Its Technical Aspects:

The word "Nano," which can be defined as 10^9 of any value or unit, was derived from the Greek word nanos, which meaning "dwarf." According to Ealias and Saravanakumar (2017), a group of substances, natural or artificial with at least one dimension less than 100 nm is referred to as nanoparticles.

Nowadays, nanotechnology is regarded as a very promising topic with a wide range of economic and scientific applications for creating innovative materials at the nanoscale. As demonstrated in **Figure 10.1** several types of nanoparticles have been identified based on the appearance and makeup of the particles.

In general, "Top down" and "Bottom up" techniques are used most frequently to synthesise nanoparticles **Figure 10.2**. When using "Top down" methods, different lithographic techniques like milling, grinding, and other methods are used to transform bulk materials into substances at the nanoscale. The "Bottom up" technique, in contrast, uses physical and chemical processes to create nanomaterials by atoms self-assembling into new nuclei and then growing into particles with nano-scales (Kulkarni, 2014a, b).

It should be mentioned that the majority of these technologies rely on intricate processes, and frequently, they need the use of severe conditions, including high temperatures and poisonous starting materials, which not only raises operating expenses but also increases minor hazardous contamination on finished goods.

Many attempts have been made to use biological catalysts (such as plants, bacteria, fungi, and yeasts) as an environmentally friendly approach in the synthesis of nanoparticles in order to overcome these obstacles (Singh et al., 2016a). The structures of the nanomaterials are characterised using a variety of methods. The most popular methods in this area are spectroscopy and microscopy techniques.

10.3 Application of Nanomaterials in Agricultural Industry to Mitigate Climate Change:

Application of nanomaterials in agricultural industries in order to increase productivity of lands and crops, especially under suboptimal situations, started at the beginning of the 21th century (Duhan et al., 2017; He et al., 2019).

Nevertheless, agricultural science's understanding of nanotechnology is still limited. Numerous nanomaterials have been developed with the potential to revolutionise the agricultural sector. These materials have both benefits and drawbacks.

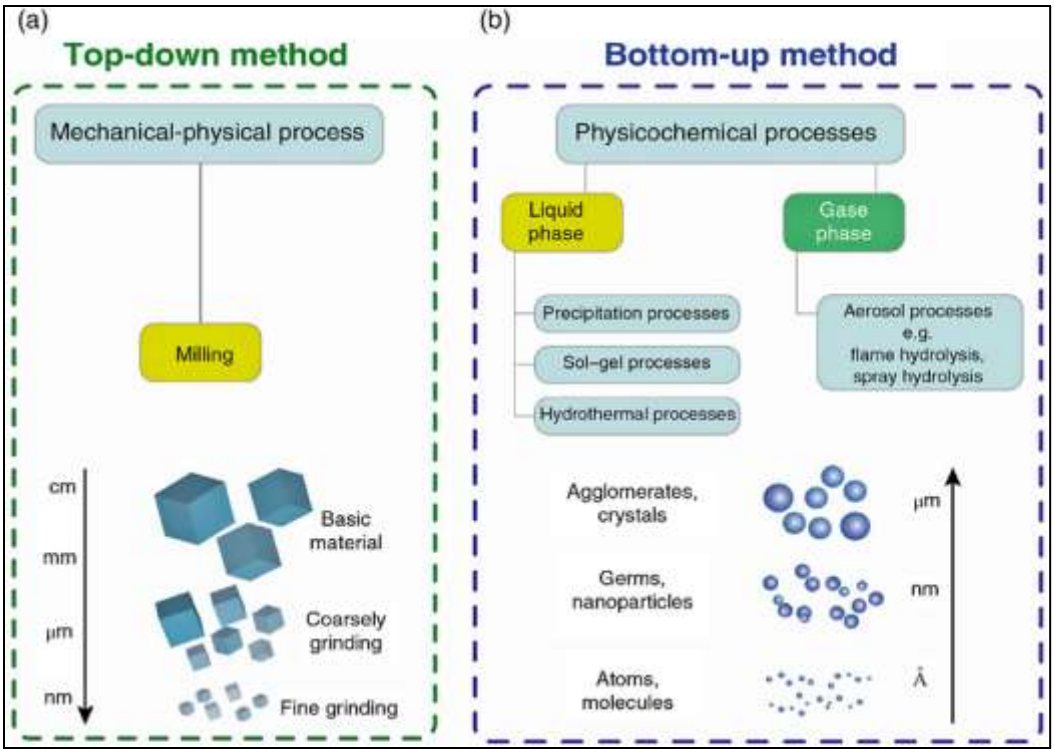

Figure 10.2: Schematic of the (a) top-down and (b) bottom-up approaches for making nanoparticles. Adapted from Roohinejad and Greiner (2017) with permission copyright © 2017 John Wiley and Sons.

In addition to addressing a variety of agricultural issues (such as the detection of pollutants, issues with soil structure, plant disease, pests and pathogens, delivery of pesticides, fertilisers and nutrients, and delivery of genetic materials), they frequently improve food quality and safety, crop growth, and environmental conditions monitoring (Siddiqui et al., 2015; Solanki et al., 2015; He et al., 2019). In the agricultural industry, a variety of nanomaterials are employed, including single-walled carbon nanotubes (SWCNTs), multi-walled carbon nanotubes (MWCNTs), graphene oxide (GO), silver (Ag), iron (Fe), silicon (Si), zinc (Zn), zinc oxide (ZnO), and titanium dioxide (TiO2) (Duhan et al., 2017; He et al., 2019).

As a result, methods of this promising methodology include controlled release, site-specific fertiliser delivery, being carriers for a variety of essential compounds, protection against pathogens and diseases, improved nutrient absorption, and increased efficiency of pesticides, fungicides, and herbicides, leading to enhanced plant growth (Kashyap et al., 2015; Solanki et al., 2015; Abobatta, 2018a; He et al., 2019).

Since they can be used in almost every aspect of the agriculture industry, including production, processing, storage, and transportation (Duhan et al., 2017), nanomaterials increase efficiency, productivity, and agricultural protection and production (Khot et al., 2012). Due to their size, high surface area, precise dosage, slow release, and other unique properties, nanomaterials generally enhance various practises in plant and crop protection, nutrition, and management as shown in the **Figure 10.3**. As a result, food quality and safety are improved, and agricultural inputs are reduced (Prasad et al., 2017).

The key benefits of this technology are the slow and controlled release of nanomaterials with a reduced dosage of the primary component (He et al., 2019). Additionally, nanoscale materials enhance soil structure and health and increase plant tolerance to a variety of environmental factors like drought, salinity, and temperature (Kah et al., 2019).

A. Nanofertilizers: As was already noted, there are several uses for nanomaterials in agriculture. Improved fertiliser delivery (Duhan et al., 2017; Abobatta, 2018a) leads to higher nutrient absorption by plant cells and reduced nutrient loss (Solanki et al., 2015), which is the first and most important function. They synchronise the administration of macro- and micronutrients (Kah et al., 2019). According to (Solanki et al., 2015) and (Siddiqui et al., 2015), major components of chemical fertilisers (N, P, and K) are not accessible to plants, which results in repeated fertiliser treatments with nutritional imbalance, environmental contamination, a decline in soil microflora, and a deficit of nitrogen fixation. The wide surface areas, targeted delivery methods, gradual and controlled release in response to environmental cues and biological demands of nanostructured fertilisers boost the efficacy of nutrient usage. The absorption, translocation, and destiny of nano fertilizers are determined by plant species, age, growing environment, physiological characteristic, functionalization stability, and the manner of distribution of nanomaterials (Solanki et al., 2015). Indeed, due to their persistent release, nanoparticles with encapsulated fertilisers increase agricultural productivity (Duhan et al., 2017).

Due to their special physicochemical characteristics, such as high reactivity, compatible pore size, particle morphology (Solanki et al., 2015; Siddiqui et al., 2015; Abobatta, 2018a), and the ability to penetrate cells and deliver themselves immediately inside organisms, they allow for cultivation on poor land. By boosting seed germination, seedling growth, photosynthetic activity, nitrogen metabolism, carbohydrate and protein synthesis, and reducing environmental side effects, nanofertilizers ultimately improve plant growth and yield (Solanki et al., 2015; Taha, 2016). The penetration of nanomaterials into seeds is the primary factor for improved seed germination (Khot et al., 2012). Nanofertilizers include nano-phosphorous (P), nano-Fe, nano-Mg, and nano-Zn. Furthermore, due to their competitive mechanical, electrical, thermal, and chemical properties, carbon nanotubes (CNTs) could be used as nutrient carriers for macro- and micro-nutrients to reduce their applied quantities with encouraging results in agriculture (Taha, 2016).

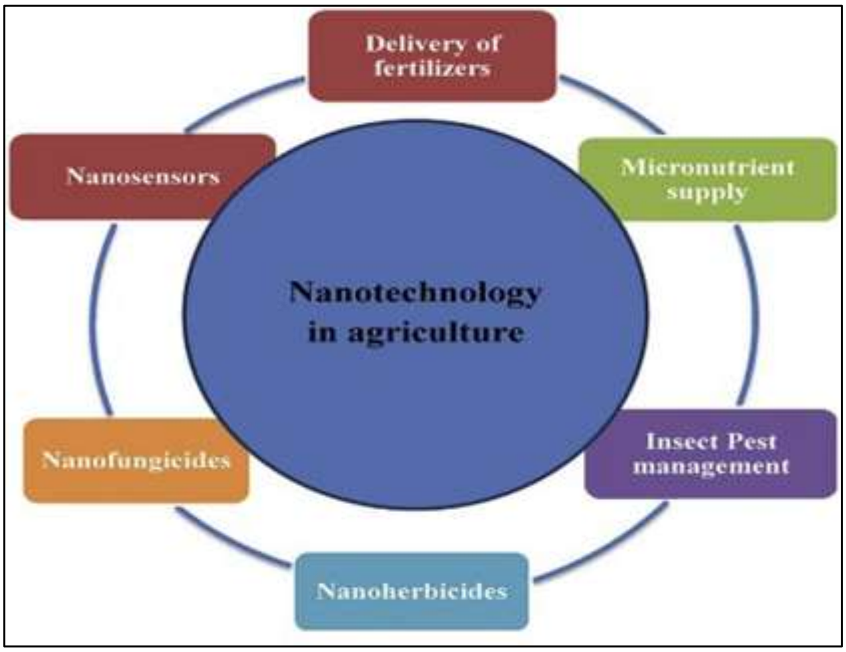

Figure 10.3: Schematic Representation of Applications of Nanotechnology in Agriculture.

B. Nanopesticides: Nano pesticides are used to control insects and pests. Due to the active and delayed release of active compounds (such as Ag, TiO2, ZnO, and Al2O3), some nanoparticles have a strong potential to manage and control pests (Duhan et al., 2017). This makes them an affordable and trustworthy alternative to synthetic pesticides that have negative side effects. Due to their high surface area and improved affinity to their target, nano pesticides reduce organic solvent runoff and unintended pesticide movement. Nano formulations also achieve faster soil degradation and slower plant degradation, with residue levels in foodstuffs that are below regulatory standards (Duhan et al., 2017). In addition, nanoparticles might serve as smart field systems and quick diagnostic instruments for pathogen identification, detecting diseases in crops and notifying producers to apply the necessary materials before the development of symptoms (Khot et al., 2012; Kah et al., 2019).

C. Nanofungicides: Chemical fungicides harm plants and pose risks to human health and the environment. Depending on the size and structure of the nanoparticles, nano fungicides offer beneficial answers to these issues. In terms of antifungal activity, silver (Ag), titanium dioxide (TiO2), and zinc oxide (ZnO) nanoparticles have the most potential (Duhan et al., 2017). Due to their large surface area and surface fraction, Ag nanoparticles are the most often used nano fungicides due to their antibacterial capabilities (He et al., 2019). Ag NPs deactivate the thiol groups in the cell walls of fungi, resulting in transmembrane damage, fungal DNA mutation, and dissociation of the respiratory chain enzyme complexes, which decreases membrane permeability and results in cell lysis (Duhan et al., 2017). While TiO2 NPs have photocatalytic and antibacterial properties that help to protect plants, ZnO NPs also exhibit antimicrobial, antibacterial, and antifungal activities (Duhan et al., 2017)

D. Nanoherbicides: Application of Nano herbicides is an environmentally benign and leaves no toxic leftovers in the soil or environment. According to Duhan et al. (2017), chemical herbicides, particularly those that get numerous applications, harm plants, impair soil fertility, contaminate the soil, and create weed resistance. Therefore, using nanomaterials to create nano herbicide formulations has the potential to address the aforementioned shortcomings (Chaudhry et al., 2018). Examples of such methods are showed that nanoencapsulation enhances the herbicidal activity of atrazine against mustard plants as evidenced by decreased net photosynthesis and PSII maximum quantum yield, and the work by Kumar et al. (2017), which demonstrated that herbicide-loaded pectin nanoparticles are more cytotoxic to Chenopodium album plants.

E. Nanosensors: Nanosensors (Duhan et al., 2017), which have been widely used in the agriculture industry due to their potential for environmental monitoring of pollution in soil and aquifers (Prasad et al., 2017), represent the last use. According to (Chaudhry et al. 2018), nanosensors might be used to swiftly and precisely assess the health of the soil, crops, and diagnose plant illnesses. In order to identify the presence of *Xanthomonas axonopodis pv. vesicatoria*, a plant pathogen that causes bacterial spot infections in solanaceous crops, fluorescent silica nanoparticles coupled with antibody molecules have been utilised. As a sensor, gold nanoparticles are used the most frequently (He et al., 2019). Due to their high sensitivity, low detection limits, super selectivity, quick reactions, and tiny size, smart nanomaterials might also be employed as nanosensors to detect pesticide residues (Khot et al., 2012). The recent creation of a nanosensor platform for the detection of hazardous Cd^{2+} and acetylcholinesterase (AChE) activity in actual water samples is a pertinent example (Fang et al., 2017).

10.4 Role of Nanomaterials to Mitigate Environmental Stresses:

In response to various abiotic stress conditions, plants experience ROS build up and oxidative damage as major growth inhibitors that significantly reduce crop output. The restriction of CO2 fixation and suppression of ROS scavenging by enzymatic and non-enzymatic processes in biological systems are the most significant effects of abiotic stressors on plants (Wu et al., 2017). Application of nanomaterials has been shown to promote plant growth and development in both stress-free and normal environments Table 10.1. When plants are exposed to abiotic stimuli including salt, drought, heat, and heavy metals, they immediately produce ROS, which severely damages the organelles, structures, and functions of the cells. Plants have evolved a sophisticated antioxidant system that includes both non-enzymatic (such as carotenoids, tocopherols, ascorbate, and glutathione) and enzymatic (such as SOD, CAT, and APX) antioxidants to protect against this damage (Gill and Tuteja, 2010) and was pictorially depicted in figure 11.4. In order to protect plants from stressful situations, nanomaterials activate these defense systems (Kim et al., 2017; Kumaraswamy et al., 2018). According to Kah et al. (2019), the principal protective mechanism of nanomaterials is connected to the enhanced activity, availability, or dissolution of materials as a function of nanoscale size. It is important to remember that every nanomaterial has a unique mode of action and unique mechanism to help plants become tolerant to environmental shocks or even to normal circumstances. However, protective effects of nanomaterials are typically attributed to their small size and high permeability to plant cells that interrupt stressful factors (Wu et al., 2017).

The precise general mechanism of protection has not yet been fully elucidated. The section that follows looks at prominent instances of nanoparticles utilised as stress-relieving chemicals.

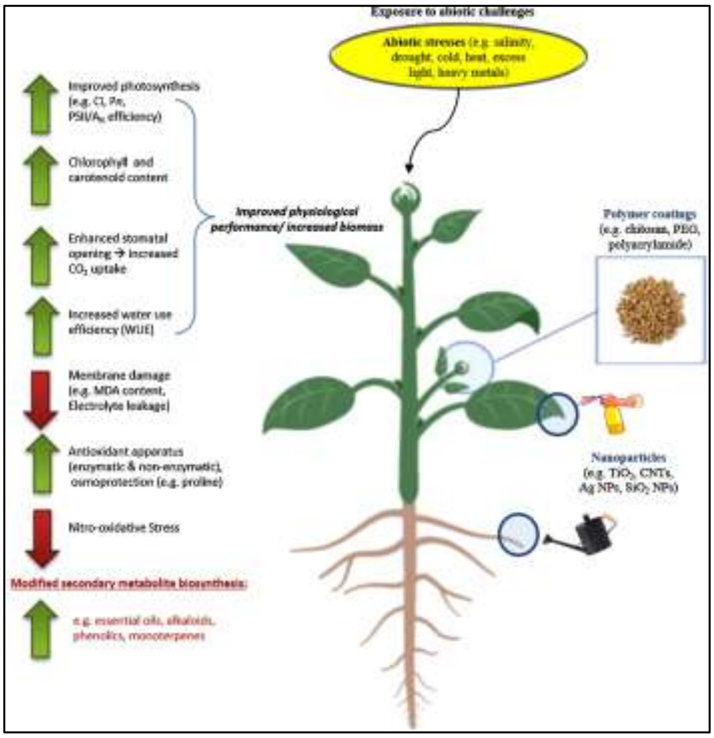

Figure 10.4: Model illustrating concept of nanomaterial application in plants and seeds and resulting alterations in physiological and biochemical parameters.

10.5 Nano Materials in The Form of Polymer Coatings as Seed Priming:

As a result of their uncontrolled release into the environment, agrochemicals used in their free, unprotected form have significant negative effects on both the environment and the economy (Mukhopadhyay, 2014), necessitate frequent application to plants and crops, and may have harmful effects on human health (Nicolopoulou-Stamati et al., 2016). In recent years, seed priming methods have paid a lot of attention to polymer coatings (Taylor et al., 1998; Scott, 1998; Sharma et al., 2015).

Biocompatible and biodegradable polymers, in particular, have been utilised as seed coverings to enable the encapsulation and prolonged release of nutrients, growth regulators, and pesticides used against diseases, pests, insects, etc. involved in seed germination, root, and shoot development processes. In addition, the application of polymer coatings in seed priming may improve the ability of plants and crops to withstand abiotic stresses such as heat, salt, drought, and heavy metals (Pitman and Läuchli., 2002). Because agriculture is one of the industries that uses the most water globally, this has a positive effect on crop yield while lowering water demand in the industry (Pfister et al., 2011). Pelleting, encrusting, and film coating are the three primary sub-categories of seed coating techniques.

Table 10.1: Effect of Nanoparticle Application in Plants Growing Under Different Abiotic Stress Conditions.

Nanoparticle	Concentration	Abiotic stress	Plant species	Effects
CeO2 (Rico *et al*., 2013)	62.5, 125, 250, and 500 mg L−1	oxidative stress	*Oryza sativa*	Decreased membrane damage and photosynthetic stress in shoots
Poly (acrylic acid) coated nanoceria (PNC) (Wu *et al*., 2018)	50 mg/L i	Salinity stress	*Arabidopsis thaliana*	Improved photosynthetic performance and biomass
CuO NPs (Lalau *et al*., 2015)	0.1–10 g/L	Non-stress	*Landoltia punctate*	Increased total carotenoid contents, induction of bleaching and pigmentation
Chitosan-PVA + Cu NPs (Hernandez-Hernandez *et al*., 2018)	50, 100, 150 mg L−1	Salinity stress	*Solanum lycopersicum*	Increased vitamin C and lycopene content, enhanced tolerance to salinity stress
Ag NPs (Karami-Mehrian *et al.*, 2015)	0, 25, 50, 75 and 100 mg L−1	Oxidative stress	*Solanum lycopersicum*	Increased production of all amino acids except methionine and tryptophan, increased SOD, CAT and POX enzymatic activities

Nanoparticle	Concentration	Abiotic stress	Plant species	Effects
Ag NPs (Iqbal *et al*., 2019)	25, 50, 75 and 100 mg/l	Heat stress	*Triticum aestivum*	Increased leaf area, leaf number, leaf fresh weight and leaf dry weight
Anionic Cerium Oxide (Wu *et al*., 2017)	50 mg/L	Light and heat and chilling stress	*Arabidopsis thaliana*	Increased photosynthetic capacity
TiO2 NPs (Mohammadi *et al*., 2014)	2–10 mg/L	Cold stress	*Cicer arietimun*	Enhanced stability of chlorophyll and carotenoid content during cold stress.
Silicon nanoparticles (Tripathi *et al*., 2015)	10 µM	chromium (VI) toxicity	*Pisum sativum*	Reduced Cr accumulation and oxidative stress, increased nutrient uptake

10.6 Conclusion:

Nanotechnology is an innovative strategy with significant promise for use in improving plant nutrition, development, and defence against harsh environmental factors. As a sustainable method with less agricultural hazards, this may be accomplished by using nanoparticles and/or sophisticated polymers in plant and seed tissue. These are multi-billion-dollar industries, but they encounter obstacles in entering the market, primarily due to the high cost of manufacturing nanotechnology products, which are needed in large quantities in the agricultural sector. The 'green' sustainable product is supported by a number of papers, and the field is seeing an increase in interest.

However, there are still a lot of unanswered questions regarding our understanding of the uptake potential and the ecotoxicity of various nanomaterials, and their mode of operation is still not completely understood. Therefore, more study is needed using interdisciplinary strategies (systems biology, toxicology, analytical chemistry) to understand how nanomaterials interact with biological macromolecules found in environments and crops, allowing for further development of this fascinating technology.

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11. Climate-Smart Fisheries and Aquaculture Globally and in India

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11.1 Introduction:

Agriculture and allied sectors in the country are vulnerable to climate variability and change. The rise in temperatures and changes in precipitation patterns due to climate change is likely to have serious implications on water resource availability.

The manifestations of climate change have serious consequences on agricultural sector which will disproportionately affect poor and marginalized groups of people who are dependent on agriculture for their livelihoods (World Bank, 2017; Sikka *et al*, 2018).

The impacts of the accumulation of Green House Gases (GHGs) in the atmosphere and in the water affect the climatic parameters including gradual changes in water temperature, acidification of water bodies, changes in ocean currents, and rise in sea levels. These physical changes affect the ecological functions in aquatic systems both in freshwater and marine ecosystems (Cochrane *et al*., 2009). These also tremendously hamper fisheries and aquaculture sectors thereby affecting the spawning, survival of the juveniles, decline in primary productivity, population size, production, and yield (Tubiello and Fisher, 2007).

These can ultimately affect the livelihoods of many people who are engaged in fisheries and aquaculture activities for their primary and secondary sources of income as well as the food security of the country. Climate Smart Aquaculture is conceptualized from the concept of climate smart agriculture which is an integrated approach to managing landscapes—cropland, livestock, forests and fisheries to address the interlinked challenges of food security and climate change (FAO, 2010).

11.2 Importance of Fisheries and Aquaculture in India:

Fisheries occupy a unique position in the agricultural sector of the Indian economy. The sector contributes to the livelihood of a large section of the economically underprivileged population of the country. In addition to being a significant source of income and jobs, fisheries and aquaculture also help to grow a number of related sectors and provide access to low-cost, nutrient-rich foods (Ayyappan and Krishnan 2004). Fisheries is a complex enterprise that functions under an integrated network of natural resources, with other stakeholders that have forward and backward linkages with fisheries and other socio-political variables. Aquaculture is a rapidly growing sector in India that contributes immensely in the country's GDP. The major functions of the fisheries enterprises, including production, transportation, storage, and processing involve value additions from labor, capital, and management which greatly influence the rapid economic development of the country. Fisheries and aquaculture play a key role in the provision of food security and livelihoods of millions of people for their social, economic, and nutritional benefits. Trade has facilitated the sector's globalization, although output is concentrated in a few nations or areas, particularly when it comes to inland fisheries and aquaculture. Small-scale/artisanal fishermen and fish growers make up a large portion of the output and trade in developing nations, particularly in Asia.

11.2.1 Impact of Climate Change on Fisheries and Aquaculture:

The links between fisheries and their ecosystems are deeper and more significant than those that exist in common agriculture system. Climate change drives modifications in aquatic ecosystems and affects fisheries' productivity and food security. The amount of snow and ice has decreased, the ocean and atmosphere have warmed, and the sea level has increased. The uptake of additional energy in the climate system is caused by the increase in the atmospheric concentration of carbon dioxide (CO_2) and other greenhouse gases (GHGs). A range of scenarios for atmospheric concentrations of GHGs are used to model and project future climates; most of these scenarios indicate that a large fraction of anthropogenic climate change is irreversible for centuries to come even after the complete cessation of anthropogenic CO_2 emissions. Climate change is expected to have different typologies of consequences not only in fisheries but to the entire ecosystems. Due to its significant impact on employment, supply, income, and nutrition in those nations, fisheries and aquaculture can have a particularly significant impact on those nations that are more dependent on them. The distribution of various species is forecast to vary as a result of shifting conditions, which will also have an impact on the availability and circulation of items from aquatic industry. The accessibility of fish supplies, especially for small-scale fishermen, the fishing methods used, and consequently the dietary habits of the surrounding people, as well as the behaviors of producers, exporters, and consumers, may all be impacted by these species transitions. The changes in the distribution of fish resources can also put international fisheries agreements and governance under pressure. Trade and its patterns can also be affected, having consequences for countries who are more dependent on trade in fish and fish products for tax revenues and foreign exchange earnings, and with a potential impact on their food security. Consumption can also be affected by these shifts by making available on domestic markets fish species more or less favored by local consumers. The repercussions on consumption are expected to be more serious for communities dependent on fishing and aquaculture, which rely on fish for food and livelihoods (Barange *et al.*, 2014) and in particular for those living near climate-sensitive environments like low-lying coastal areas. When specific species affected by climate change are used for export or consumption, the implications could be worse, especially if there is no help provided by focused policies on adaptation to climate variability and change. The availability of aquatic resources and the global supply, as well as the price of the items, infrastructure, and services needed for the production, processing, and distribution of aquatic foods, are all projected to change as a result of climate change. By 2050, it is predicted that the impact of anticipated changes in temperature and precipitation on food output will increase food costs worldwide (Porter et al., 2014). When compared to a no-climate change scenario in 2050, the highest emission scenario examined in the Intergovernmental Panel on Climate Change's (IPCC) fifth assessment report is predicted to increase food prices by two percent to 35 percent (Nelson et al., 2014). This may also apply to fish prices, particularly if there is a decrease in supply on local markets or as a result of shocks brought on by unanticipated catastrophic events. The demand for and consumption of these goods may decline as a result of higher fish prices, which might have a significant negative impact on food security and malnutrition, especially among the most disadvantaged households. Higher prices could decrease demand, especially among those who are less affluent consumers.in countries that rely heavily on imports for their consumption.

11.2.2 Climate-Smart Fisheries and Aquaculture:

Three primary important objectives are addressed by climate-smart initiatives in fisheries and aquaculture. The first objective, which includes aquaculture and the environmental, social, and economic elements of fisheries, including both commercial fleets and artisanal fisheries, is linked to the goal of developing sustainable food systems. The second goal focuses on the requirement to lessen the industry's sensitivity to the effects of climate change and increase the industry's resilience so that it can manage the effects that climate variability and climate change are projected to have on resource availability as well as natural disasters brought on by a rise in the frequency of severe weather episodes. The third objective is to enable the sector to contribute to the mitigation of greenhouse gases emissions during the harvest and production stages and throughout the entire value chain, which, given the high level of processing, transport and marketing activities involved in the sector, is extremely important. Climate-smart approaches in this sector are connected with most, if not all, of the major cross-cutting themes of sustainable development. As in other sectors, several issues need to be recognized and reconciled for climate-smart approaches to become the default pathway for development. Existing practices, such as ecosystem-based management, fall within climate-smart approaches. Climate change, climate variability, and their effects on resource distribution are projected to have some of the biggest effects on productivity and livelihoods in the fisheries and aquaculture sector. Each region has different climate change effects and response choices. To lead the industry towards a sustainable future, local context-specific, climate-smart agriculture solutions will be necessary. Climate-smart aquaculture aims to support food security taking into account the need for adaptation and the potential for mitigation. It addresses the challenges of building synergies between the related objectives of climate change mitigation, adaptation and productivity and income increase and minimizing their potential negative trade-offs. Climate-smart aquaculture requires the following:

a. Increasing the production of fish and aquatic meals while using less natural resources.
b. preserving the communities that depend on and depend on resilient aquatic systems so that the sector can continue to contribute to sustainable development;
c. Learning how to lessen the vulnerability of individuals who are most likely to suffer adverse effects from climate change.

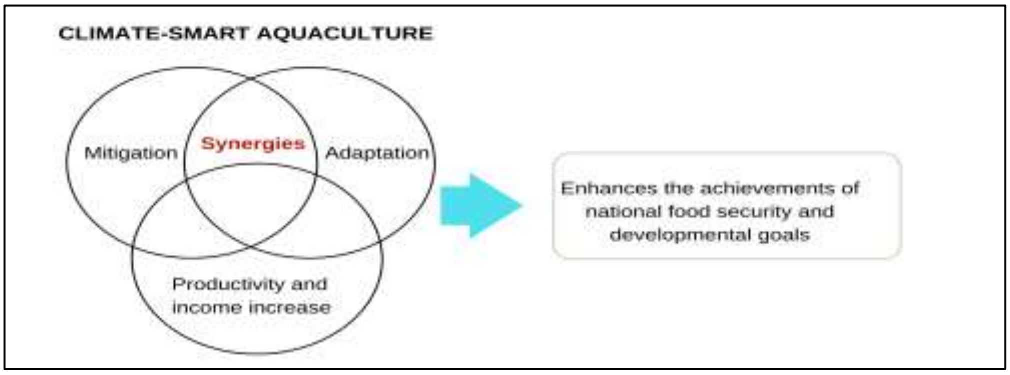

Figure 11.1: Components of Climate - Smart Aquaculture

Source: FAO, 2014

11.3 Fisheries and Aquaculture have Distinct Characteristics:

- Challenges specific to ecosystem complexity, including interactions at numerous scales across seascapes, watersheds, and landscapes, uncertainties regarding change and impacts, and the challenge of creating reliable and usable models;
- The potential hazards to productivity, stocks, and human health posed by the unusually quick interactions between pollutants and diseases in aquatic ecosystems, which are impacted by numerous factors of acidification and climate change;
- Lack of data, challenges in gathering data in complex, highly diversified social, economic, and ecological systems, and difficulty in getting stakeholders from these various systems and systems to agree on critical topics.
- The substantial degree of social and economic reliance on wild fish stocks in large- and small-scale ecosystems, which is connected to a variety of activities that exacerbate climate change;
- Socioeconomic problems associated with the utilisation of fishery resources in "last-resort" or emergency situations, as well as the prevalent social marginalisation and poverty in fishing villages along numerous supply chains;
- Aquaculture and capture fisheries have very little developed risk and insurance markets, and there are few options for community-based responses to less stable situations;
- Persistent governance problems, notably with regard to fisheries resources, such as significant IUU fishing and extensive fleet overcapacity;
- The political complexity of resource management systems, as well as the transboundary nature of key resource systems, encompassing places outside of national jurisdiction;
- The tropical regions' high concentration of aquaculture and their dense populations;

- The vital role small-scale fisheries play in ensuring food security and nutrition by producing fish at reasonable prices available and accessible to poor populations and are a key means for sustaining livelihoods in marginalized and vulnerable populations, compared to large-scale industrial fishing (HLPE, 2014).

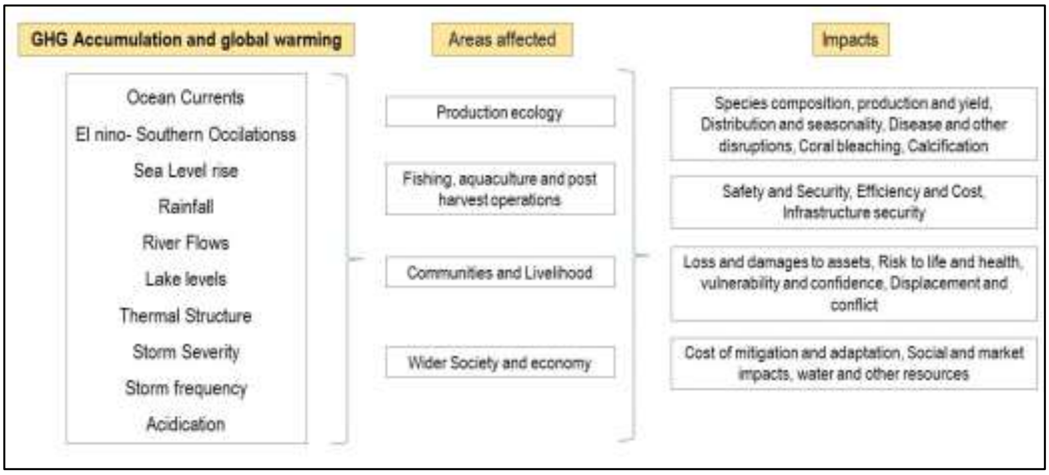

Figure 11.2: Potential Climate Change Impact Pathways for Fisheries and Aquaculture

Source: FAO, 2014

11.4 An Ecosystem Approach to Fisheries and Aquaculture:

A comprehensive method for managing catch fisheries and aquaculture that incorporates all of the ecological, socioeconomic, and institutional aspects of the industry is the ecosystem approach to fisheries and aquaculture. The strategy emphasizes management of fisheries and aquaculture, rather than just the development and management of commercially significant species. It takes into account the interconnections between the essential components of the productive fish system, the people who depend on them, as well as the other social and ecological components of the system.

It encourages the sector's contributions to more comprehensive multisectoral goals and is consistent with overall ecosystem approaches to development. The ecosystem approach to fisheries and aquaculture aims to direct planning, development, and management of these industries in a way that meets the many needs and aspirations of society without jeopardising the opportunities for future generations to benefit from the full range of goods and services provided by aquatic ecosystems.

By considering both the knowledge and the uncertainty about the biotic, abiotic, and human components of ecosystems and their interactions, the strategy uses an integrated management approach within ecologically appropriate boundaries and aims to balance various social objectives. The use of the ecosystem approach to fisheries and aquaculture must abide by the following guidelines in order to achieve progress towards the overarching objective of enhancing the wellbeing of communities and the ecosystem. (FAO, 2003):

- Apply the precautionary approach when faced with uncertainty;
- Use the best available knowledge, whether scientific or traditional;
- Acknowledge multiple objectives and values of ecosystem services;
- Embrace adaptive management;
- Broaden stakeholder participation with due consideration to gender;
- Ensure equitable distribution of benefits from resource use; and
- Promote sectoral integration and interdisciplinarity.

A broader and more comprehensive approach to analysis and management practises is required by the ecosystem approach. The method itself can help with tracking climate change and its effects. Using an ecosystem-based approach would enable the tracking of changes in aquatic ecosystems and the pathways via which they have an influence on fisheries and aquaculture systems.

The identification of issues that require management attention and the prioritisation of those issues through risk assessment are crucial steps in any ecosystem approach process. This must include all direct and indirect effects on supply chains, industry processes, and larger aquatic and coastal systems. The identification of problems that may be external to the management system is also a part of this process, including global demand, input prices, climate variability and change, that are affecting, or could affect in the future, the performance of the system and its management.

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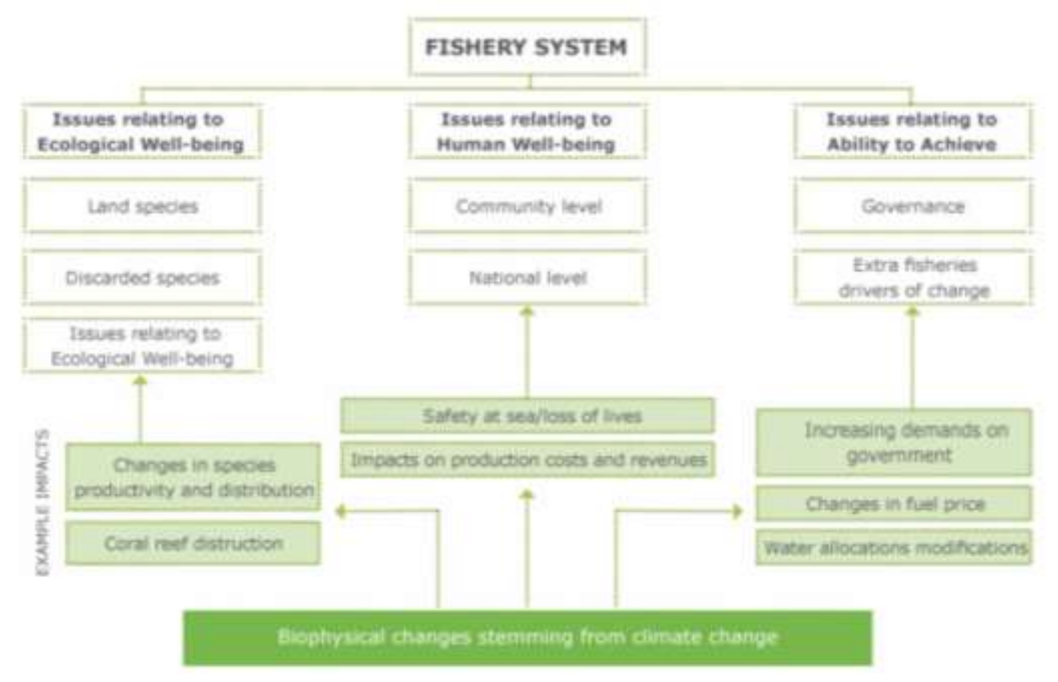

Figure 11.3: Ecosystem Approach to Fisheries issue identification process to identify climate change impacts (Source: FAO, 2017)

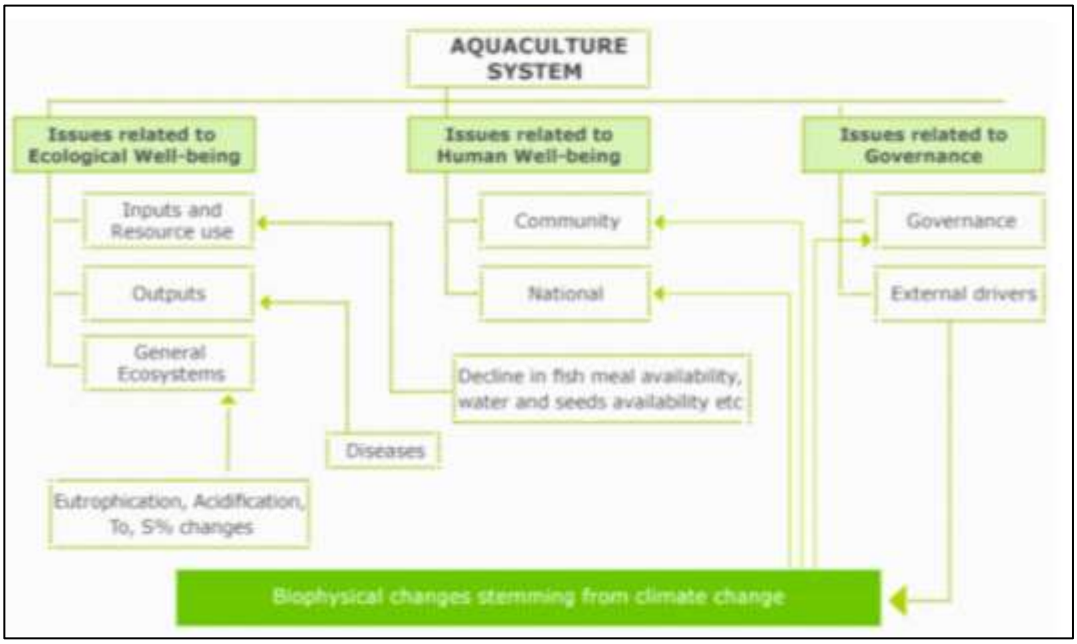

Figure 11.4: Ecosystem Approach to Aquaculture issue identification process to identify climate change impacts (Source: FAO, 2017)

11.5 Climate Change Processes and Impacts:

The Intergovernmental Panel on Climate Change (IPPC) Fifth Assessment Report offers proof that global warming is happening and that it is having an impact on the seas, coastal regions, and inland waterbodies (FAO, 2016a). The number and distribution of fishery resources as well as the viability of some geographic sites for aquaculture systems are being impacted by climate change in addition to other factors that influence climate variability, such as El Nio-Southern Oscillation and extreme weather events. Rising carbon dioxide emissions are associated with physical and chemical changes connected to the climate. Aquatic systems are absorbing a significant portion of these emissions, which is leading to significant changes in aquatic ecosystems and impacting the crucial functions they offer for preserving food security and livelihoods (FAO, 2016b). changes in the climate that have an impact on how often and how ecological processes occur, changes in salinity and freshwater content, oxygen concentration, carbon absorption and acidification, temperature and thermal stratification, sea levels, ocean circulation, surface wind, storm systems, and waves all affect the severity and location of extreme weather events (Cochrane et al., 2009; FAO, 2016b). In fisheries and aquaculture, these changes are likely to have a variety of direct and indirect effects.

There is proof that the distribution of marine species is changing as a result of climate change. To find their perfect ecological circumstances, many species are moving towards the poles and deeper oceans. These alterations in migratory patterns alter the dynamics of interspecies interactions, trophic connections, and food webs. Several aquatic species are expected to experience changes in their size, reproductive cycles, and survival rates if migration is not possible. Depending on the area and latitude, both positive and negative effects will be felt. New invasive species will probably fill the void left by some commercial species moving offshore and away from conventional fishing sites. There may be new livelihood opportunities in some areas if these novel species are suitable for ingestion by humans or other animals.

Ecosystem production is probably going to decrease in the majority of tropical and subtropical marine settings, seas, and lakes despite the incursion of species that are tolerant of higher temperatures and changes in the chemical composition of coastal waters. According to projected scenarios, capture fisheries productivity will rise in high-latitude systems while declining in low- and mid-latitude systems. Extreme weather events, hypoxic zones, rising temperatures, and acidification are all threats to coastal systems (FAO, 2016b).

Increasing sea levels have the potential to destroy a variety of agricultural methods in delta zones by displacing brackish and freshwater ecosystems. The productivity of freshwater fisheries and aquaculture is also impacted by the loss of coastal wetlands. Rising sea levels, nevertheless, might also open up new ecosystems and business prospects for the industry (e.g. through marine aquaculture and the expansion of mangrove forests). Sea level rise could directly threaten fishermen and communities that depend on fishing on coasts and at sea, as well as cause damage to housing, community facilities, and infrastructure used for fisheries and aquaculture. These factors include increased storm frequency and intensity, coastal flooding, coastal erosion, and saltwater intrusion. Aquaculture systems for marine shellfish are particularly susceptible to changes in carbon chemistry, which can influence how some species build their shells. For most species, the sensitivity to acidification and pathogens becomes greater when they are forced into habitats at the edges of their thermal ranges (FAO, 2016b).

It is anticipated that climate change would have a considerable influence on freshwater fisheries and aquaculture. The productivity of rivers, lakes, and floodplains will be impacted by the increasing variability in precipitation levels and changes in air and water temperatures. Higher temperatures and other climatic factors that affect inland ecosystems and species distribution are frequently made worse by non-climatic factors such invasive species, pollution, habitat destruction, and the damming of rivers. Freshwater reservoirs in the region will come under increasing pressure to supply the rising demand for irrigation. In general, places with severe water stress and intense competition for water resources will put inland fisheries at danger (FAO, 2016b). As a result of "gradual warming, ocean acidification, and changes in the frequency, intensity, and location of extreme events," aquaculture systems will be impacted by climate change (IPPC, 2014a). There will be certain production systems that need to be moved (IPPC, 2014a).

Climate change may have a substantial impact on post-harvest operations, production processes that add value, and the delivery of fish to regional and national markets in the fisheries and aquaculture sector. Changes in the availability of other crucial inputs, such as electricity and water for processing, as well as changes in the location and fluctuation of supply, are also possible. These climate-related changes will all take place concurrently with additional national, regional, and international socio-economic pressures on natural resources. It will increase the impacts on food security and nutrition, habitation and social stability.

11.6 People, Communities and Vulnerability:

The IPCC has amended its theoretical risk framework in its Fifth Assessment Report to better understand how to promote the adaptation process of natural and human systems to climate-related changes by acknowledging that "climate change is not a risk per se" (IPPC, 2014a, p. 1050). Only in systems that are unable to handle it does climate change become a risk.

a. The probability of climate-related events or changes (such as sea level rise, acidification, and increasing water temperatures)
b. how much of the system is exposed to the risk (for example, the number of coastal communities in the area where the climate event happens, the number of commercially significant fish species in a lake, or the presence of coral reefs);
c. as well as the system's flaws (e.g. the lack of an early warning system, overfished resources, undiversified practices and livelihood strategies).

The effects of climate change put hundreds of millions of people who depend on fisheries, aquaculture, and fish processing for their livelihoods, food security, and nutrition at danger (FAO, 2016a). Extreme occurrences (such as hurricanes and cyclones) and sea level rise pose a particular hazard to fishermen, coastal communities, and sector-related infrastructure. In its Fifth Assessment Report, the IPPC noted that one model predicts a 21 percent annual decline in the value of marine fish landed in West Africa, a nearly 50 percent decline in employment related to fisheries, and an overall annual loss of US$ 311 million to the region's economy compared to 2012. (IPCC, 2014b). Several research have looked into how climate change can affect fisheries and aquaculture. Allison et al. (2009) examined how vulnerable national economies are by looking at how climate change has affected their fisheries. Bell et al. (2011) examined tunas, feeding habits, coral reefs, mangroves, freshwater habitats, and fishing operations in the context of the vulnerability of species, food webs, and ecosystems tropical Pacific islands.

The sensitivity of coral reef systems to climate change was incorporated into measures relating to the vulnerability of fishing communities that depend on coral reefs by Cinner et al. (2012) in order to capture the connections between human activities and aquatic systems. By combining the expected effects of climate change with the reliance of economies and food systems on fisheries, Barange et al. (2014) argue that these implications will be most concerning in South and Southeast Asia, South West Africa, Peru, and several SIDS in the tropics. Cambodia and Viet Nam are two of the nation’s most vulnerable to the effects of climate change on fisheries in the Lower Mekong Delta of Asia (IPCC, 2014b).

According to the Fifth Assessment Report, Colombia and Peru are the South American nations whose fisheries are most at risk from the effects of climate change. The combined consequences of actual and predicted warming trends, species transitions, productivity changes in oceanic upwelling systems, the relative importance of fisheries to country economies and diets, and their limited ability to adjust to associated risks and opportunities have made them vulnerable (IPCC, 2014a). Climate change is likely to have a negative effect on nations that border semi-enclosed oceans and/or significantly rely on their inland fisheries.

Extreme climate events can have a particularly negative impact on cities and nations around the coast as well as those near large rivers and lakes. According to an FAO estimate undertaken between 2003 and 2013, the agriculture sector in developing countries, including fisheries and aquaculture, absorbs about 22% of the economic damage brought on by medium- and large-scale natural disasters. The effects of climate change and climate variability tend to be more severe for SIDS, whose economies are heavily dependent on fisheries and where the industry is crucial for food security and employment (FAO, 2015a). Supply and value chains are likely to be affected by changes in temperature and humidity. For example, traditional food processing in the Arctic (e.g. the drying of fish) is at risk due to increasingly wet conditions. Evidence of rising rates of food-borne illnesses, such as ciguatera fish poisoning, are heightening concerns about the impact of climate change on food safety (IPCC, 2014b). Along with its impacts on food security and safety, climate change may also threaten human health by increasing the incidence of other types of diseases. The impacts are likely to affect infrastructure in all sectors, as well as social services, causing displacement of communities and subsequent migration and/or conflict. Small-scale fishermen are particularly vulnerable to climate change because they rely so largely on inland and coastal fishing. Almost 47 million people are employed by small-scale fisheries, with 12.5 million of them directly involved in fishing and another 34.5 million working in post-harvest activities (IPCC, 2014b). These fisheries, particularly in tropical nations, are frequently at risk because of a variety of issues, such as the great degree to which low-latitude regions are exposed to the effects of climate change, subpar governance and management systems, and scant or no information on fish stocks (IPPC, 2014a). The majority of aquaculture production takes place in the tropics, which also have large people populations, making the industry particularly vulnerable (De Silva and Soto, 2009).

Adaptation and Mitigation Strategies:

By preserving or boosting adaptive capacity and system resilience, adaptation is described as actions that "increase the resilience of human or natural systems to the consequences of climate change and climate-related threats."

Adaptation Strategies:

a. Addressing the causes of vulnerability Increase household income diversity
b. Take part in income stabilisation programmes Implement social protection programmes
c. Encourage community-based risk management strategies to deal with production failure and product price fluctuations
d. Create novel risk financing and insurance instruments to lower climate-related risks
e. Developing reaction capability, protecting genetic resources, and putting co-management procedures in place.
f. Handling the Climate of Disasters

Mitigation Strategies:

In addition to "technological advances that minimize resource inputs and emissions per unit of output," mitigation supports initiatives to lower or restrict greenhouse gas emissions or to improve greenhouse gas sequestration.

The following are the main options to reduce climate change:

a. Lowering emissions by implementing better aquaculture management
b. Removing or avoiding emissions

decreasing post-harvest losses, using fishing methods in accordance with the code of conduct for responsible fisheries, removing emissions, and replanting mangroves in aquaculture areas are some of the objectives.

Constraint to Climate-Smart Fisheries and Aquaculture:

a. Initial costs that are higher; formal and informal tenure systems that have unstable tenure;
b. cultural barriers including community norms and rules;
c. Limited information and accessibility to extension services
d. Restricted access to inputs in the local market, no credit or insurance markets.

11.7 Conclusion:

A climate wise approach is necessary because it combines adaptation and mitigation in a way that will improve sustainable fisheries production in the face of climatic change. Climate change is a severe challenge for the entire world. The climate wise strategy is also not widely known.

A greater understanding of climate-smart fishing techniques has the potential to improve food security and farmers' ability to make a living over the long term. Farmers and scientists alike are working around the clock to ensure cleaner and more effective methods of processing fish in India. Improved and modern fishery/aquaculture techniques are required to adapt to the changing climate as well as reduce the release of GHGs from processing activities into the atmosphere.

A fundamental strategic and operational issue is to provide quick and efficient solutions to climate change in the fisheries and aquaculture sector, and to mainstream climate-responsive practises within broader development goals. Within established fields and situations, conventional methods for constructing and validating evidence might not always be workable. It will be necessary to develop experience through an adaptive management method based on action learning with widespread stakeholder participation and information exchange. Also, more research will need to be done on how vulnerable people are to climate change. To ensure that the most vulnerable states, production systems, communities, and individuals have the ability to design and apply solid climate-smart methods, practical measures must be established. To expand information technology and modelling of climate change data, it will be important to create conveniently accessible regional, national, and local depositories for climate and related data. To respond to expected changes in rainfall and temperature, appropriate adaptation and mitigation measures should be site-specific. Regeneration of fish stocks and ecosystems would require models for sustainable fisheries management and the preservation of aquatic resources.

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12. Agriculture Practices to Reduce In-Field Greenhouse Gas Emissions

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Abstract:

Population growth and climate change together pose a serious threat to the availability, accessibility, and security of food in emerging nations. The result of past overexploitation of natural resources is the climate as it is today. Even the agricultural sector contributed to it by transforming the naturally diverse nature into a cultivated, uniform area. Through a disciplined review of the literature, an effort is made to understand the concept and to pinpoint the linked ideas.

The global temperature raised and there was less fresh water available as a result of increased greenhouse gas emissions. Agricultural practices that emit carbon dioxide, methane, and nitrous oxides into the atmosphere include burning litter, anaerobic decomposition of organic matter, rice grown in flooding areas, etc. The effect is typically lessened by conservation agriculture, intercropping system, cover crop, crop rotation, effective cropping systems, good crop residue management, and increased nutrient usage efficiency.

Precision farming, the use of slow release fertilisers, effective water management in rice fields, the use of dung and energy crops, requirement for specific agroforestry and grazing management practices, and the replacement of fossil fuels with crop residues all significantly reduce greenhouse gas emissions.

Biochar, a product of the pyrolysis of plant and animal biomass, increases soil fertility, lowers pollution, and promotes agricultural residue recycling in addition to sequestering carbon. Henceforth, for India's agricultural production systems to be viable into the future there is a need to reduce the in-field greenhouse gases emissions through climate smart agriculture practices.

Keywords:

Carbon sequestration, Climate change, Climate smart agriculture practices, Conservation agriculture, Greenhouse gas emission.

12.1 Introduction:

Global climate change is accelerating. As a result, catastrophic weather occurrences like droughts, floods, heat waves and others are becoming more frequent. The primary contributor to these occurrences is the growing temperature of Earth's atmosphere, which is brought on by rising emissions of climate-relevant greenhouse gases (GHGs), which trap heat in the atmosphere. Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are three major GHGs (Figure 12.1). These GHGs are the most potent gases which trap the outgoing long wave solar radiations and are the most probable reason for the global climate change. The major sources of these most dreadful greenhouse gases as given in Table 1 indicated the potential for their reduction.

Table 12.1: Major sources of greenhouse gases and their global warming potential

Gases	Global warming potential for a 100-year time horizon	Natural causes	Anthropogenic sources
Carbon Dioxide (CO_2)	1	Oceanic-atmosphere exchange, animal respiration, soil microbial respiration, plants, and volcanic eruptions.	Combustion of fossil fuels (coal, natural gas, and oil), deforestation, and the cultivation of land, agricultural and animal leftovers.
Methane (CH_4)	21	Wetlands, termite activity, and the ocean	landfills, paddy fields, enteric emission from ruminants, and the production and use of fossil fuels, and methanogenic archaea by anaerobic mineralization.

Gases	**Global warming potential for a 100-year time horizon**	**Natural causes**	**Anthropogenic sources**
Nitrous oxide (N_2O)	310	Oceans and soils under natural vegetation	Intensification in agriculture, increased use of synthetic fertilizers, inefficient use of irrigation water, the deposit of animal wastes (urine and dung) from grazing animals, ineffective application of animal manures and techniques increasing soil organic N mineralization.

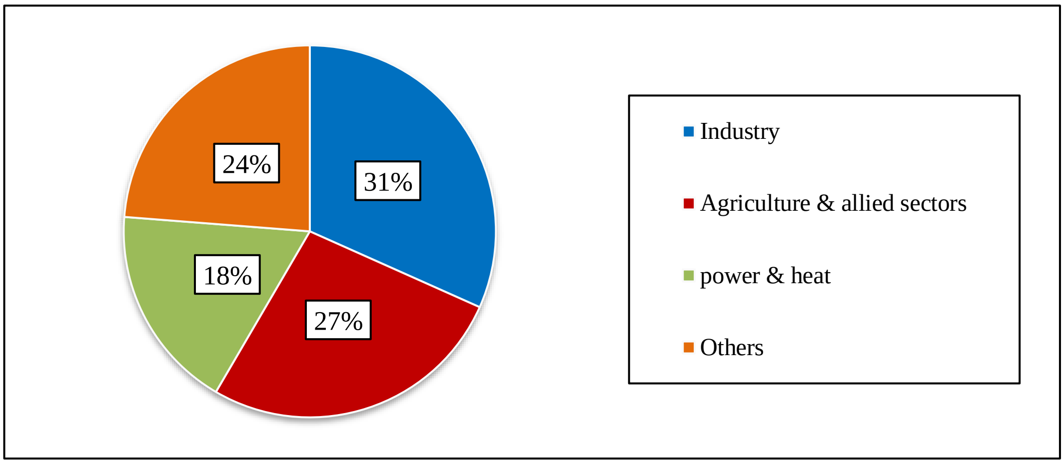

Figure 12.1: Contribution of different Sectors in Greenhouse Gases Emission

Agriculture contributes significantly to greenhouse gas emissions that drive climate change and is a direct victim of it. According to [1], 37.6% of the world's land area is covered by agricultural lands, and this sector is a substantial source of GHG emissions.

CO_2, CH_4, and N_2O are the main trace gas types that contribute most to the global warming impact. Agricultural soil management (such as tillage), the use of synthetic and organic fertilizers, dairy management, the burning of fossil fuels for agricultural operations, and crop residues burning are all factors that contribute to agricultural GHG emissions (Figure 12.2).

According to [2], agriculture may be the source of 52% and 84%, respectively, of the world's anthropogenic CH_4 and N_2O emissions. Certainly, advanced approaches are needed to minimize agricultural emissions of CH_4 and N_2O since they have substantially larger global warming potentials than CO_2 based on per unit mass and a 100-year time frame.

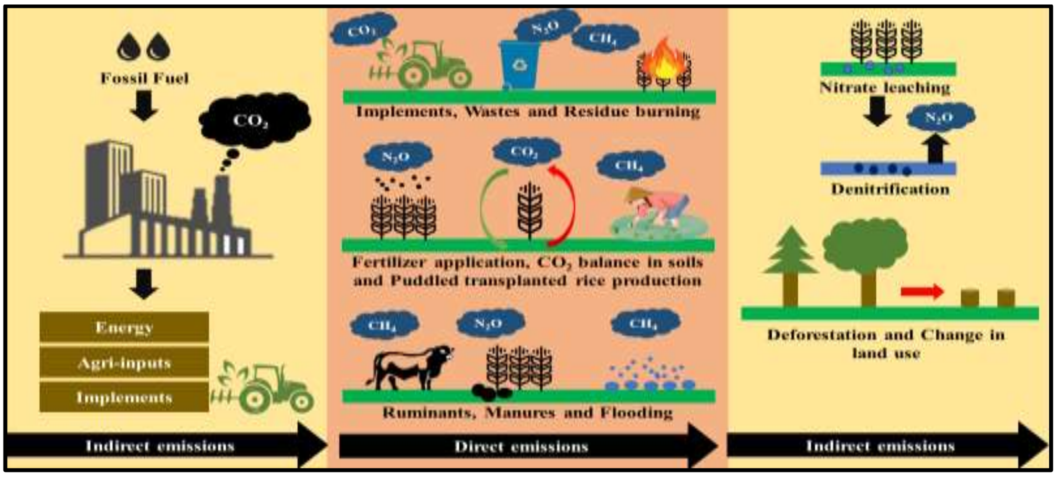

Figure 12.2: Representation of direct and indirect GHG emissions from crop production

Human settlement in previously uninhabited areas results in the conversion of natural ecological systems to agricultural production, which results in the loss of 20–40% of the soil organic carbon (SOC) after cultivation, with the majority of that loss happening during the first couple of years [3]. This conversion also increases levels of GHG emissions. According to a recent estimate, since agriculture began roughly 12,000 years ago, 133 billion tonnes of SOC, or about 8% of the total worldwide SOC stock, have been lost from the top two meters of soil, with the rate of loss sharply increased since the beginning of the industrial era [4]. According to the study, farmland suffered a bigger overall proportion of SOC loss than grazing land, despite grazing on more than twice as much land overall. This suggests that while agriculture has a better ability to boost SOC gain, grazing land has a greater capacity to increase SOC storage overall.

Since the soil and vegetation retain approximately three times the amount of organic carbon of the atmosphere [5], slight variations in the organic carbon stock in the soil and vegetation may have a significant impact on the global carbon dioxide concentration. As a result, significant attempts must be created to improve SOC storage in terrestrial environments and to decrease GHG emissions from these systems. In managed systems, management practices including not burning agricultural waste after harvest and using compost, charcoal, and animal dung to improve organic C input to the soil can boost SOC storage.

The fact that agriculture is a major source of GHGs and much of the carbon in the soil gets lost through cultivation. But the agricultural sector offers a significant opportunity to reduce anthropogenic sources of greenhouse gas emissions and boost soil carbon storage.

If permanent vegetation can be sustained, soil carbon storage could rise, benefiting from the C cycle becoming more closed in the system and the soil being able to capture more carbon. For instance, agricultural management practices can be enhanced in order to reduce disturbance to the soil by reducing the frequency and extent of cultivation as a way to minimize soil C loss and to increase soil C storage.

By strategically applying fertilizers, one can increase fertilizer nitrogen use efficiency (NUE) and decrease nitrogen loss, including gaseous and leached forms of nitrogen loss [6]. Additionally, management actions can be implemented to reduce the burning of agricultural biomass. Climate-smart agriculture (CSA) management practices, which include the strategic use of synthetic and organic fertilizers, conservation tillage, use of cover crops, and the addition of lime, biochar, and nitrification inhibitors to agricultural fields, can help to reduce GHG emissions from agriculture [7].

According to the [8], CSA is defined as a systematic approach for designing agricultural policies that can provide sustainable food security. Based on this concept, a variety of agricultural techniques can be created to aid in enhancing both environmental and food security at the same time in relation to global change.

Since soil can act as a sink or source of CO_2 and influence climate change if we can strengthen the carbon sink and remove more CO_2 from the atmosphere by implementing CSA, we will be in an advantageous position in not only battling the adverse impacts of climate change but also reducing emission of greenhouse gases emission and enhancing soil quality and health, which includes nutrient and water retention, and increasing agricultural productivity [9].

12.2 Agriculture Practices to Reduce In-field Green House Gas Emissions:

There are various areas in agriculture which contribute differently to the GHG emissions (Figure 12.3.). Thus, it is very important to prioritize those areas for reduction of GHG emissions.

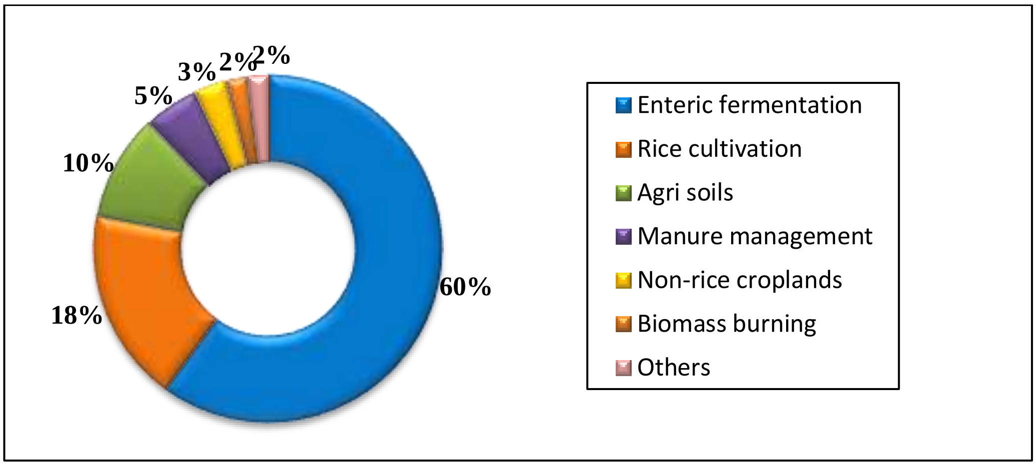

Figure 12.3: Contribution of different agriculture sectors to greenhouse gas emissions

Agriculture has the ability to reduce GHG emissions at a low cost by changing agricultural methods and management techniques. Different agriculture practices focuses on enhanced risk management, improving information flows, and encouraging local institutions to increase the community's adaptive capacity to climate change [10]. The following are some agricultural practices that help to reduce in-field greenhouse gas emissions:

12.3 Adoption of Conservation Tillage Practices:

Contrarily, conservation tillage (CT) systems focus on retaining and managing crop residue while minimizing disturbance to the soil by limiting any field preparation operations to a shallow depth and preventing soil inversion [11]. They include non-inversion tillage, eco-tillage, minimal tillage, mulch tillage, reduced tillage, zone tillage, or no-tillage.

A minimum of 30% of the earlier crop residues should still be visible on the soil surface, according to CT [12]. Adopting CT can increase soil organic matter (SOM), lower CO_2 emissions, and improve SOC sequestration, especially when combined with agricultural residue retention. When compared to conventional ploughing, conservation tillage has been proven to produce more soil that is present in macro-aggregates and more carbon that is connected with micro-aggregates [13]. Increased biological activity in such soils is the source of the increased aggregate strength under CT management [14], and residues that leave on the soil surface provide additional protection, slowing down the degradation of the top soil particles [15]. Compared to normal tillage, no-tillage greatly lowered the release of methane from fields of rice. By increasing soil bulk density and inhibiting the breakdown of organic matter, no-tillage reduces the volume percentage of big pores and methane emissions. Conservation tillage has a higher near-surface soil C content than conventional tillage because it keeps more plant remains on the soil surface, especially in cool, humid climates [16]. In comparison with residues that are thoroughly mixed into the soil through standard tillage practices, the degradation of plant residues may occur more slowly under these circumstances due to the reduced soil-residue contact. Conservation agriculture has the ability to increase the use efficiency of resources that are renewable, including water, air, fossil fuels, and soil through the adoption of resource-conserving technologies like zero or minimum tillage with direct planting, permanent or semi-permanent residue cover, and rotations of crops. By maintaining the base of available resources and reducing GHG emissions, the technologies can enhance the sustainability of agriculture. By carbon accumulation inside the small macro aggregates and micro aggregates at the 5–15 cm depth, tillage intensity and frequency were reduced, increasing soil carbon [17].

12.3.1 Agronomic Practices:

Intercropping, as a traditional multi-cropping system, has been well proven to improve crop production and fertilizer use efficiency by utilizing niche crop and seasonal differentiation, as well as advantageous relationships between species when handled properly [18]. Intercropping thus becomes critical for achieving the dual goals of boosting crop yields and lowering GHG emissions [19]. Many researches have shown that a cereal-legume system reduces soil CO_2 and N_2O emissions when compared with monoculture [20]. Soil physicochemical properties and microbial community diversity are changed with increased crop diversification, resulting in changes in soil N_2O emissions [21]. Intercropping regimens that use various legume species and cultivars might also cause differences in N_2O emissions [22]. In contrast to typical monocropping, maize farming, nitrogen fixation of legume crops and nitrogen transport between maize and legume crops greatly altered the nitrogen cycle in intercropping systems. Maize-peanut intercropping was observed to reduce soil N_2O emissions by 13% when compared to maize monoculture [23]. This could be linked to increased nitrogen utilization efficiency in cereal-legume intercropping.

Cover crops are a common agronomic strategy that can reduce nutrient losses, such as soil inorganic N, and improve carbon dioxide (CO_2) sequestration. Legumes, grasses, mustards, or mixer of those species can be cultivated as cover crops to increase soil quality, reduce harmful soil erosion, increase soil structure and fertility, control pests, and reduce the loss of nutrients from the root zone [24]. In comparison to winter fallows, a combination of cereal rye (*Secale cereale* L.) and hairy vetch (*Vicia villosa* Roth) drilled into crop stubble every year increased soil organic carbon, nutrient retention, and water aggregate stability, according to research by [25]. By absorbing nitrogen and storing it in their biomass, a number of cover crop species have been demonstrated to reduce soil $N\text{-}NO_3$ levels [26].

This reduces the amount of nitrogen that can enter rivers or be released to the atmosphere via gaseous pathways. Because the reduction in soil water would not favour circumstances of denitrification via which N_2O might be formed, cover crops can also reduce N_2O production by absorbing soil moisture in their living plant tissue [27]. Following cover crop suppression, the mineralization or immobilization of the residue N would be made possible by the breakdown of cover crop residues in the presence of oxygen. Use of crop rotation is another mitigating strategy discovered to lower N_2O emissions. A corn-soybean rotation lowered N_2O emissions by 35% compared to continuous corn, and it also increased yield by 20% [28].

The key to lowering the system's total footprint is to grow crops with minimal production input requirements and those that produce a lot of straw and roots for the soil to absorb carbon. According to [29], switching from the conventional double-rice system of cultivation to a more diversified structure that included upland crops lowered irrigation water consumption in the dry season by about 70% and lowered CH_4 emissions by 97% without having adverse economic impact. System carbon footprints can be decreased by up to 250% in more intensive systems with less frequent summer-fallow in the rotation.

When summer-fallow is replaced with fodder or grain legume as opposed to an approach with a high frequency of summer-fallow, farming income can more than quadruple [30]. In the summer fallow-cereal cropping system, where substantial increases in inputs of carbon were accomplished using currently available legume species, green manuring played a significant role in increasing soil carbon levels [31]. Increasing cropping frequency in order to minimize bare fallow was also found to improve soil carbon sequestration [32], including perennial forages like lucerne (Medicago sativa L.). Due to larger belowground biomass carbon input and ongoing root growth compared to annual cropping systems [33], increased dryland soil carbon sequestration and biological soil quality were achieved by increasing microbial biomass and activity [34].

Additionally, building agroforestry systems, or the production of crops, livestock, and tree biomass on the same plot of land, can successfully boost SOC sequestration [35]. This is done by planting trees with high roots-to-aboveground biomass ratios and trees that fix nitrogen. It consists of woody species-filled riparian zones and buffer strips as well as shelter belts. Planting trees may also boost soil carbon sequestration. The standing stock of carbon above ground is typically greater than the equivalent land use without plants. To increase carbon sequestration rates and the mechanisms causing SOC to stabilize in soil profiles, detailed agroforestry management techniques are required.

12.4 Reduce Enteric Fermentation Through New Technologies:

Approximately one-third of all anthropogenic CH_4 emissions worldwide are produced by livestock, primarily ruminants like cattle and sheep [36]. Eructation is used to expel the methane, which is predominantly produced by enteric fermentation. Because N is excreted in urine and faeces, all cattle produce N_2O emissions from manure. In order to lessen these CH_4 and N_2O emissions, try the following:

- **Improved feeding practices-** Feeding more concentrates which often replace forages can lower methane emissions. [37] recommend improving pasture quality by including specific oils or oilseeds in the diet to increase animal productivity and decrease the amount of energy lost as CH_4 as well as optimising protein intake to lower nitrogen excretion and N_2O emissions [38].
- **Specific agents and dietary additives-** Antibiotics called ionophores contribute to reducing methane emissions. Halogenated substances suppress methanogenic bacteria, although they can also have adverse effects like lower intake and their effects are frequently transient. Probiotics, like yeast culture, have only had minor, negligible impacts, but choosing strains particularly for their capacity to reduce methane could lead to better outcomes [39]. Fumarate and malate, two precursors of propionate, serve as substitute hydrogen acceptors to lessen methane synthesis [40]. Propionate precursors are pricey nevertheless because the response is only evoked at large doses [41]. Bovine somatotropin (bST) and hormonal growth implants can lower emissions per kilogram of the animal product even if they do not explicitly suppress the creation of CH_4.
- **Longer-term management changes and animal breeding-** Methane production per unit of animal product is frequently decreased by improving productivity through breeding and better management techniques, such as a decrease in the total number of replacement heifers [42]. Meat-producing animals become slaughter weight earlier and have lower lifetime emissions thanks to increased efficiency.

12.5 Soil Amendments for Reducing GHG Emissions:

Mulches- Mulch will alter the amount of carbon (C) and other minerals that are available to microbial communities, which will have an impact on soil GHG emissions. In addition to controlling the temperature of the soil systems, mulches preserve soil moisture [43]. However, too much straw applied to the soil's surface can hinder seed germination, necessitating the administration of additional fertilizer to make up for any N that may become immobilized during the crucial early period of growth [44]. When it comes to CO_2 emissions, mulching typically causes an increase because labile C is added to the mulch, and the rate of CO_2 emissions rises as the rate of mulch addition increases. In comparison to adding no mulch, adding mulch can immobilise mineral N in the soil, lower the availability of NH_4 for nitrification and NO_3 for denitrification, and therefore minimise N_2O emissions.

Biochar- The cycling of C and N is one of soil properties that can be altered by adding biochar. According to numerous reports, applying biochar can lower N_2O emissions [45]. By aiding the final stage of denitrification and increasing the production of N_2 rather than N_2O, biochar lowers N_2O emissions [46]. A significant amount of crop residues are produced in farming operations, and the return of crop residues in the raw state vs after the crop residue has been transformed to biochar can have a significant impact on the emissions of all three trace gases.

A. Improved Manure Management:

Livestock urine and manure are substantial producers of methane and nitrous oxide when decomposed under anaerobic conditions. When the nitrogen in animal manure is nitrified and then denitrified, nitrous oxide is created [47]. When manure is kept in big heaps or settlement ponds to handle the waste from numerous animals kept in a small space (such as dairy farms, cattle feedlots, pigteries, and poultry farms), anaerobic conditions sometimes develop [48]. Aeration and composting of manure stockpiles lower methane emissions. Nitrous oxide emissions can be decreased by adding urease inhibitors to manure heaps. Urease inhibitors are chemical additives that slow down or prevent the conversion of urea found in animal urine and manure to nitrous oxide [49].

B. Fertilizer Management:

Agricultural management practices, such as nitrogen in splits and the use of controlled-release fertilizers have greatly influenced the crop production and nitrogen use efficiency by balancing the nitrogen demand of crops and the nitrogen availability of soils [50]. The effects of these practices on greenhouse gases emissions, particularly in systems of intercropping have not yet been thoroughly assessed. The largest contributor of GHG emissions was discovered to be fertilization with irrigation. Therefore, applying nitrogen in three splits and using a slow-release fertilizer may be an easy and efficient way to increase grain output while lowering GHG emissions [51].

C. Rice Management and Varieties:

Climate change is a crucial environmental problem for the twenty-first century since it might have a large impact on rice productivity and speed up the paddy ecosystem's greenhouse gas emissions, both of which are extremely concerning for the environment. Due to rice fields' advantageous production, consumption, and transportation systems, CH_4 and N_2O gases are released concurrently into the environment. Because of the enormous pressure that the intensive rice farming system places on rice fields to grow more rice in order to feed the growing global population [52]. Soil fertility is declining, and the ecological balance of the rice paddy is being disrupted by increased CO_2, CH_4, and N_2O fluxes into the atmosphere. Extreme weather conditions like high temperatures, high water vapour or relative humidity, and drought stress may severely stifle beneficial microbial activity, soil nutrients, and water availability to rice plants; as a result, rice yield may decline noticeably while greenhouse gas emissions may rise noticeably [53]. In this situation, field-level farmers should be taught about conservation tillage, water-saving irrigation techniques like alternate wetting and drying, soil amendments with biochar, vermicompost, azolla-cyanobacterial mixture, recommended silicate slag, and phospho-gypsum with minimum NPKSZn fertiliser (IPNS), and more. Another crucial step in lowering methane production is the removal of rice straw from the field before re-flooding [54]. Straw can also be used to grow mushrooms or produce bioenergy, among other useful uses.

Reduce duration of flooding to reduce growth of methane-producing bacteria. In the middle of the growing season, farmers can temporarily lower water levels or sow rice on land that is initially dry rather than flooded [55]. Direct seeded rice is also recommended instead of transplanted rice to reduce the methane emission from the field [56]. The DSR and SRI crops do not require continuous soil submergence, and therefore reduce or totally eliminate methane emission when rice is grown as an aerobic crop. The DSR and SRI have potential to reduce the GWP by about 35-75% compared to the conventional puddled transplanted rice [57]. Grow rice with less methane as well. However, these characteristics have not been developed into the majority of commercial cultivars. A few extant types leak less methane than others, and researchers have demonstrated great experimental promise.

- **Increase agricultural energy efficiency and shift to non-fossil energy sources:**

By 2050, agricultural emissions from the usage of fossil fuels will still be at 1.6 Gt CO_2e/year. The methods for mitigating energy emissions are similar to those used to lower them in other industries; they rely on improving efficiency and transitioning to renewable energy sources. On-farm energy use will account for 65 percent of anticipated agricultural energy emissions in 2050. Solar and wind energy may frequently be used to generate electricity and heat, though it will take creative, small-scale solar heating systems to replace on-farm coal. It will be more challenging to reduce the use of diesel fuel by tractors and other large machinery, and it might be necessary to switch to fuel cells that use hydrogen energy produced by solar or wind energy. Alternative technologies could include battery-powered devices and artificial carbon-based fuels produced from renewable electricity. Additionally, since the synthesis of nitrogen fertilizer currently requires a lot of energy, renewable sources of hydrogen might eliminate 85% of the emissions that result from this process. Fortunately, extensive research is being done on the manufacture of hydrogen using electricity from solar energy, and the price of solar electricity has been falling quickly due to the needs of other sectors. Even with efficiency benefits incorporated into our baseline, significant work is still necessary [58].

- **Focus on realistic options to sequester carbon in soils:**

Due to the difficulty of reducing agricultural production emissions, significant research and policy emphasis has been focused on techniques to trap carbon in agricultural soils to balance such emissions. There are just two options for increasing soil carbon: add more or lose less. However, new research and experience show that soil carbon sequestration is more difficult to perform than originally anticipated [59]. Ploughing practices that originally appeared to avoid soil carbon losses, such as no-till, now appear to give relatively minor or no carbon benefits when assessed at greater soil depths than earlier reported. No-till tactics must also struggle with negative effects on yields in particular areas, as well as the reality that numerous no-till farmers still plough up soils every few years, releasing much of the carbon gain [60]. Adding mulch or manure to soils are proposed carbon-addition solutions, however, they effectively double-count the carbon that would have influenced carbon storage elsewhere. Allowing crop wastes that would otherwise be used for animal feed to become soil carbon necessitates that the animals' feed comes from other sources, which has a carbon cost because growing that feed often necessitates more agricultural land [61, 62].

12.6 Conclusion:

Good agriculture practices, with an emphasis on climate change adaptation and mitigation, can take many different forms. The climate smart agriculture practices have many roles to play in agricultural sustainability and in reducing in-field GHG emissions, as well as in increasing soil carbon sequestration. Practices such as the use of conservation tillage, crop rotations, application of biochar to the soil, use of soil amendments, nitrification and urease inhibitors, mulching, fertilization management and use of intercropping are all options available to landowners to effectively adapt to and mitigate regional to global climate change. Thus, we have to improve the existing ways to mitigate greenhouse gases through better land based agricultural practices without compromising the food production.

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13. Crop Breeding Strategies for Climate Resilient Agriculture

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Abstract:

Climate change is a danger to global food security because of the decline of crop productivity around the world. Stakeholders and policymakers are worried about food security because it's expected that the world's population will exceed 10 billion in the upcoming years. The best path ahead for meeting future food needs is crop development through current breeding techniques, effective agronomic practises, advances in microbial applications, and leveraging the natural diversity in neglected crops. In this study, we outline the next-generation breeding techniques that can be utilised to boost crop productivity by creating superior genotypes that are climate-resilient to meet the problems of future global food security. The creation of fully annotated crop pan-genomes is now possible because of recent advancements in genomic-assisted breeding (GAB) techniques, which provide a picture of the whole spectrum of genetic diversity (GD) and restore a species' extinct gene repertoire. Pan-genomes offer fresh ways to take advantage of these distinctive genes or genetic variation for breeding programme optimisation. The idea that genome editing is being redesigned for crop improvement has become institutionalised with the introduction of next-generation (CRISPR/Cas) systems, including prime editing, base editing, and de nova domestication. Moreover, the editing process was made more effective by the availability of adaptable Cas orthologs such Cas9, Cas12, Cas13, and Cas14. CRISPR/Cas systems are now widely used in agriculture research, successfully editing major crops to enhance resistance to abiotic and biotic stress. Agriculture is moving towards automation or digitalization by utilising high-throughput phenotyping methodologies and big data analytics tools such as artificial intelligence (AI) and machine learning (ML). When speed breeding is combined with genomic and phenomic technologies, it is possible to identify genes quickly and thus accelerate crop improvement programmes. Furthermore, the integration of next-generation multidisciplinary breeding technologies can open up new pathways for developing climate-ready crops that contribute to global food security.

Keywords:

Climate resilient, food security, climate change, CRISPER/Cas9, next-generation breeding, pan-genoms, genome editing.

13.1 Introduction:

Climate resilient varieties are crop varieties that are developed and selected to withstand the impacts of climate change such as increased temperatures, droughts, floods, and pests. These varieties are bred using techniques such as conventional breeding, molecular breeding, and genetic engineering, among others. Modern agricultural practise is struggling to get the level of primary output required to feed about ten billion people by 2050 since land is becoming scarcer and population is increasing rapidly [1].

The development of climate-resilient varieties is crucial to ensure food security and to adapt to the changing climate. Climate change is expected to cause significant yield losses and affect the quality of crops, making it difficult for farmers to feed growing populations. Some of the characteristics of climate-resilient varieties include drought tolerance, heat tolerance, pest and disease resistance, and the ability to adapt to changing climatic conditions. They can also have higher yields and better nutritional content. According to predictions, severe climatic circumstances will generally result in lower worldwide yields of economically significant crops like maize (7.4%), wheat (6.0%), rice (3.2%), and soybean (3.1%) for every degree Celsius that the world's average temperature rises[2].

Developing climate-resilient varieties requires collaboration between scientists, farmers, and policymakers. Farmers need to be educated about the benefits of these varieties and provided with access to the necessary resources and information. Policymakers need to support the research and development of climate-resilient varieties and ensure that they are widely available to farmers.

Some important methods that may support in adaptation to climate change include in-situ moisture conservation, water harvesting and recycling for supplemental irrigation, residue incorporation other than burning, growing cultivars that are both abiotic and biotic stress tolerant, appropriate agronomic and nutrient management, and breeding for multiple traits of interest, including quality.

Promising technologies for climate-resilient agriculture:

Some significant actions that aid in adjusting crop output to climate change including

- **Adapted cropping techniques and cultivars:** (crop diversification, a shallow-deep root system that combines legumes and cereals, and enhanced short-duration crop cultivars that are tolerant to heat and drought),
- **Developing soil strength and resilience**: (Avoid bare soil, provide fertiliser after required soil testing, regulate tillage, add organic manure to the soil to boost soil carbon, rotate crops or intercrop with legumes, and use green manuring),

- **Farm machinery:** (Opening the furrows with a chisel and mb plough conserves rainwater, and using a laser leveller to increase nutrients and increase water use efficiency),
- **Rainwater harvesting and recycling:** (Farm ponds and reservoirs with inter-plot and inter-row water collection systems),
- **Crop contingency plans**: (Fishery interventions and livestock
- **Weather based agro advisories**: (Time specific weather data, like as rainfall, temperature, and wind velocity, are recorded by automated weather stations set up at experimental farms and small weather observatories).

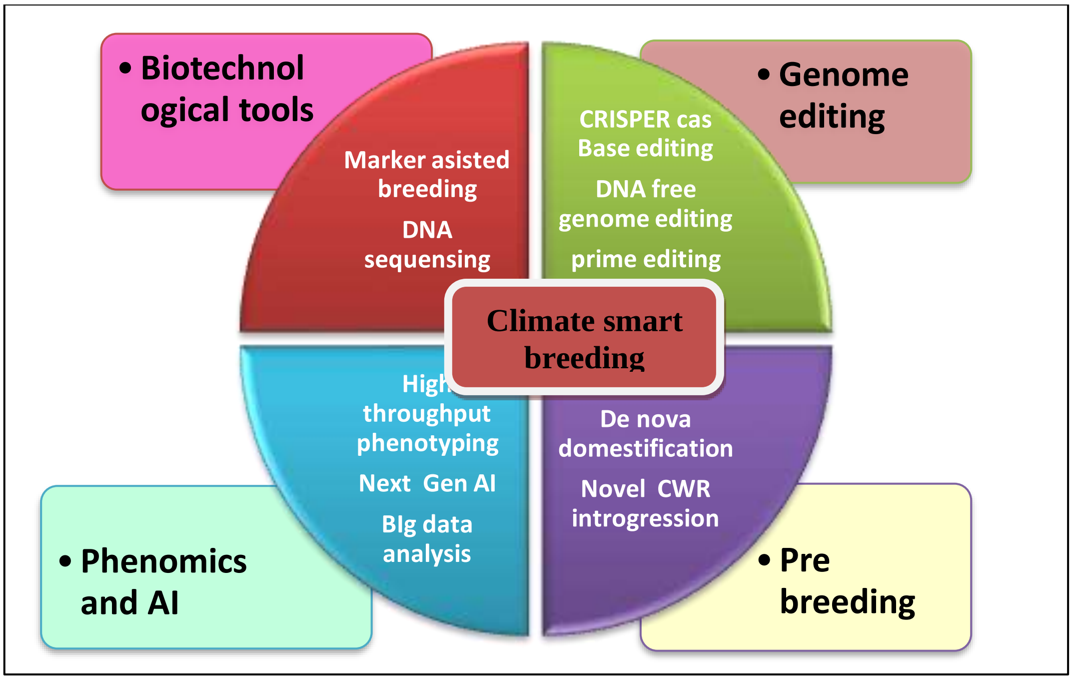

Figure 13.1: Climate Smart Breeding

13.2 Pre-Breeding and Crop Wild Relatives (CWR):

Crops would be subjected to higher biotic and abiotic pressure due to the introduction of plant diseases and pests brought on by adverse climate condition. Crop resilience in the era of climate-change is made feasible by breeding crop plants with diverse genetic backgrounds.

For the purpose of supplying the mushrooming population with food, it is vitally important to use crop wild cousins to develop larger spectrum kinds to address various biotic and abiotic challenges. Modern crops have a restricted genetic history as a result of selection preferences throughout the domestication era. This limits their capacity to adapt to their environment and to reproduce using modern germplasm.[3] Wild relatives and ancestors typically have wide climatic and environmental adaptation, which results in a better potential for agricultural development.

Pre-breeding activity connects the beneficial qualities of crop wild relatives to the production of current cultivars by giving breeders access to more readily exploitable wild genetic variation[4 ,5]. Pre-breeding is one of the opportunity to insert desired genes into the primary, secondary, and tertiary gene pools of elite breeding lines, and genotypes from wild species in order to reduce linkage drag. As domestication naturally reduces genetic variation, nearly all agricultural crop species were domesticated from wild plants species at some point[6]. In a variety of crops, including cotton, sugarcane, triticum, paddy, maize, potato, chickpea, tomato, tobacco, and pigeon pea, the genetic capacity of wild forms has been documented.

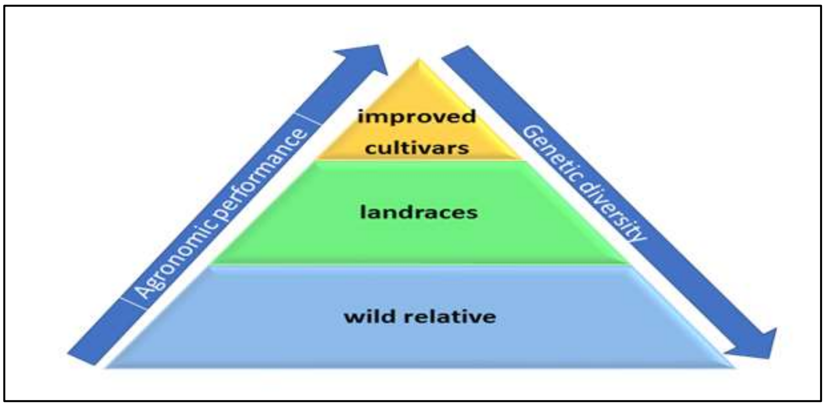

Figure 13.2: Genetic diversity and agronomic performance of germplasm

A. Introduction of Exotic Species into Superior Varieties:

wild species are largely employed to introduced biotic and abiotic stress resistance/tolerance gene in several key crops. This is because most infections can adapt to the climate more quickly than humans, making cultivars susceptible to devastating new diseases[7]. It is common practice to use intergeneric or interspecific hybridization to introduce disease resistance. Making polyploidy crops by hybridization, which mimics natural evolution, this is another method to improve genetic diversity and crop vigour with adaptation to various environmental conditions[8]. Through comparative genome pool sequencing of genes for both biotic and abiotic stress resistance of crop wild relatives can be examined, elucidating the probable genomic regions relevant for adaptation to various ecology. They have been studied in the wild counterparts of numerous crops, such as chickpea, barley, and maize[9-12]. Pan-genomics, based on a complete species' gene repository, can expose the genetic variations, like that the numerous structural variants and single nucleotide polymorphisms present in plants, to address the variety within species. One illustration of structural variants is how differences in the ELR gene's presence or absence between wild and cultivated potatoes affects the plants' susceptibility or resistance to the late blight disease (*phytophthora infestance)*[13]. Larger pan genomes that include both cultivars and their wild relatives might accumulate a surplus of dispensable genes that cause phenotypic variances, making it easier to characterise the trait linked genomic variants. *Aegilops tauschii*, a wild diploid wheat, has many pan-genomic R genes that have been successfully found and cloned in order to combat the rust infections that affect wheat in the reference of a changing climate[14].

B. Introgressiomics Strategies for Adaptation to Climate Change:

As a consequence of linkage drag and numerous breeding challenges with the crops, the CWR's real opportunity for plant breeding is yet mostly unrealized. The introduction of introgression lines from crop wild relatives into the genetic makeup of crops is made possible by the introgressiomics approach[15]. Depending on the goal, this preventive breeding strategy could be concentrated or unfocused. In addition to genetic examination of traits found in crop wild relatives, the establishment of genetically described elite material is made possible by MAS (marker assisted selection) driven generation of chromosome substitution lines and introgression lines, or MAGIC (multiparent advance generation intercross) populations. High throughput genetic markers and other genomic techniques make it easier to characterise and generate Introgressiomics populations, which can be easily introduced into large-scale breeding programmes to address the escalating environmental issues.

C. Several other Methods for CWR use:

After the CWR gene was introgressed into a domesticated background, populations were created to study the introgressed gene, including backcross populations(BC), recombinant inbred lines(RILs), doubled haploids(DH), near isogenic lines(NIL), multiparent advance generation intercross (MAGIC) populations, and nested association mapping (NAM) populations.

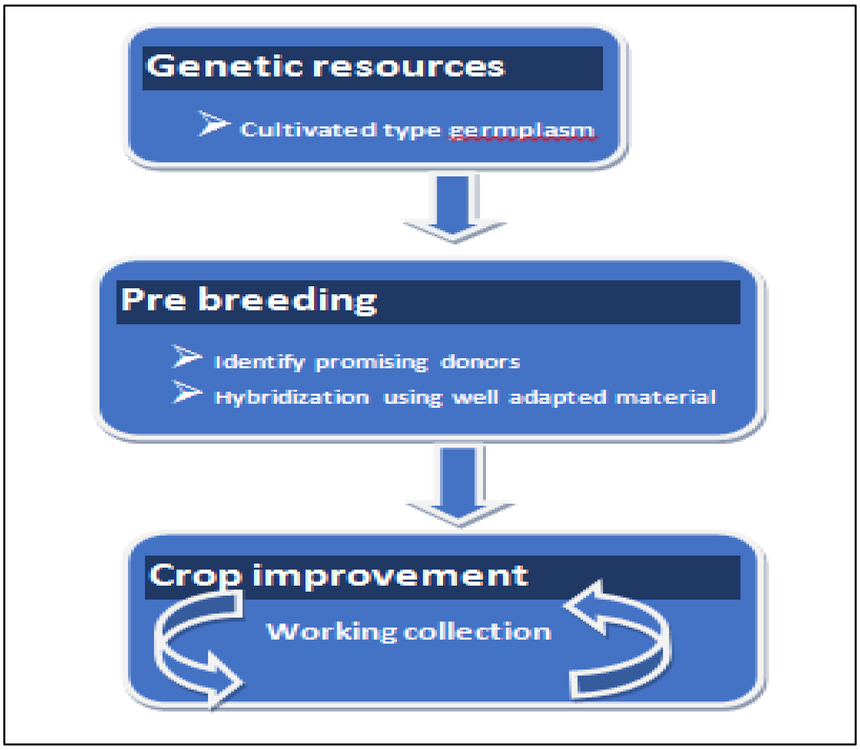

Figure 13.3: Introgression of CWR in breeding programs

13.3 Biotechnology: A Strategy for Climate Resilient Agriculture:

The rapid degradation of arable land and the illogical rainfall patterns, along with the numerous direct as well as indirect effects of climate change on agriculture, all result in a variety of abiotic stresses like drought and heat & biotic stresses like insect, pest and diseases. The advance techniques of biotechnology toolbox has the potential to address these enormous challenges of developing the stress tolerant crops[16].

In order to achieve more sustainable and effective yield increases, it is urgent to switch from conventional breeding practices that rely on fertilizers and pesticides to crop improvement methods supported by genomics. This is because the world's population is expanding quickly under the threat of climate change[17].

A. Marker Assisted Breeding:

Marker-assisted breeding (MAB) is a plant breeding technique that uses molecular markers to identify and select plants with desirable traits, such as tolerance to environmental stresses like drought, heat, and salinity.

This technique can be particularly useful in developing climate-resilient crops that can withstand the effects of climate change, including extreme weather events, changes in temperature and precipitation patterns, and increased pest and disease pressure.

The development of molecular markers like Single Nucleotide Polymorphism (SNP), Rapid Amplified Polymorphic DNA, Kompetitive Allele Specific PCR, Simple Sequence Repeat, Cleaved Amplified Polymorphic Sequence, and others has revolutionised the study of genetics and facilitated molecular crop breeding[18].

The Smart breeding programme places a lot of emphasis on the breeding programmes that have switched from phenotype-based (conventional breeding) to a combination of conventional and genotype-based selection[19].

The process of MAB involves first identifying genetic markers that are associated with the desired trait, such as a gene that confers drought tolerance. Once these markers are identified, plant breeders can use them to screen large populations of plants to identify those with the desired trait, without having to rely solely on time-consuming and expensive phenotypic screening methods.

MAB has already been used to develop climate-resilient crops, such as drought-tolerant maize, rice, and wheat varieties. For example, in Africa, the International Maize and Wheat Improvement Center (CIMMYT) has used MAB to develop maize varieties that are better adapted to drought-prone areas. These varieties have shown increased yields and improved resistance to drought stress.

Overall, MAB can be an important tool for developing climate-resilient agriculture by allowing breeders to more efficiently and accurately select for desirable traits, such as tolerance to environmental stressors.

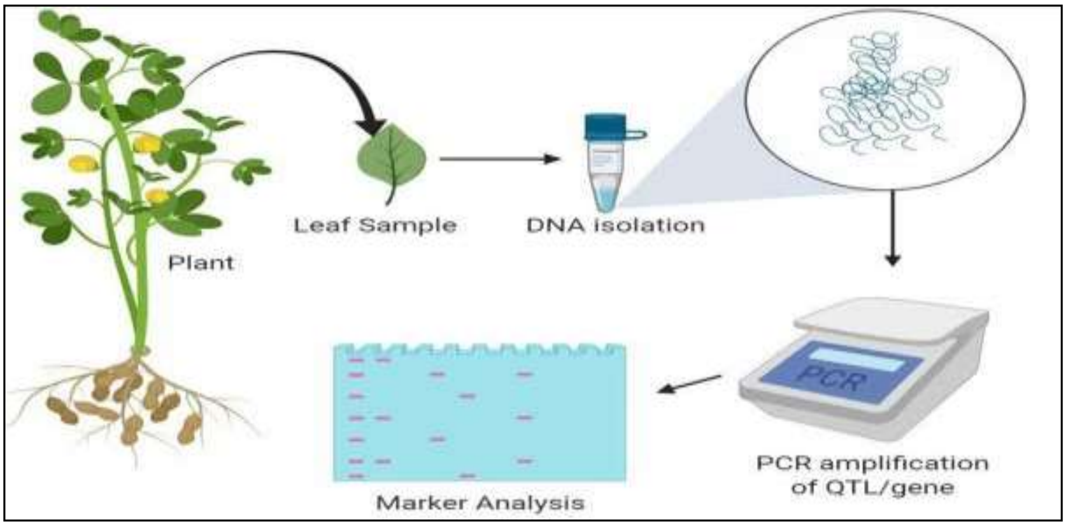

Figure 13.4: Marker Assisted Breeding Selection

B. Dna Sequencing and The Development of Genomics-Aided Breeding:

DNA sequencing is the process of determining the precise order of nucleotides (adenine, thymine, guanine, and cytosine) in a DNA molecule. The sequence of these nucleotides determines the genetic information that is encoded in the DNA.

Using RNA sequencing and the gluten gene families, this method can be used to define genetic diversity in disease resistance gene repositories in Solanaceae and Triticeae plants[20].

There are different methods for sequencing DNA, but the most commonly used method is called "chain termination" or "Sanger sequencing".

In Sanger sequencing, a DNA molecule is first amplified using the polymerase chain reaction (PCR) to produce many copies of the DNA fragment of interest. These fragments are then mixed with a set of DNA primers and DNA polymerase, as well as a mixture of the four nucleotides (A, T, G, and C) and a small amount of modified nucleotides that terminate the chain. As the polymerase synthesizes new DNA strands, occasionally a modified nucleotide is incorporated instead of the regular nucleotides, causing the chain to terminate.

The resulting mixture of DNA fragments of varying lengths is then separated by size using gel electrophoresis. The sequence of the DNA fragment can be determined by reading the order of the terminating nucleotides at the end of each fragment, which is revealed by the positions of the separated bands on the gel.

More recently, new methods of DNA sequencing have been developed, such as next-generation sequencing (NGS) and single-molecule sequencing. These methods can sequence DNA faster and more efficiently than Sanger sequencing, and have enabled the sequencing of entire genomes in a relatively short time.

13.4 Genome Editing: A Revolutionary Tool for Breeders' Toolbox:

Genome editing is the process of making precise changes to the DNA sequence of an organism, typically using a molecular tool such as CRISPR/Cas9. This technology allows scientists to add, delete, or modify specific DNA sequences in a genome, which can have a wide range of applications in areas such as medicine, agriculture, and environmental science[21, 22].

One of the most popular tools for genome editing is CRISPR/Cas9, which is a system that uses a guide RNA to target specific DNA sequences and a nuclease (Cas9) to cut the DNA. This cut triggers the cell's natural DNA repair mechanisms, which can be manipulated to insert or delete specific genetic material[23].

Genome editing may accelerate the domestication of novel crops drawn from their wild relatives or small-scale crops with their ability to adapt to extreme climatic conditions. In order to maximise the use of germplasm adapted to climate change, this will accelerate the spread of currently small gene pools by altering crucial genes for domestication in possible new crops. Additionally, multiplexing CRISPR devices to edit numerous genomic loci simultaneously can greatly speed up and increase effectiveness. Due to the drawbacks of this method, such as off target effects, poor HR efficiency, limited PAM sequences, and regulatory challenges, more complex technologies, such as DNA free genome editing, base editing, and prime editing, have been developed.

A. DNA Free Genome Editing:

DNA-free genome editing (DFGE) refers to a genome editing technique that does not involve the direct modification of DNA. DNA-free genome editing approaches use various methods to deliver editing tools, such as proteins or RNAs, directly into cells without modifying the DNA.

The CRISPR-Cas9 ribonucleoprotein was first effectively used in rice and tobacco with protoplast transfection (RNP)[24]. Moreover, a DFGE method mediated by particle bombardment has been established in wheat and maize[25, 26].

B. Base Editing:

The process of base editing involves the base editor protein being guided to the target DNA sequence by the Cas9 enzyme, where it then binds to the DNA and converts the targeted nucleotide[27]. This process does not involve breaking the DNA, and therefore results in less off-target effects and potentially fewer unintended mutations than traditional genome editing methods.

C. Prime Editing:

With the aid of prime editing guide RNA (pegRNA), a contemporary occurrence in the era of genome engineering, all 12 known base to base conversions as well as mutations like insertions and deletions can be introduced[28].

This promising strategy offers a wide range of opportunities for successfully targeting and changing desirable genome sequences to speed up functional genomics and the inclusion of genes for adaptation to climate change, which will enable breeding for climate resilient crop varieties in the near future[29].

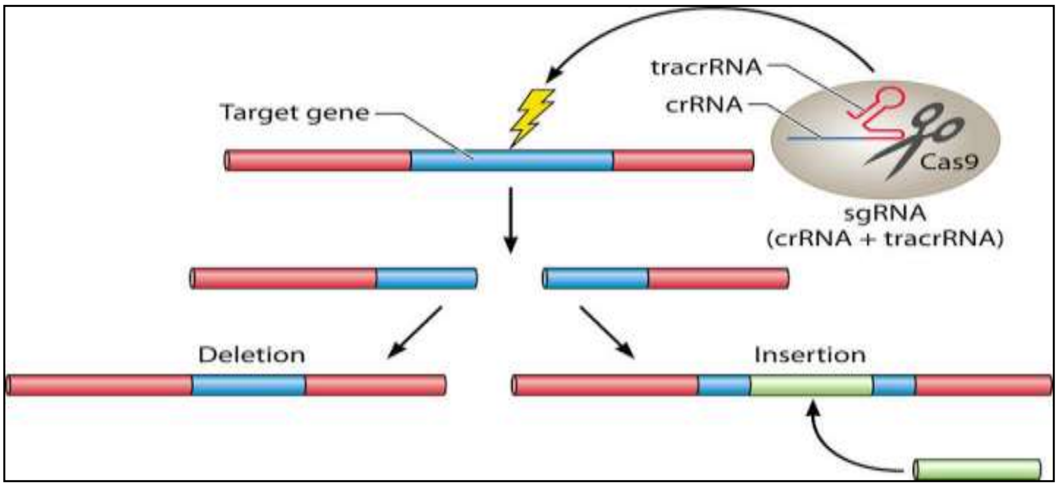

Figure 13.5: Genome editing using Cas9

13.5 Phenomics and Artificial Intelligence:

Phenomics is the study of the physical and biochemical characteristics of an organism, often at a large scale, with the goal of understanding how genes and the environment interact to produce a specific trait. In the context of plant breeding, phenomics can be a powerful tool for identifying and selecting desirable traits in crops.

Phenomics involves the use of high-throughput technologies, such as imaging, sensors, and molecular profiling, to collect large amounts of data on plant traits, such as growth rate, yield, and resistance to pests and diseases. This data can then be analyzed using advanced computational methods, such as machine learning, to identify patterns and correlations between traits and genetic markers.

By using phenomics in plant breeding, researchers can more efficiently and accurately identify and select desirable traits, which can lead to the development of new crop varieties that are more productive, resilient, and adaptable to changing environments[30]. This can be especially important in the face of challenges such as climate change, population growth, and food security.

Overall, phenomics is a powerful tool for advancing plant breeding and improving crop production, and it is likely to become an increasingly important area of research in the coming years. By integrating with phenomics and genomics and utilising big data, artificial intelligence (AI) technologies can accelerate the production of climate resilient varieties with better yield potential, stability, and tolerance to predicted concurrent environmental challenges (abiotic and biotic stresses).

A. Field Phonemics:

High resolution, a large capacity, field level phenotyping that can efficiently screen among higher performing breeding material across bigger populations is crucial for accelerated plant breeding for climate resilience[31]. Over the past ten years, phenomics has raised the collection of more phenotypic data through the creation of novel sensors (such as unmanned aerial vehicles, or UAVs), high resolution imaging, and new platforms for a wide range of features and situations[32,33]. Plant architectural features can be screened for using high throughput phenotyping (HTP), which also enables the early identification of attractive genotypes. It allows for precise, reproducible measurements of physiological parameters as well as agronomical traits (canopy structure, biomass and grain yield seedling vigour, flower counts, flowering duration, height and leaf erectness,) (photosynthesis, disease and stress tolerance). To detect, measure, and keep records of plant diseases, HTP techniques such as fluorescence imaging, RGB imaging, thermal and hyper spectral sensing and 3-D scanning have been effective[34].

B. Next Gen Based GS:

In the past ten years, genomic selection has been widely employed in breeding for climate resilience in agriculture, particularly for complex quantitative traits. It entails developing prediction models by evaluating the simultaneous effects of all current markers on a desired phenotype. By reducing breeding cycles, very accurate prediction can lead to increased levels of yields.

Next-generation sequencing (NGS), also known as high-throughput sequencing, is a method of DNA sequencing that allows the rapid and efficient analysis of large amounts of genetic information. It has revolutionized the field of genomics and has enabled researchers to study genomes at an unprecedented level of detail.

NGS technologies have greatly improved the speed, accuracy, and cost-effectiveness of genome sequencing. These technologies use various methods to generate millions of short DNA sequences in parallel, which are then assembled into a complete genome sequence.

Some examples of next-generation sequencing technologies include Illumina sequencing, Ion Torrent sequencing, PacBio sequencing, and Oxford Nanopore sequencing.

13.6 Speed Breeding: an Acceleration to Crop Improvement:

Speed breeding is a technique that uses controlled environments and optimized growth conditions to accelerate the breeding and development of crop plants. It is a relatively new method that has emerged as a response to the challenges of modern agriculture, including climate change, population growth, and food security.

One common approach to speed breeding is to use LED lighting and other controlled environmental conditions, such as increased carbon dioxide levels, to speed up the growth and development of plants. This technique allows multiple generations of plants to be grown in a single year, significantly accelerating the breeding process[35].

Speed breeding has the potential to revolutionize plant breeding and enable the development of new crop varieties faster and more efficiently. It may also allow for the development of crops that are better acclimatized to changing environmental conditions and more resilient to pests and diseases. Although, more research is needed to evaluate the effectiveness and long-term sustainability of this technique.

Breeders can now able to harvest up to six generations annually by adopting a variety of "speeding breeding" techniques that use longer photoperiods and controlled temperatures.

Speed breeding setup:

Light: PAR region (400-700), ambient lighting with LED.

Photoperiod: 22 hours with 2 hours of darkness.

Humidity: ideally 60-70%

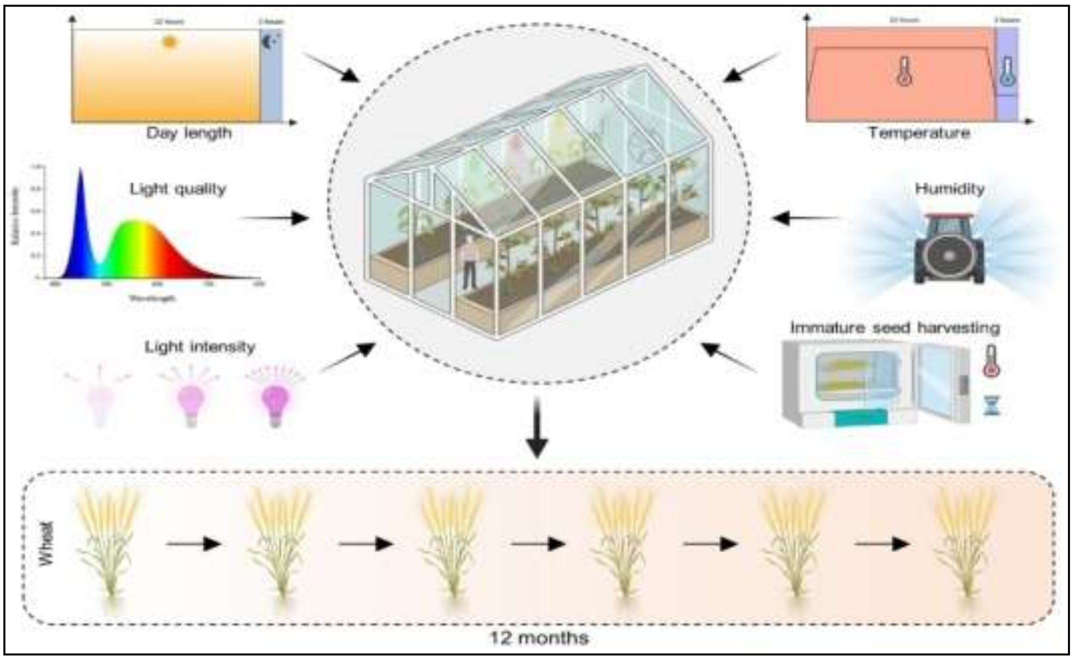

Figure 13.6: Speed breeding

13.7 Conclusion:

Crop plant breeding for greater production and tolerance is critical to ensuring global food security in the face of ongoing and expected climate change, which will result in increasing temperatures and much more unpredictability in the weather throughout a huge part of the world. The goal of climate resilient agriculture can only be achieved in the near future with improved plant varieties which effectively utilise fewer resources, can withstand diseases and pests, and demonstrate consistent yields in stressful situations. Research focus is essential for currently underutilized agricultural species if they are to contribute to climatic resilience. To address crop plants' sensitivity to climate change, smart breeding relies heavily on creating huge breeding populations, effective high throughput phenotyping, large management technologies, and downstream molecular approaches. Climate-smart breeding also requires the effective preservation and protection of plant genetic resources. Using cutting-edge methods like genome editing to introduce new alleles discovered in wild plants into domesticated crop types is one method for acquiring novel diversity. With further knowledge of their fundamental physiological and genetic principles, it will be possible to create crop cultivars that can withstand numerous pressures. The development and use of climate-smart cultivars in future could be facilitated by technological advancements in both phenotypic and genotypic analyses, and also in the biotechnological and digital revolutions.

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14. Conservation Agriculture in Drylands of World and India

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Abstract:

The empirical evidence at a global level demonstrates that the implementation of Conservation Agriculture (CA) principles, led by farmers, is increasingly gaining momentum and transforming agricultural production systems, representing a new paradigm for the 21st century. Information provided here is a comprehensive overview of the adoption and spread of CA by country and continent.

The global evidence indicates that the shift from tillage-based to CA-based production systems is now a worldwide phenomenon, gaining even more momentum in recent years as a sustainable intensification method and as an example of climate-smart agriculture. CA systems, which involve minimal mechanical soil disturbance, organic mulch soil cover, crop diversification, and good crop and production management practices, are currently practiced on approximately 157 million hectares worldwide, accounting for around 11% of field cropland in all continents and most land-based agricultural ecologies, including various temperate environments.

This represents a 47% increase globally since 2008/09 when the spread was recorded as 106 million hectares. No-tillage CA is practiced on all farm sizes, ranging from less than half a hectare to thousands of hectares, with all crops being able to grow adequately in CA systems. The authors have not yet identified a crop that would not grow and produce under this system, including root and tuber crops.

Keywords:

Conservation Agriculture, Tillage, Climate-Smart Agriculture, Crop Diversification, Sustainable.

14.1 Introduction:

Conservation Agriculture (CA) is a method of managing soil and water resources to ensure sustainable agricultural production systems that are environmentally, socially, and economically sound. It consists of three interconnected principles: minimizing mechanical soildisturbance throughout the entire crop rotation, maintaining permanent soil cover, and using diversified crop rotations or plant associations. Only when all three principles are strictly followed can CA be considered truly practiced. CA, when combined with other best practices,such as using quality seeds, integrated pest and nutrient management, and weed and water management, serves as the foundation for sustainable agricultural production. It also providesopportunities for integrating various enterprises such as crop and livestock, as well as trees andpastures, into agricultural landscapes.

Conservation Agriculture (CA) is a promising approach to sustainable and productive agriculture that involves a combination of reduced soil disturbance, cover crop management, crop rotation, and improved management practices. In dryland areas, such as arid and semi-arid regions, where water and nutrients are often limited, implementing CA practices can help improve soil health, crop yields, and mitigate environmental impacts. Drylands comprise 41% of the world's land surface, and they face numerous challenges to traditional agriculture production. In this context, CA practices can help address soil degradation, water erosion, and low productivity, improving farmers' livelihoods by increasing yields and reducing input costs. This chapter provides insights into the principles, benefits, and challenges of implementing CA practices in dryland areas, both globally and in India.

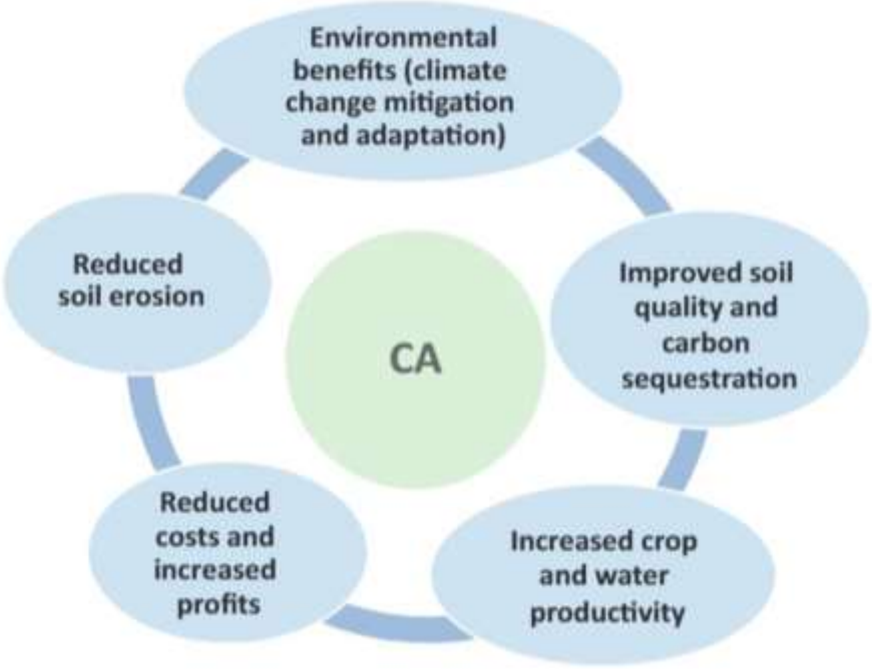

Figure 14.1: Multi-Dimensional Benefits of Adopting CA

10.2 Need for Conservation Agriculture in Drylands

Conservation Agriculture (CA) is a sustainable and productive approach to agriculture that involves the implementation of various practices, including minimal soil disturbance, soil cover, crop diversification, and good management practices. In dryland areas, where water and nutrients are scarce, implementing CA practices can help improve soil health and crop yields while mitigating the environmental impact of agriculture. Drylands cover 41% of the world's land surface and face numerous challenges related to traditional agriculture, including soil degradation, water erosion, and low productivity. CA practices can help address many of these challenges, improving the livelihoods of farmers by increasing crop yields and reducing input costs. Reduced soil disturbance, or no-till, is an essential aspect of CA that helps maintain soil structure and minimizes soil erosion. Cover crop management plays a crucial role in maintaining soil cover and protecting soil moisture

The importance of Conservation Agriculture (CA) in drylands lies in its ability to address the various challenges faced by farmers in these regions. Some of the critical benefits of CA in dryland areas include:

- **Improving soil health:** Drylands have low nutrient levels, poor soil structure, and low water-holding capacity, making it challenging to sustain agricultural productivity. CA practices such as cover crop management and crop diversification enhance soil health and organic matter, leading to improved soil fertility, water-holding capacity, and reduced erosion.
- **Enhancing crop yields:** By improving soil health and reducing soil erosion, CA practices can lead to better crop yields, even in areas with limited water and nutrient resources. In this way, CA can improve food security for farmers in dryland areas.
- **Mitigating environmental impacts:** Tillage-based agricultural practices have significant environmental impacts, such as contributing to climate change, reducing soil quality, and reducing biodiversity. CA practices lead to improved soil health, reduced erosion, and decreased greenhouse gas emissions, mitigating these impacts.
- **Reducing input costs:** CA practices such as crop rotation, use of organic fertilizers, and reduced tillage help to reduce input costs, such as fuel, fertilizer, and labor. This reduction in expenses has the potential to improve the economic well-being of farmers.

14.2 An Overview of Global Perspectives on Conservation Agriculture in Drylands:

Globally, Conservation Agriculture (CA) practices have been recognized as a promising approach to promote sustainable and productive farming in drylands. Many countries worldwide are adopting CA practices as a strategy to mitigate the challenges faced by farmers in dryland areas. These challenges include poor soil health, low crop yields, soil erosion, and water scarcity. CA practices are gaining popularity in arid and semi-arid regions, and they are recognized as a solution to increase productivity and reduce the impact of agriculture on the environment. According to a report by the Food and Agriculture Organization of the United Nations (FAO), CA is currently being practiced on approximately 157 million hectares worldwide, representing around 11% of field cropland.

In recent years, the adoption of CA practices has gained momentum globally due to several factors, including the need to reduce carbon emissions, mitigate climate change, and improve food security. Additionally, several multinational organizations and agencies have recognized the importance of adopting sustainable farming practices and have supported CA initiatives across the world. However, despite the increasing popularity of CA practices, there are still challenges to their widespread adoption. These challenges include high initial costs for equipment, limited access to extension services, lack of knowledge, and technological barriers. Overall, the global perspective on Conservation Agriculture in drylands is positive, and there is growing recognition of its potential to address the challenges faced by farmers in dryland areas. By improving soil health, increasing crop yields, reducing carbon emissions, and preventing soil erosion, CA practices have the potential to transform agricultural production systems, increase long-term sustainability and protect productive natural resources. The adoption of CA practices in drylands can also create socio-economic benefits for farmers, particularly in developing countries where farming is a primary source of livelihood. In this context, CA practices can lead to better market access, higher incomes, and improved living conditions. Moreover, the spread and innovation of CA practices are facilitated by cooperation among different stakeholders, including governments, research organizations, farmers, civil society organizations, and the private sector. The dissemination of innovative approaches to CA such as precision agriculture and digital farming, can enable farmers to adopt efficient and more sustainable farming practices.

In the 1970s, no-tillage technology was introduced to Brazil, where it was developed into the Conservation Agriculture (CA) system by farmers and scientists. However, it was not until the1990s that CA began to be widely adopted in southern Brazil, Argentina, and Paraguay. This growth in adoption caught the attention of development and research organizations such as FAO, World Bank, GIZ, CIRAD, and CGIAR, leading to study tours, workshops, and development and research projects being organized in various parts of the world. As a result, CA has gained increased awareness and adoption in African countries like Zambia, Zimbabwe,Mozambique, Tanzania, and Kenya, as well as in Asia, particularly in Kazakhstan and China. The success of CA in improving conservation and no-tillage practices within an integrated farming concept has led to increased adoption in industrialized countries such as Canada, USA,Australia, Spain, Italy, Finland, Ukraine, and Russia. Currently, CA crop production systems are of interest to most countries around the world, with only a few exceptions where CA is notpracticed by any farmers and there are no local research results available on CA (Jat et al., 2014).

Table 14.1: Area under conservation agriculture in different regions

Continent	Cropland under CA (MA ha)	Per cent of global CA area	Per cent of cropland
South America	66.4	42.3	60.0
North America	54.0	34.4	24.0
Australia & NZ	17.9	11.4	35.9
Asia	10.3	6.6	3.0
Russia & Ukraine	5.2	3.3	3.3

Continent	Cropland under CA (MA ha)	Per cent of global CA area	Per cent of cropland
Europe	2.0	1.3	2.8
Africa	1.2	0.8	0.9

14.3 An overview of Indian Perspectives on Conservation Agriculture in Drylands:

In India, the importance of Conservation Agriculture (CA) in drylands has gained significant attention as its adoption has grown. Dryland areas in India comprise about 70% of the country's total net-cropped area, and farmers in these areas struggle with low yields and poor soil fertility due to harsh environmental conditions like soil degradation, water scarcity, and high temperatures. The Indian Council of Agricultural Research (ICAR) has led efforts to promote CA practices through research, capacity building, and extension activities. The ICAR has developed several new technologies, including zero-tillage seed drills, promotion of organic farming practices, and use of new cropping systems, to enhance transferability of the technology from the researcher's lab to the farmer's field. The government of India has also launched various schemes and programs, such as the National Mission for Sustainable Agriculture (NMSA) and the Pradhan Mantri Fasal Bima Yojana, to encourage farmers to adopt CA practices. These programs provide financial support for farmers to purchase CA equipment and promote the uptake of sustainable agricultural practices. Due to these efforts, the adoption of CA practices in India has increased significantly in recent years. For instance, the area under zero-tillage farming increased from 2.3 million hectares to 3.4 million hectares between 2017 and 2020, representing a 45% growth. Despite these encouraging developments, there are still challenges to the adoption of CA practices in India. For example, farmers may face financial constraints when investing in CA equipment and may lack access to extension services. Moreover, some farmers may resist changes in traditional farming practices that they have been using for generations. Overall, the perspective on CA in drylands in India is generally positive, with efforts made by the government and the ICAR to promote the uptake of sustainable farming practices. However, continued support for research and development is needed to address challenges, promote awareness, and build capacity among farmers to effectively utilize CA practices in dryland areas. Such support is essential to encourage widespread adoption of CA and promote sustainable and productive agriculture systems to meet the food needs of a growing population while also mitigating adverse environmental impacts.

In Punjab, the practice of burning crop residue has led to environmental pollution and loss of nutrients. The adoption of CA practices in the region has been facilitated by the introduction of direct seeding of wheat in the 1980s and later the CA program by CYMMYT in the 1990s. The rice-wheat consortium (RWC) was established by CGIAR in 1994to focus on the rice-wheat farming systems widely practiced in the Indo-Gangetic plains and Himalayan mid-hills region. Today, CA-based technologies are being practiced on nearly 1.5 million hectares of irrigated land in India, particularly in the Indo-Gangetic plains. This is a significant achievement and shows the potential for the wider adoption of CA practices in theregion. This history of research on CA technologies was from irrigated cropping systems particularly in rice–wheat system.

The research on typical CA involving tillage levels, crop– residue retention on soil surface and N management under rainfed conditions with sorghum–castor (Ricinus communis L.) rotation was initiated in 1995 at the ICAR–CRIDA farm.Subsequently several experiments on typical CA with anchored crop–residues involving zero till planters under major rainfed crop rotations were started from 2005 onwards at CRIDA, Hyderabad. Under Consortium Research Platform on CA(CRP–CA), CA experiments were extended to selected centres of All India Coordinated Research Project on Dry-land Agriculture (AICRPDA) and farmers' fields in 2012–13. The research work done in India on CA in rainfed and dryland ecosystems is reviewed critically here, to identify suitable CA practices, prospects and potential benefits of CA, and issues and opportunities for adoption ofCA practices in rainfed areas over large scale. In 7–8–year–old experiment with maize (Zea mays L.)– pigeonpea [Cajanus cajan (L.) Millsp.] and maize–horse gram [*Marcrotyloma uniflorum* (Lam.)Verdc.] sequences on Alfisol showed that, the ZT resulted in about 28%, 16– 26% and 40% higher pigeonpea[Cajanus cajan (L.) Millsp.], maize and horse gram yields respectively, over the CT. At Benguluru, zero tillage and reduced tillage gave 29 and 4.6% lowerfinger millet yields, respectively, as compared to CT on Alfisols soil during the third year of experimentation. Vertisols at Akola, Maharashtra, ZT resulted in 9% and14% lower yields of soybean and chickpea (*Cicer arietinum* L.), respectively, compared with CT.

14.4 Conservation Agricultural Practices in World & India:

Conservation Agriculture (CA) practices are gaining popularity as a sustainable and productive approach to agriculture globally and in India. In the world, CA practices are being adopted on about 157 million hectares of land, accounting for around 11% of field croplands. These practices promote minimal soil disturbance, plant residue retention, and crop rotation schemes. The United States of America (USA), Brazil, Argentina, Canada, and Australia are some of the countries that have adopted CA practices, primarily in the context of large-scale agriculture. In India, studies report that several states in India including Punjab, Haryana, Gujarat, and Rajasthan have adopted CA practices. Punjab and Haryana have increased the area under zero-tillage farming to reduce tillage-based agriculture and maintain soil health. In Gujarat, the government has promoted the Ragi-Indian bean cropping system to build soil fertility. The state of Rajasthan has focused on rainwater harvesting and the development of soil-conservation structures. To support the widespread adoption of CA practices in India, the government and research organizations have launched several programs and initiatives. For instance, the National Mission for Sustainable Agriculture (NMSA) and the Rashtriya Krishi Vikas Yojana (RKVY) are two examples of flagship programs that aim at promoting sustainable agriculture practices in India. The Indian Council of Agricultural Research (ICAR) has been supporting CA practices through research, extension, and capacity building activities, such as developing new crop varieties and agronomic practices, improving cropping models, and promoting innovative technologies.

14.5 Conclusion

In conclusion, conservation agriculture is a sustainable and effective approach for farming in drylands, both in India and across the world. By adopting practices such as minimum tillage, crop rotations, and cover cropping, farmers can conserve soil moisture, reduce erosion, and improve soil health. This, in turn, leads to higher yields and more resilient crops, which are especially important in regions with limited water resources and unpredictable weather patterns. In India, where dryland farming accounts for a significant portion of agricultural production, conservation agriculture has been increasingly adopted by farmers in recent years. The Indian government has also promoted this approach through various schemes and programs aimed at improving soil health and water conservation. Despite the many benefits of conservation agriculture, its widespread adoption still faces several challenges, including lack of awareness and knowledge among farmers, lack of access to inputs such as seeds and fertilizers, and limited infrastructure for marketing and distribution of produce. Addressing these challenges will require concerted efforts from governments, civil society, and the private sector.

Overall, conservation agriculture holds great promise for improving the sustainability and resilience of agriculture in drylands, and its continued promotion and adoption should be a priority for policymakers, farmers, and other stakeholders in India and around the world.

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15. Conservation Agriculture in World, History, Status, Implications and Sustainability Issues

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Abstract:

With other complementary good agricultural practises of integrated crop and production management, conservation agriculture (CA) is the practical application of three interconnected principles, namely: no or minimal mechanical soil disturbance, biomass mulch soil cover, and crop species diversification. The practical evidence from throughout the world demonstrates that farmer-led transformation of agricultural production systems based on CA principles is already taking place and gaining momentum as a new paradigm for the 21st century. For intensive crop production, tillage-based soil management typically causes soil degradation and ultimately crop productivity loss.

Additionally, intense cropping forces farmers to pay high prices for labour, fuel, agrochemicals, and other production inputs. Farmers are getting better organised in their cooperative efforts and networking, which has led to the development of CA across Asia, Africa, and Europe in recent years. Stakeholders are giving CA adoption support for farmers and the creation of new knowledge to enhance their performance more time and money. The physical environment changes have an impact on many different groups of organisms, and while various species have a wide variety of reactions, most organism groups are more abundant under conservation agriculture than in tillage-based systems. For farmers to meet their economic needs, consumer concerns, and environmental concerns while also minimising their negative effects, sustainable agricultural systems will be more important than ever.

Keywords:

Conservation Agriculture, Sustainable, Tillage, Intensive Crop Production, Crop Diversification, Soil Management.

15.1 Introduction:

The soil resource base has been significantly deteriorated by conventional farming methods, particularly tillage and crop residue burning (**Montgomery 2007; Farooq et al. 2011**), which has resulted in a decrease in crop production capacity (World Resources Institute 2000).

Conservation agriculture (CA) is a farming strategy that puts an emphasis on the preservation and sustainable use of natural resources while both boosting output and enhancing incomes. By minimising soil disturbancethrough the use of minimal tillage, maintaining a layer of crop residue or cover crop on the soil's surface, and rotating crops, this practice can improve the health of the soil (**Kassam et al., 2013; Jat et al., 2014; Siddique and Farooq, 2014**) since CA provides a means of battling climate change, enhancing food security, and lowering poverty, it has been gaining popularity around the world, especially in developing nations. CA is an important agronomic practice which is concerned about agriculture sustainability and has progressively augmented globally to cover ~11 % of the globe’s cultivable land (157.8 Mha) (**FAO 2016**).

CA is based on an all-encompassing method of farming that aims to maximise the utilisation of natural resources while reducing adverse effects on the environment. This strategy recognises that earth's natural resources, such as soil, water, and biodiversity, are limited and that their deterioration could have an adverse long-term impact on people's livelihoods and general well-being. In order to conserve natural resources without sacrificing the ability of future generations to meet their needs, CA promotes agricultural practices. The growing acceptance of CA on a worldwide scale reflects the understanding of the significance of sustainable agriculture in ensuring food security and eradicating poverty.Currently CA is practiced by farmers in almost 80 countries on over 200 million hectares that makes about 15 percent of annual cropland globally. Most of the farmers benefitting from CA are smallholders; 50 percent of areas adopting CA practices are in developing countries, according to the Food and Agriculture Organisation (FAO) of the United Nations, with great room for growth (**FAO, 2021**).

This chapter examines the tenets, advantages, and difficulties of CA and emphasises its significance as a sustainable agriculture strategy for tackling the complex problems the globe faces today.

History and status of Conservation Agriculture in world:

A mechanical manipulation of soil is referred to as "tillage". When people began engaging in more sedentary and traditional agriculture, particularly in the Euphrates, Nile, Tigris, Yangtze, and Indus valleys, they also began tillage millions of years ago (**Hillel, 1991**).

The Dust Bowl catastrophe of the 1930s in the United States, brought on by unsustainable agricultural practices, is where CA first emerged (**Friedrich *et al.*, 2012**). The "Dust Bowl" was a serious environmental catastrophe brought on by widespread soil disturbance and plow-over that resulted in soil erosion, desertification, and decreased agricultural production. As scientists and farmers began to experiment with reduced tillage and crop rotations to conserve soil and water resources, it became clear that sustainable agriculture practices were necessary.With time, the idea of preserving soil by minimising tillage and keeping the soil covered became more and more well-liked. The method of soil preservation that followed had been referred to as conservation tillage (**Friedrich *et al*., 2012**).

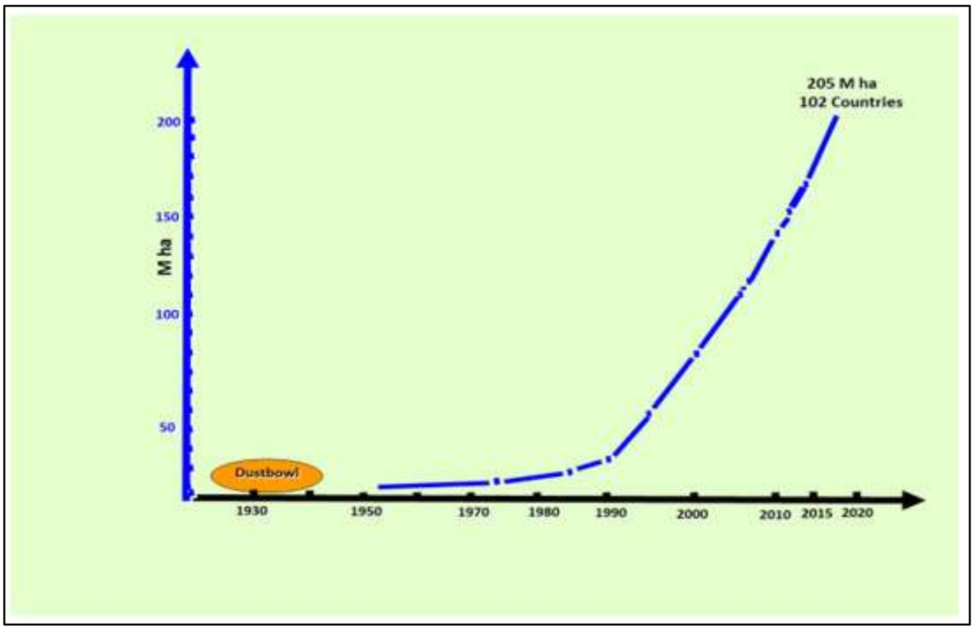

Figure 15.1: Historical chart of CA uptake at the global level (Kassam et al., 2021)

In the 1940s, the development of seeding machinery made sowing possible without soil tillage (**Friedrich *et al*. 2012**). Global agriculture was altered by the Green Revolution in the 1950s and 1960s with the introduction of high-yielding crop types, chemical fertilisers, and pesticides. Even though the Green Revolution significantly increased agricultural productivity, it also had detrimental effects on the environment, such as soil erosion, water pollution, and the loss of biodiversity.In addition, rising fuel prices in the 1970s encouraged farmers to switch to resource-saving farming systems (**Haggblade and Tembo, 2003**). In this situation, commercial farmers adapted CA to combat drought-induced soil erosion along with the fuel savings (**Haggblade and Tembo, 2003**). As the need for sustainable agricultural methods grew, researchers began looking into the potential of CA.

A programme called "Soil Conservation for Small Farmers in the Humid Tropics" was started by the FAO (Food and Agriculture Organisation) in the 1970s to encourage soil conservation methods in underdeveloped nations. Crop rotation, mulching, and intercropping were emphasised as crucial techniques to increase soil fertility and stop erosion. Additionally, the FAO acknowledged that CA had the potential to improve soil health, raise agricultural productivity, and lessen environmental degradation. The World Conservation Agriculture Network (WCAN) was founded in the 1980s to advance CA internationally. The network aims to promote policy reforms to assist sustainable agriculture and exchange information and knowledge on CA practices. The WCAN emphasised crop rotation, cover crops, and low tillage as essential CA practices.

As CA gained popularity as a sustainable agriculture technique in the 1990s, numerous nations began putting CA programmes into place. For instance, Brazil launched the "Zero Tillage" programme in the middle of the 1990s with the goal of lowering soil erosion, increasing soil moisture, and encouraging crop diversity. Brazil is currently one of the top countries for the adoption of CA practices considering the program's success.

With the promotion of CA's advantages by numerous organisations and institutions, it has become even more recognised in the twenty-first century. In order to promote CA internationally, the FAO founded the Global Conservation Agriculture Network (GCAN) in 2001.

Additionally, the UN proclaimed 2015 as the International Year of Soils, highlighting the significance of sustainable agricultural practices. Today, CA is used in many nations around the world and has proven successful in enhancing biodiversity, boosting crop yields, and reducing environmental degradation.

Conservation agriculture (CA) has a long history that extends back to the early 20th century, and it has developed into a recognised sustainable agriculture practice over time. Due to the detrimental effects of unsustainable agricultural practices, sustainable agricultural practices became apparent, and CA evolved as a method to enhance soil health, boost agricultural productivity, and protect the environment. Today, CA is used all over the world and has established itself as a crucial tool for achieving sustainable agriculture and guaranteeing food security.

Table 15.1: Global spread of CA cropland area ('000 ha) in different regions for 2008/2009, 2014/2015, and 2018/2019, and corresponding percent change

Region	**CA cropland Area 2008/2009**	**CA cropland Area 2013/2014**	**CA cropland Area 2015/2016**	**CA cropland Area 2018/2019**	**Percentage change in CA area since 2015/2016**	**Percentage change in CA area since 2013/2014**	**Percentage change in CA area since 2008/2009**	**Percent CA cropland area in the region 2018/2019**
S and C America	49564.10	66377.00	69895.00	82996.18	18.7	25.0	67.5	68.7
North America	40003.80	53967.00	63181.00	65937.22	4.4	22.2	64.8	33.6
Australia and New Zealand	12162.00	17857.00	22665.00	23293.00	2.8	30.4	91.5	74.0
Russia and Ukraine	100.00	5200.00	5700.00	6900.00	21.1	32.7	6800.0	4.5
Europe	1560.10	2075.97	3558.20	5601.53	57.4	169.8	259.0	5.2
Asia	2630.00	10288.65	13930.20	17529.02	25.8	70.4	566.5	3.6
Africa	485.23	993.44	1509.24	3143.09	108.3	216.4	547.8	1.1
Total	106505.23	156759.06	180438.64	205.400.04	13.8	31.0	92.9	14.7

(Source: Kassam et al., 2021)

Implications and Sustainability issues of Conservation Agriculture in world:

Even in affluent countries with competent agricultural extension agencies and educated farmers, the adoption of CA has not been quick. This is probably because farmers are constantly drawn to quick fixes and tangible rewards, whereas the full technical and financial benefits of CA can only be realised in the medium- to long-term, once its guiding principles (no-tillage, permanent cover crops, and crop rotation) are well-established within the farming system. Today, CA is used on millions of hectares all over the world (**FAO 2011**), in countries like the USA, Argentina, Bolivia, Brazil, Chile, China, Colombia, Falkland Islands, Finland, Kazakhstan, Kenya, Malvinas, Morocco, Uganda, Western Australia, and Zambia, on soils that range from 90% sand (like those in Australia) to 80% clay (like those in Brazil's Oxisols and Alfisols).

According to **Derpsch and Friedrich (2009)**, any crop, including tuber and root crops, may be grown well under CA. The spread of CA has been incredibly quick in recent years. The current pattern of use of home resources by the farmer may no longer be beneficial due to shifting policies, falling financial incentives, or declining natural resource quality. The degree to which farmers believe that their natural resource base is gradually deteriorating is a matter of debate. There is currently enough information to say that smallholders are frequently aware of soil degradation, even when other production-affecting factors occasionally obscure this. This method of conservation agriculture has several implications for the world, including:

a. Sustainable food production: Conservation agriculture encourages actions that maintain soil fertility and health throughout time, which can contribute to a sustainable rise in food output. By doing this, farmers may be able to grow food in the same location year after year without causing environmental damage or soil degradation.
b. Mitigation of climate change: By lowering greenhouse gas emissions from agriculture, conservation agriculture can assist to prevent global warming. Farmers can limit the quantity of carbon dioxide released from the soil into the atmosphere by minimising tillage. A further benefit of conservation agriculture is that it can increase the amount of carbon that is stored in the soil, which can assist to balance emissions from other sources.
c. Biodiversity conservation: Natural habitats and ecosystems can be preserved or improved through conservation agriculture, which can then encourage biodiversity. In order to do this, techniques including crop rotation, intercropping, and the use of cover crops may be used. These techniques can create habitat for beneficial insects and other wildlife.
d. Economic benefit: Farmers may profit financially from conservation agriculture since it can lessen their reliance on costly inputs like pesticides and synthetic fertilisers. Additionally, by preserving soil health over an extended period of time, conservation agriculture can assist to guarantee that farmers can continue to grow crops on the same land for many years to come.
e. Food security: By encouraging sustainable food production and lowering the susceptibility of agricultural systems to climate change and other environmental challenges, conservation agriculture can support food security. Farmers can produce more food with less inputs by preserving the fertility and health of the soil, which can help guarantee that food is accessible and cheap for everyone.

15.2 Sustainability Issues:

According to CA's definition, regenerative sustainable agriculture and land management are approached from an ecosystem perspective, based on the effective implementation of three interconnected, regionally adapted, context-specific principles. They are frequently referred to as the three "pillars" of CA because they serve as the systemic support for CA's ecological sustainability, which is necessary for both economic and social sustainability. The integration of the three interconnected principles into practises has been shown to have a strong ecological science foundation, providing a base upon or into which complementary practises can be integrated, further strengthening the biophysical and biochemical processes of the system that nourish and protect plants and facilitating the functioning of the ecosystem. CA has demonstrated the enhanced potential of agricultural land usage for farmers, their families, communities, the larger community, and the planet. Natural resources including soil, water, and biodiversity are not destroyed in CA systems, in contrast to tillage-based farming systems, but rather become better over time. CA enhances the financial viability of farm households by lowering production costs while stabilising, maintaining, or even raising yield levels. By utilising diverse production methods, CA encourages the local production of a variety of foods, provides small family farmers and rural entrepreneurs with commercial options, and improves the social structure of rural communities while halting the trend towards urbanisation. CA is tackling sustainability in its three main spheres- environmental, economic, and social. Conservation agriculture's sustainability is influenced by a number of variables, such as the particular techniques employed, the regional environment and climate, and the socioeconomic setting in which it is carried out. To maintain the long-term viability of conservation agriculture, a few important elements might be considered:

a. Soil health: To ensure the long-term viability of conservation agriculture, soil health must be preserved and improved. This entails techniques like reducing tillage, utilising cover crops, and rotating crops, which can assist to increase soil organic matter, boost soil biodiversity, and improve soil structure.
b. Biodiversity conservation: Maintaining ecosystem services such as pollination, pest control, and soil fertility is vital for the sustainability of conservation agriculture. Practises including crop rotation, intercropping, and the usage of agroforestry systems can help achieve this.
c. Climate resilience: Resilience to the effects of climate change, such as drought, flooding, and extreme weather events, should be a goal of conservation agriculture. This can be accomplished by using techniques like water harvesting, drought-tolerant plant selection, and adoption of climate-smart agriculture methods.
d. Socio-economic viability: In order to ensure conservation agriculture's long-term sustainability, it must be profitable for farmers and communities. This calls for the adoption of local context-appropriate practises as well as the creation of institutions and laws that facilitate farmers' access to the tools they require to engage in conservation agriculture.
e. Knowledge sharing and capacity building: Sharing of knowledge and the development of capacity among farmers, communities, and other stakeholders are essential for the sustainability of conservation agriculture. This can entail the creation of training programmes, the sharing of knowledge and experiences among farmers, and the backing of conservation agriculture by regional organisations and institutions.

In general, it is accurate to say that established CA systems consume significantly less seed, water, fertilisers, pesticides, energy, and time than tillage systems, and with higher output, they provide jobs along the value chain. In order to reduce the consumption of agrochemicals, fuel, and farm power while increasing productivity and ecosystem services using CA, sustainable mechanisation activities and extension support are required. In response to the demand for food security, climate change adaptation, and carbon sequestration, CA is becoming more and more recognised as a sustainable production base. Because it generally makes good commercial sense, the private sector firms seem to be supporting agricultural change towards CA more and more.

15.3 Conclusion:

Food insecurity, climate change, biodiversity loss, environmental degradation, unsustainable diets, and human illness all contribute to the global burden of chronic crises. All of these situations can be addressed with CA systems. A major shift in the way we think about production systems is demanded by CA, which stands for the key elements of a new alternative paradigm for the twenty-first century. It requires a lot of expertise and management and goes against conventional wisdom. For environmentally friendly, sustainable crop production, CA is an intricate combination of technologies that includes adaptive soil manipulation, crop residue retention as soil cover, planned and diversified crop sequences, and efficient weed management. In terms of crop output, income, sustainable land use, ease of farming, and the timeliness of ecological services and crop practises, CA has shown to be helpful. Worldwide, the use of CA systems is growing, although in some nations, adoption is either minimal or nonexistent. Technologies for conservation agriculture are what will make agriculture sustainable in the future. Conservation agriculture has potential advantages for various agro-ecoregions and farmer groups. From the nano level (improving soil qualities) to the micro level (saving inputs, lowering cost of production, boosting farm revenue), to the macro level (reducing poverty, enhancing food security, and reducing global warming), there are many advantages of CA. In general, CA as a substitute paradigm for sustainable production intensification offers a lot of advantages to the producers, society, and environment that are not attainable with tillage agriculture (**Kassam *et al.,* 2010**). Therefore, Ca is smart in many other areas in 21addition to the environment.

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