Strategies to Practice Climate-Smart Agriculture to Improve the Livelihoods Under the Rice-Wheat Cropping System in South Asia

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Abstract

The rice-wheat cropping sequence (RWCS) is the world's largest agricultural production system occupying around 12.3 M ha in India, 0.5 M ha in Nepal, 2.2 M ha in Pakistan, and 0.8 M ha in Bangladesh; and around 85% of this area falls in the Indo-Gangetic Plain (IGP). It is energy, labor, and capital intensive, favors global warming, and ultimately has a detrimental effect on the natural resources and soil biodiversity. Furthermore, the rice-wheat cropping sequence has a number of sustainability issues, viz., declining land and water productivity, poor soil health, and arising micronutrient deficiency which is an alarming issue. Integrated approaches must be developed for improving the declining livelihoods in the region. The changing climate and its consequences are complicating the situation of the available natural resources, viz., water, soil, atmosphere, etc. Carbon (C) and water footprints need to be identified in the currently practiced rice-wheat cropping sequence for filling the gaps to improve livelihoods by one or other means. Resource conservation technologies (RCTs) partition greater fraction of water from unproductive evaporation to the desired transpiration which is further reflected on the higher grain yields. Transpiration causes a greater inflow of water and nutrients which ultimately increases the grain yield with lesser consumption of irrigation water, which further increases water productivity. There is a need to focus on the issue to sustain the rice-wheat productivity in South Asia. This book chapter is focused on all the strategies to practice climate-smart agriculture for improving livelihoods in South Asia, which include irrigation based on scheduling, precision laser leveling, direct seeded rice (DSR), mechanical transplanting, crop diversification, short-duration crop varieties, and delaying transplanting time, and reevaluate their effect on water and land productivity under divergent soil textural classes under different climatic conditions in South Asia. There is a need to come out with an integrated package for the farmers depending upon their conditions. Delineation of the residual consequence of used RCT on available moisture during the intervening periods is there, as it affects the performance of intervening crops and certainly adds to the livelihood of the farmer. The aim of this chapter is to review different technologies and their impact on land and water productivity and thereby try to come up with some integrated approach for improving livelihoods of farmers of the region. Therefore, scientists must be very careful while advocating any single RCT or a set of RCTs to the farmers with a must consideration of their social, financial, and geological conditions for enhancing both land and water productivity in South Asia.

Keywords

Climate-smart agriculture · Rice-wheat cropping sequence · South Asia · Water productivity

Abbreviations

AWD	Alternate wetting and drying
CA	Conservation agriculture
CE	Carbon equivalent
CF	Carbon footprint
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CSA	Climate-smart agriculture
DSR (ZT)	Direct seeded rice under zero tillage conditions
DSR (CT)	Direct seeded rice under conventional tillage conditions
ET	Evapotranspiration
FIRBs	Furrow-irrigated raised beds
GEU	Gypsum-enriched urea
Gt	Gigatons
IGP	Indo-Gangetic Plain
INPM	Integrated nutrient and pest management
LCC	Leaf color chart
MDG	Millennium development goal
MT (P)	Mechanical transplanting under puddled conditions
MT (ZT)	Mechanical transplanting under zero tillage conditions
MTR	Mechanical transplanting of rice
N_2O	Nitrous oxide
NOCU	Neem oil-coated urea
NUE	Nitrogen use efficiency
PAU	Punjab Agricultural University
PGEU	Phosphogypsum-enriched urea
PM	Particulate matter
ppm	Parts per million
PTR	Puddled transplanted rice
RCTs	Resource conservation technologies
RWCS	Rice-wheat cropping sequence
SEU	Sulfur-enriched urea
SOC	Soil organic carbon

SOM	Soil organic matter
SPAD	Soil plant analysis development
SRI	System of rice intensification
SSNM	Soil-specific nutrient management
SSRM	Site-specific residue management
STCR	Soil test crop response
Tg	Teragram
WP_I	Irrigation water productivity
ZEU	Zinc-enriched urea
ZT	Zero tillage

2.1 Introduction

The rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping sequence (RWCS) is the world's largest agricultural production system occupying around 12.3 M ha in India, 0.5 M ha in Nepal, 2.2 M ha in Pakistan, and 0.8 M ha in Bangladesh; and around 85% of this area falls in the Indo-Gangetic Plain (IGP) (Bhatt et al. 2016). South Asian agriculture has undergone significant growth during the last five decades because of scientific and technological advancements in agriculture called "Green Revolution" owing to policy interventions and scientific workforce (Bhatt et al. 2016). The Green Revolution we inherit in the twenty-first century in South Asia represents some of the greatest achievements of human civilization. Crop improvement and production technology advancements have greatly increased the agricultural production; but the outcome of Green Revolution is poor on many counts like natural resource management (NRM), climate resilience, and nutritional quality (Olk et al. 1996). Conventional agriculture has resulted in a decline in factor productivity, natural resource base, soil health, and water availability, groundwater depletion, and increased susceptibility to diseases and pests as well (Aggarwal et al. 2004; Bhatt et al. 2016; Meena and Meena 2017). Hence, the current production scenario represents some of the greatest threats to agricultural sustainability. Today, prevailing global food systems contribute around one-third to the global warming by producing different greenhouse gases (GHGs), viz., methane (CH4), nitrous oxide (N2O), and carbon dioxide (CO2). Seventy percent of all water withdrawn from aquifers, streams, and other groundwater resources is used for agriculture often at unsustainable rates. Furthermore, conventional agricultural systems have contributed significantly to land degradation, soil health decline, as well as the destruction of natural habitats and biodiversity at large (Paul et al. 2014; Dass et al. 2016a, 2017b). Therefore, indeed the foundation on which current production systems stand is becoming fragile in a holistic manner. In a nutshell, current agronomical production technologies are not in place to sustain food security and natural resource management. On another hand, the millennium development goal (MDG) of quality grains for each must be generated through climate-smart and sustainable agriculture so as to improve global health, more particularly of developing nations.

In South Asia, the conventional cereal-based production systems (rice-wheat and rice-rice) are facing yield stability turndown causing a severe challenge for agricultural and environmental sustainability (Prasad 2005). The conventional rice production technologies are capital, labor, water, and energy intensive, which further reduces their adaptability because of lesser grain yields (Kaur et al. 2015; Pooniya et al. 2018; Ashoka et al. 2017). As per one estimate, rice, wheat, and maize (*Zea mays*) land productivity needs to be increased by about 1.1, 1.7, and 2.9% per annum, respectively, for providing ensured nutrition to the growing population of South Asia (Pfister et al. 2017; Sofi et al. 2018).

Short-duration crop cultivars, delaying transplantation time, and crop diversification are the key components, which play a significant role in improving/declining both land and water productivity in the rice-wheat system (Pooniya et al. 2017). Presently, there is a need to switch over to holistic integrated methodological approaches involving innovative agronomic management principles with climate-smart agriculture (CSA) (Dass et al. 2016b). The key drivers for the innovative agronomic interventions are declining factor productivity, groundwater depletion, deteriorated quality, and the ever-increasing cost of irrigation. However, degraded soil health, climate change effect on crop productivity, rising cost and declining availability of agricultural labor, rapidly expanding agribusiness sector associated with mechanization and value addition, and policy fatigue are also some other contributing factors. Some of the innovative agronomic practices such as conservation agriculture (CA) with judicious crop rotations and site-specific residue management (SSRM) are leading the path of transition toward sustainable food production systems (Paul et al. 2014; Dass et al. 2016b; Choudhary and Suri 2018; Meena et al. 2015d).

Different resource conservation technologies (RCTs) were being adopted at around 5.6 million ha area in South Asia (National Agricultural Research and Extension Systems (NARES) (GOI 2016). Likewise, CA is being promoted to improve nutrient and water use efficiency (WUE). In India, the overall savings is USD 164 million with an investment of only USD 3.5 million on zero-tillage (ZT) technology with an internal rate of return of 66%. In addition to the savings on production inputs, CA-based management practices have other potential benefits such as natural resource conservation, reduced emission of GHGs, and better resilience to climatic extremes. However, moving from conventional to CA-based technologies involves a paradigm shift not only in key elements but also in approaches to develop component technologies of cultivar choice, nutrient, water, weed, and pest management while optimizing cropping systems (Bhatt et al. 2016; Mitran et al. 2018). Different agroecological methodologies, viz., system of rice intensification (SRI), are being promoted to manage plants, soil, water, and nutrients to improve the overall production potential in the region (Choudhary and Suri 2018). The SRI comprises three essential principles: planting young seedlings, planting single seedlings, and applying "minimal irrigation water" that keeps the soil just at and below saturation (Dass et al. 2016b). All the recommendations for drainage and irrigation need to be revised as per different soil textural classes, and different integrated approaches comprise one or more than one technology needed to be adjusted for having better livelihoods for the farmers. In SRI, increase in yield is possible because of young seedlings transplanted in rows; but still, farmers are not accepting it because of labor-intensive transplanting operation, precise water and input management, and higher labor cost. Like SRI technology, the time demands a thorough understanding and integration of different technologies as a package for various production systems. The current farmer dilemma and multifaceted technology delivery system highlight the need for characterization area and a cropping system suitable for "integrated package of production technologies" and subsequently technology targeting. It also demands wider emphasis and integration between leaders in different institutions advocating stand-alone production technologies.

From the last half century, crop production meets the landmarks because of breeding new better crop cultivars, new pesticides/insecticides, better fertilization and irrigation facilities, etc. Feeding the ever-increasing population with ever-decreasing/diminishing resources, viz., land and water, is the main challenge in front of the agricultural scientists under the present scenario of climate change. In the developing countries like India, still agriculture is the main occupation of the rural people. Since the 1960s, world per capita agricultural production has increased by 25% with varying trends as in Asia it increases while in Africa it decreases because of many countable and uncountable factors, at a cost of environmental degradation, declined underground water table, deteriorated soil structure, etc. as crop production and sustainability entirely depend on land, water, forests, pastures, nutrients, etc. A different technique of climate-smart agriculture must be adopted in a holistic manner so as to practice sustainable agriculture by producing for the present generation but reserving the natural resources for the generations to come.

2.2 Sustainable Agriculture and Its Principles

Sustainable agriculture describes different principles which meet the need of food for the present population by using the available natural resources of land and water but also considering the future generations. The major goals of this approach are to develop economically viable agroecosystems to enhance the quality of the environment so as to keep the arable lands productive indefinitely. Thus, sustainable agriculture involves farming systems that are environmentally sound, profitable, productive, and compatible with socioeconomic conditions. Improved nutrient cycling, improved soil quality, reduced degradation of land, and integrated nutrient and pest management (INPM) techniques along with good marketing to ensure better profits are the main pillars of sustainable agriculture. Improving the soil organic matter (SOM) is the only key factor which further improves the soil physical, chemical, and biological properties in one or other ways. Improved nutrient cycles and adopted INPM techniques at the farms improve the livelihoods of the poor farmers by minimizing their input cost and at the same time getting a better price for their produce because of better quality. There are five basic goals of sustainable agriculture, viz., food security, environmental security, economic viability, social acceptability, and food safety and quality which need to be fulfilled by adopting one or a set of resource conservation technologies.

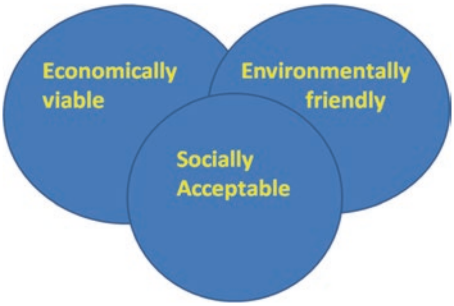

Fig. 2.1 Dimensions of sustainable agriculture

Sustainable agriculture covers different approaches which achieve an environmentally sound, economically profitable, ethically acceptable, and socially responsible form of land husbandry. Sustainable agriculture means more efficient use of arable land and water with improved agricultural practices and technologies to increase crop yield on a long-term basis without detrimental effect on the environment. Agricultural sustainability has three dimensions: ecological, economic, and social (Fig. 2.1).

Sustainable agriculture aims at judicious use of available natural resources in such a way to minimize adverse impacts on environments while providing sustained production. It is a form of agriculture system which aims to satisfy the needs of the present generation without endangering the resource base for upcoming generations. The three dimensions of sustainable agriculture are ecological, economic, and social criteria. Under ecological criteria, consideration is given to natural resources; under economic criteria, livelihoods are mainly dealt with; and social criteria entirely depend on respecting the farmers' indigenous knowledge, beliefs, and value systems in such a way to convince them for the adoption of the improved practices over theirs.

2.3 Strategies to Improve Land and Water Productivity in South Asia

The South Asia population shares 22% of the world population which entirely depends on the 3.31% of the world's land mass (SAARC country profiles 2014) for meeting their requirement of land and water. Natural and agricultural areas shifted to residential and urban areas under the impact of increasing population. Indiscriminate use of natural resources led to a situation where food production reached a stagnant stage and, even at every struggle, production not increased which further put pressure on the agricultural scientists to work out new farmer-friendly climate-smart technologies which work (Shukla et al. 2008; Lobell et al. 2008). Change in the land use trends affected all the natural nutrient and water cycles by one or other ways which need to be corrected at the earliest (Turner and Annamalai 2012; Madsen 2013; Yadav et al. 2018b). For bringing positive significant change in the present land and water use systems, a scientist has to be aware by demonstrating the new agricultural technologies in front of the farmers at the farmers' fields instead of publishing them in reputed journals for having promotions. Furthermore, there is a need to delineate the change in the land cover over the last decade for framing some new improved policies for making a change which if not acceptable by the farmers then must be imposed on them by some legal structure. For example, in Punjab, transplanting paddy after June 20 is mandatory for all the farmers from the year 2018 onward; otherwise, his nursery will be slowed down in the field. Furthermore, farmers' leaders, local politicians, and, most importantly, regional scientists who are most able to identify the research gaps and priorities in the region must be involved in the different projects. Intensive agriculture, puddling operations, lower use of fertilizers, non-adoption of INPM, etc. have resulted in the higher rate of soil nutrient depletion in South Asia, while the use of mulching; leguminous crops for biological nitrogen fixation, viz., pulses; farmyard manure; and other organic inputs is limited to a significant extent, and the reasons are many.

Land degradation led to lowered water and land productivity which further led to food insecurity. Substantiation of land degradation is widespread in Uganda as soil erosion, soil fertility mining, soil compaction, waterlogging, and surface crusting. Soil erosion and soil fertility mining are claimed the most. In some regions of Uganda, 60–90% of the total land area is affected by soil erosion. Soil fertility mining in Uganda is occurring at among the highest rates, with an estimated average annual rate of total nutrient depletion (Stoorvogel and Smaling 1990). Furthermore, the soil erosion problem needs to be attended soon to prevent bifurcation of the land and for improving the livelihoods of the farmers.

2.4 Causes of Land Degradation

In India, Punjab and Haryana states are referred to as the "Food Bowl" states which produce 50% of the national rice production (Dhillion et al. 2010). A gravity satellite named "GRACE" recently delineated those northern regions of India as facing a sharp decline in underground water (Soni 2012; Meena and Lal 2018). Rice in these states is normally flood irrigated during most parts of the season leading to declined water levels since the 1970s (Hira et al. 2004). The fall in water table particularly in central Punjab has been reported to increase from 0.2 m year^{-1} during 1973–2001 to about 1.0 m year^{-1} during 2000–2006. Majority of the blocks in Punjab are being overexploited for pumping out groundwater (Humphreys et al. 2010). The lowering of the groundwater table in the state has been resulting in an increase in the energy requirement and tube well infrastructure cost and deteriorating groundwater quality (Hira 2009). Moreover, subsurface compaction in these soils (Sur et al. 1981; Kukal and Aggarwal 2003a) (after repeated puddling of coarse- and medium-textured soils) results in poor root growth of the succeeding crops, viz., wheat, commonly referred to as "plough pan" (Kukal and Aggarwal 2003b). Plough pan with high bulk density at 15–20 cm creating aeration stress poses threat for the proper wheat root growth (Aggarwal et al. 1995; Kukal and Aggarwal 2003b; Buragohain et al. 2017). Thus, rice established through puddling operations leads to soil deterioration and environmental degradation and proves a hurdle in front of sustainable agriculture.

Another major issue related to the rice-wheat cropping sequence (RWCS) is effective management of rice crop residue, which due to high silica content is not fed to the animals and is normally burnt by the farmers. The burning of rice residues is the main adopted disposal method especially in the areas where machine harvesting is being practiced. Disposal of crop residues by burning is not a viable option due to losses of SOM and nutrients, C- emissions, intense air pollution, and reduced soil microbial activity (Kumar and Goh 2000). As per the estimates, 113.6 Mt of rice and wheat residues containing 1.90 Mt nutrients are produced every year in the IGP of India (Sarkar et al. 1999). In Punjab, about 12 Mt of rice straw is burnt annually causing 0.7 Mt of N loss apart from the emission of 70% CO2, 7% CO, 0.66% CH4, and 2.09% N2O (Singh et al. 2010). Dobermann and Fairhurst (2002) reported that nitrogen (N) (90%), sulfur (S) (60%), and phosphorus (P) and potash (K) (around 20–25%) of the rice straw are lost while burning. Studies (Sidhu and Beri 1989; Beri et al. 1995) have shown that incorporation of rice residues decreased grain yield of wheat from that with removal or burning, due to N immobilization attributable to the slow rate of residue decay. Residue incorporation just before rice transplanting results in accumulation of phenolic acids in soil and increases CH4 emissions under flooded conditions (Grace et al. 2003; Meena and Yadav 2015). The intensive tillage for wheat seedbed preparation breaks down the aggregates to expose soil organic carbon leading to its loss into the atmosphere (Ashagrie et al. 2007; Meena et al. 2018c).

2.5 Strategies to Improve Land Management

In order to take care of the abovesaid issues of declining groundwater and soil health and residue management in RWCS in the region, various RCTs which also manage the soil/land more preciously, viz., laser land leveling, mechanical transplanting, zero-tillage wheat, unpuddled rice, raised beds, mulching, etc., are being advocated for increasing profitability of this system by reducing structural degradation of soil and air pollution and increasing water, labor, and nutrient use efficiencies. These technologies mainly focus on three fundamental principles of conservation agriculture, viz., conservation tillage, intercropping, and use of crop residues (Jeffrey et al. 2012) as mulch and conservation irrigation (Bhatt 2015).

Conventionally, rice settled by puddling (tillage under stagnant water conditions) has an aim to have a bumper crop by minimizing the weed bank, percolation losses, etc. However, this operation not only is labor intensive (300–350 h ha^{-1}) but also results in structural deterioration of soil which certainly affects the upland wheat crop (Kukal and Aggarwal 2003a; Kumar et al. 2017b). The alternate tillage practices viz., mechanical transplanting (Raj et al. 2013), direct seeding of rice under dry (Sharma et al. 2005) and wet conditions (Rana et al. 2014) delineated to mitigate the adverse effects of puddling.

2.5.1 Mechanical Transplanting of Rice (MTR)

Mechanical transplanting in untilled soils has been shown to be a promising technology for establishing rice in Haryana with large energy and labor savings and regular plant spacing (Bhatt and Kukal 2014). This could particularly be beneficial in view of increasing labor scarcity in Punjab because of the Mahatma Gandhi National Rural Employment Guarantee Act (2007) which promises 100 days of paid work to the people from villages (Anonymous 2011). However, whether zero-tillage mechanical transplanting results in water or energy savings in comparison with the puddled transplanted rice is not established yet. There are few studies comparing water use in the puddled and unpuddled transplanted rice. Singh et al. (2001) observed that in sandy loam soil, puddled transplanted rice (PTR) consumed 125 mm lower irrigation water than transplanted rice in untilled soil. There is insufficient data on the components of water balance in zero-tillage transplanted rice and its water productivity. Moreover, the abovesaid studies while reporting the irrigation water savings do so in comparison to the farmers' practice of irrigation scheduling, who in general have a tendency to over-irrigate.

Mechanical transplanting of rice (MTR) helps in timely transplanting than any other method. Furthermore, DSR is reported with somewhat higher water productivity as DSR arrives a month earlier than mechanical transplanting (Bhatt 2015). Self-propelled transplanter produced similar grain yield as with the manual transplanting but produced significantly higher grain yield than that through direct sowing both under dry and wet conditions. This was attributed to the higher number of seedlings per hill planted through mechanical transplanter reported with a comparatively higher tiller, test weight of grains, and grain yield. Mechanical transplanting (MT) is preferred over manual transplanting even though yields in the latter are somewhat higher (4.87 t ha^{-1}) (though statistically at par) than the former (4.85 t ha^{-1}) (Pandirajan et al. 2006). MT of rice with self-propelled rice transplanter helps in getting the highest grain yields as compared to PTR and DSR (Singh et al. 2015a) as early establishment and uniform growth owing to uniform settlement of seedlings under MT significantly influence the plant height, total panicles m^{-2}, effective panicles m^{-2}, grain panicles -1, and weight of 1000 grains which finally resulted in higher land productivity (Table 2.1).

However, irrigation water productivity (WPI) of MTR plots was delineated to be greater than that of DSR plots and the same with that of PTR plots (Fig. 2.2). The higher WPI of mechanically tilled puddled plots (MT-P) than that of mechanically tilled zero-tillage plots (MT-ZT) plots was due to lower land productivity in MT-ZT plots. The WPI in direct seeded conventionally tilled plots (DSR-CT) was higher than that in direct seeded zero-tillage plots (DSR-ZT) plots, which was due to lower land productivity in DSR-ZT plots. This led to greater water feeding of DSR plots than in PTR. This resulted in lower WPI in no-tilled plots compared to the extensively tilled plots. Thus, in sandy loam soil, mechanically transplanted rice in puddled system performs similarly to conventionally transplanted rice. However, the crop yield decreased when rice seedlings were mechanically transplanted in zero-tillage soil (Bhatt 2015; Meena et al. 2014). However, Bhatt et al. (2014)

Table 2.1 Effect of different establishment methods on the different agronomic parameters

Treatments	Panicle length (cm)	Filled spikelets per panicle^{-1}	Unfilled spikelets per panicle^{-1}	Fertility % age	1000 grain weight (g)	Plant height (cm)	Chlorophyll index
MT (P)	23.0	124.8	13.1	91.4	23.9	82.4	43.9
MT (ZT)	22.3	115.9	18.3	86.6	20.8	72.8	42.6
DSR (ZT)	20.9	69.7	25.6	72.7	20.8	66.3	39.9
DSR(CT)	21.6	75.3	19.4	79.7	22.2	65.2	39.0
PTR	25.6	115.8	37.4	76.4	22.9	91.7	45.2
LSD (0.05)	2.2	16.8	10.5	6.2	1.6	5.4	2.25

Adopted from Kukal et al. (2014)

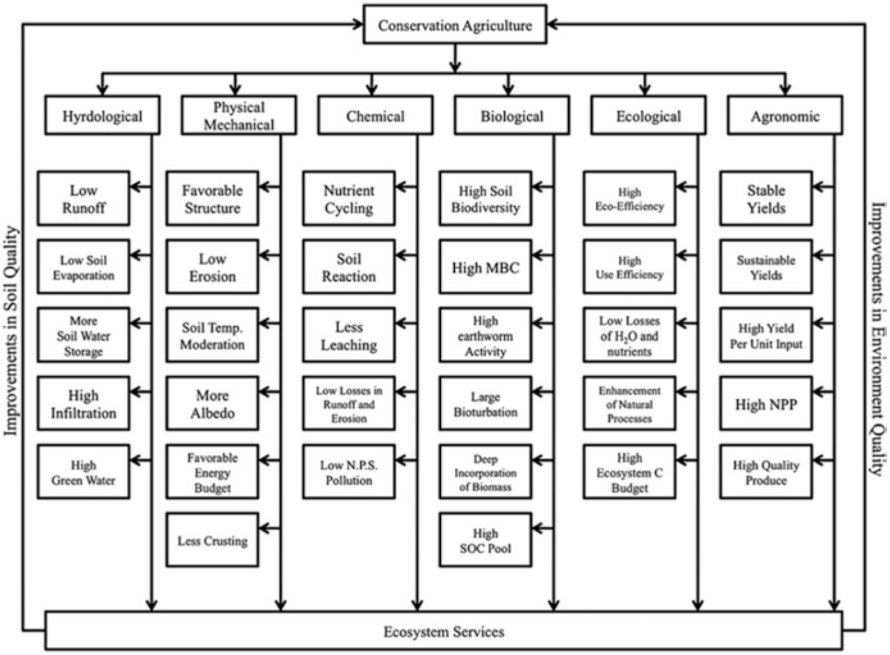

Fig. 2.2 Improved soil and environment quality through adoption of the conservation agriculture (Adopted Lal 2010)

documented reasons for non-adoption of mechanical transplanting of rice among the region's farmers even though it is found to provide good effective results more particularly in the labor shortage scenario in the comparatively shorter window period after wheat harvesting.

2.5.2 Direct Seeded Rice (DSR)

To avoid the use of considerable amount of irrigation water for puddling and continuous flooding till 15 days after transplanting in alternate wetting and drying (AWD), direct dry sowing of rice at field-capacity moisture content has been gaining ground over the last couple of years. Significant savings of irrigation water was reported under AWD at 20 kPa at 8-inch depth in a clay loam soil (Sudhir Yadav et al. 2011; Datta et al. 2017a, b). As compared to the MTR, DSR is reported with somewhat lower land productivity (Bhatt and Kukal 2017) because of already explained reasons above. This reduction in irrigation water was mainly reported due to reduced seepage losses. Sudhir-Yadav et al. (2011) reported significantly higher irrigation water productivity of DSR than PTR, but total input water productivity and ET-based water productivity were statistically at par at 20 kPa soil matric potential (SMP)-based irrigation scheduling. Very few studies related to detailed water balance characterization in DSR are reported in the literature (Bhatt 2015), particularly in coarse- and medium-textured soils. Moreover, increased irrigation water productivity of DSR could impact the irrigation water productivity of the following wheat crop, the studies on which are lacking in the literature. This technology of the DSR is site specific and cannot be suggested at all the sites as DSR proves to be a failure in the light-textured soils which is further complicated with iron deficiency and significantly higher weed population. Thus, DSR must be used with an integrated approach at heavy-textured soils. Thus, there is a need to study soil water dynamics in RWCS as a whole instead of individual crops.

2.5.3 Zero Tillage in Wheat

Direct drilling of wheat in standing rice stubbles and untilled soils (Sidhu et al. 2008) has long been advocated as a zero-tillage technique to reduce irrigation water amounts and increase water productivity (Balwinder Singh et al. 2011a). Mulch material suppresses soil evaporation (Es) (Balwinder Singh et al. 2014) and undesired plants, improves SOM by avoiding direct contact of hot sunrays onto soil surface, and decreases vapor pressure gradient which finally improves land productivity (Siddique et al. 1990; Singh et al. 2005; Meena et al. 2015c). Zero tillage improves the soil physical environment (Paccard et al. 2015) because of residue retention in the fields resulting in increased infiltration rate, water retention, hydraulic conductivity, lower soil compaction (Zheng et al. 2015), etc., while conventional tillage disperses the macroaggregates, which discloses the once concealed organic matter to microorganisms which oxidizes them into CO2 which further escapes into the atmosphere and causes global warming (Kuotsu et al. 2014; Layek et al. 2018). The contradictory results related to zero-tillage effects on soil and crops are reported in the literature (Singh et al. 2015a, b; Dhakal et al. 2015). It is mainly due to site-specific conditions including soil type, climatic conditions, and cultural practices especially for herbicide use (Singh et al. 2015a, b).

Furthermore, Jat et al. (2014) in their 7-year experiment on the clay loam soil reported higher grain yields and economical advantage of conservation agriculture (CA) which was realized after 2–3 years as the adaptation of conservation agriculture-based component technologies evolved overtime and the farmers have to settle with somewhat lower yields during the initial years. Thus, the farmers need to be convinced about lower crop yields during the initial few years for adoption of this technology for better land and input productivity at later stages. Therefore, conservation agriculture, zero tillage, mechanical tillage, and direct seeded rice are some of the resource conservation technologies which one could adopt with an integrated package of techniques for practicing climate-smart agriculture in the present era of climate change.

2.5.4 SRI System for Natural Resource Management

The pressure on land has risen from various factors, chief among them being deforestation, overgrazing, and overcultivation which caused a decline in fertility and productivity, thus aggravating poverty. In short, the tremendous increase in population and per capita economic activity has resulted in a considerable strain on our natural resource foundation. Among different initiatives taken to improve natural resource management, rice management is the most important one. Rice is the most vital food crop in most parts of the developing world including Asia besides Africa. With an increase in population growth, limited land resources, and rising demand for food, rice yields will have to increase further. Yield growth has slowed down recently, and the law of diminishing return is holding good for additional inputs. However, increase in rice production by providing higher inputs leaves a significant environmental footprint; for example, excessive use of fertilizers/pesticides could lead to environmental problems, and excessive use of water could lead to depletion of natural resources. Greenhouse gas emission and climate change issues are also there with heavily fertilized and continuously flooded rice production systems, with climate change itself likely to impact rice production negatively. Farmers in some regions are already coping with drought and water scarcity issues. Thus, future yield and growth in rice production systems have to be accomplished with less water use, less resource depletion, and less environmental degradation.

The SRI has been considered as a promising approach to increase rice production, without harming the environment. Originating in Madagascar as a way to increase the productivity of rice with a concomitant decrease in water and other input requirements, SRI is currently benefitting a large number of small farmers. The SRI and other natural resource management (NRM) technologies do have the potential to increase productivity while reducing the use of external inputs. But they are knowledge intensive and require local adaptation; hence, successful adoption by small farmers depends on proper outreach programs.

The system of rice intensification is basically an integrated approach which took into account soil, water, and nutrients in addition to managing rice plants for overall improving the livelihoods. In this regard, the work of Fr. Henri de Laulanié, SJ, who spent much of his era in Madagascar to improve livelihoods of the poor farmers and work out different combinations for growing rice, is worth mentioning. Furthermore, different methodologies developed by him were well grounded in agronomic science and helped the farmers a lot in improving their livelihoods and standards of living.

In applied terms, SRI is transplanting of 8–10-day seedlings, taking care to protect the young roots. It involves planting in a tetragonal pattern with wider spacing to give roots and canopy more chambers to grow and capture more sunlight and take up more nutrients. It maintains soil in mostly aerobic conditions and controls weeds by a simple and easy-to-use mechanical weeder that also ventilates the soil. The SRI promotes wide use of organic matter such as compost and mulch that helps to guard the growing rice plant. However, SRI can be fully carbon based also, but mineral fertilizers can also be used in case of an emergency. Generally, the best land and water productivity could also be obtained from the SRI technique. SRI in general is useful for the local farmers with local varieties and with new, improved varieties and hybrids; so they can practice sustainable agriculture in the present era of global warming. The higher requirement of labor and management is during the early stages of SRI adoption. Overall, SRI is showing promise to reduce input costs, improve water use, and produce greater yields.

Already, countries like China, Indonesia, Sri Lanka, etc. reported to be benefitting from the SRI technique. Evaluation of the SRI method of cultivation in China was performed by the China National Hybrid Rice Research and Development Center in 2000, and it was found that water intakes could be reduced by 65% with this technique as compared with conventional technique with higher land productivity of about 1–2 t ha^{-1} production. The SRI evaluation initially started on 1.6 ha with new farmers; and by the end of 2005, trials were conducted on 1363 ha, with an 84% increase in land productivity with water and cultivation cost cutting of 40% and 25%, respectively. The International Water Management Institute surveyed the water-saving potential of SRI in Sri Lanka and found that yield was increased by 44% with SRI and the income was doubled per hectare as compared to conventional method of rice cultivation.

2.6 Sustainability Issues on the Rice-Wheat Cropping System

The rice-wheat cropping system is the most prominent food production system in South Asia contributing ~45% of digestible energy (Timsina and Connor 2001). The RWCS is cultivated on ~22.5 million ha area in this region (Singh and Paroda 1994; Pooniya et al. 2018; Meena et al. 2015e). In post-Green Revolution era, the cereal-cereal production systems, mainly rice-wheat cropping system, in South Asia relied upon the unbalanced and high use of chemical fertilizers with no use of organic manures which directly posed a threat to agricultural sustainability (Paul et al. 2014; Gogoi et al. 2018). The RWCS is also the most prominent and widely adopted cropping system in India, and the farmers are frequently and intensively using this system. But due to intensive cultivation of RWCS, the region has now come to a level where yields become stagnant, micronutrient deficiencies rise, and sustainability is threatened. Regardless of gigantic growth of this cropping structure in the country during the earlier couple of decades, gossips of declining production levels, with possible decline in production in the future owing to receding resource base, have raised serious doubts about its sustainability. Important sustainability issues of RWCS in South Asia in broader sense are as follows:

- Overmining of nutrients including micronutrients
- Declining soil organic matter content
- Deterioration in soil health/soil aggregates due to wet tillage (puddling)
- Declining factor productivity especially poor response to applied nutrients
- Receding groundwater
- Waterlogging problem in canal-irrigated areas
- Low input use efficiency
- Buildup of diseases/pests and shrinking genetic biodiversity due to cultivation of fewer genotypes in rice and wheat leading to more biotic and abiotic stresses
- Lack of appropriate varietal combinations and limiting crop intensification
- Labor scarcity during the optimum period for transplanting paddy

- Changing climate with more climate variability especially in wheat leading to severe heat stress in subtropical arid agroecologies of RWCS
- Conventional puddle transplanted rice sequence resulting in the production of GHGs, viz., methane (CH_4) and nitrous oxide (N_2O)
- Buildup of herbicide resistance in *Phalaris minor* and other weed flora

Continuous cereal-based cropping systems have led to resource base degradation and production vulnerabilities at large with contaminated plant-soil-water continuum. Population pressure, climate change threats, and global trade are also challenging the sustainability of South Asian agriculture. The irrigated ecosystems have different kinds of production vulnerabilities which are the limiting factors for our national food security, and they are the threats to our national agricultural economy and rural livelihoods as well. In spite of tremendous agricultural growth during the past, reports of unsound production levels and stagnation in the productivity of major crops and cropping systems because of receding resource base and climatic variabilities have resulted in a question mark about their sustainability (Prasad 2005; Singh et al. 2011a, b). Promotion and adoption of eco-friendly practices, viz., high-yielding crops/cultivars; crop diversification imbedded with legumes; integrated nutrient, weed, disease, and pest management approaches; water-efficient crops/cultivars; climate-smart resource conservation technologies; etc. on a scale-neutral to niche area and site-specific basis would definitely address the emerging agrarian threats for agricultural sustainability (Choudhary and Suri 2014; Paul et al. 2014; Yadav et al. 2017c). Broadening of RWCS with other crops could be an important pathway to solve many problems. The policy changes would also be needed to encourage legume interventions in the rice-wheat sequence for improving sustainability and soil health (Pooniya et al. 2018; Verma et al. 2015a). Other agronomic interventions to overcome production vulnerabilities in RWCS are as follows:

- Inclusion of short-duration summer legume crops and their residue recycling
- Balanced fertilization according to soil and crop needs on a localized basis like soil test, STCR, SSNM, nutrient expert, LCC, SPAD value, and GreenSeeker
- Use of farm yard manures, biofertilizers, and green manuring
- Use of slow-release N fertilizers, viz., gypsum-enriched urea (GEU), phosphogypsum-enriched urea (PGEU), sulfur-enriched urea (SEU), zinc-enriched urea (ZEU), and neem oil-coated urea (NOCU)
- Nitrification inhibitors, i.e., N-Serve, dicyandiamide
- Adoption of resource conservation technologies like conservation agriculture, ZTR, DSR, furrow-irrigated raised bed (FIRB), and alternate furrow irrigation system
- Switching over to direct seeded rice and adoption of SRI in small and marginal farm holdings
- Integrated crop management practices with respect to weeds, diseases, nematodes, and pests
- Improved institutional credit facilities and extended availability of quality seeds and other agro-inputs

- Precision water management to improve water productivity and use efficiency
- Crop and varietal diversification with legumes and high-value cash crops for better farm profitability and rural livelihoods to create ample employment generation and check rural migration
- Integrated farming system modules for small and marginal farmers

2.7 Climate Change and Its Mitigation in the Rice-Wheat System

Climate change is responsible for increased air temperatures, erratic rainfalls, and increasing sea levels because of emission of GHGs, viz., CO_2, N_2O, and CH_4. This resulted in further continued changes in different weather parameters which affect the agricultural production by one or other means which on the other hand increased the prices of eatables. In a summarized way, the following are the consequences of global warming:

1. **Water cycle**: Because of global warming, there were frequent floods and droughts observed in different pockets of the region which further affected the agriculture by altering soil-plant-moisture interphase.
2. **Heat**: Over the next three to five decades, average temperatures will likely to increase by 1.0 °C. Global warming certainly piles up frequency of heat waves and warm nights with lesser frost days, higher respiration rates, and lower grain filling time in plants and longer growing season in temperate zones.
3. **Crop biodiversity**: Wild genotypes with important genes will be certainly affected which further on the long run certainly affects the different breeding programs operated in different regions of the country for evolving temperature- and salt stress-tolerant crops.
4. **Carbon dioxide (CO_2)**: The CO_2 concentrations will increase to about 450 parts per million (ppm) by volume over the next three to five decades. The CO_2 response is expected to be higher on C_3 species (wheat, rice, and soybeans), which account for more than 95% of world's species, than on C_4 species (corn and sorghum). The C_3 weeds have responded well to elevated CO_2 levels, symbolizing the potential for increased weed pressure and reduced crop yields.

Greenhouse gases are contributing to global warming which further affected the agricultural production in one or other ways. New technologies, viz., soil test-based fertilization, direct seeded rice, slow-release fertilizers, etc., will certainly hold the promise of reducing GHG emissions. Global warming is mainly because of extra-production of CO_2, CH_4, and N_2O. CH_4 comprises 18% of total GHGs. Cropland management, livestock management, bioenergy, grassland management, manure/bio-solid preparation, and management of lands are the main areas on which we have to focus for reducing the production of these GHGs for minimizing the damage caused by global warming (Smith et al. 2008). To mitigate the global warming consequences, reducing emissions of CH_4 (by using improved resource conservation technologies) and N_2O (by using improved fertilizer application technologies) from agriculture along with fossil fuel by enhancing removal of atmospheric GHGs must be encouraged. Mitigation could be accomplished through intensification (may increase emission of GHGs ha^{-1}) and intensification (may reduce emission of GHGs ha^{-1}) of agriculture but total land requirement may increase slightly.

Different mitigation strategies can be classified into three categories:

1. By reducing gas emissions with practices which ultimately improve fertilizer use efficiency by minimizing their losses and reducing CH_4 emissions by implementing suitable RCTs to mitigate global warming consequences.
2. By enhancing carbon sequestration through increasing land productivity in one or other ways, thereby requiring less land for cultivation, by taking carbon for the development of plant edible portions, by increasing photosynthetic storage of carbon through agroforestry ecosystems, and by reducing CH_4 from the atmosphere by reducing the agricultural lands.
3. Avoiding emissions: Biofuels and biodiesel avoid excessive consumption of fossil fuels as CO_2 (Houghton et al. 1996). Fossil fuel burning, industrial processes, and transport fuel contribute about 29.50%, 20.60%, and 19.20%, respectively (Raupach et al. 2007).

Fossil fuel burning led to an upsurge in the concentration of atmospheric CO_2 at the rate of 1.8 ppm $year^{-1}$, which might reach 550 ppm by the end of this century (IPCC 2007a, b, c). The CO_2 concentration is reported to be peak up to now (IPCC 2007a, b, c). Fossil fuel burning (5.7 Gt) and deforestation (2.3Gt) further contribute to it. Soil organic carbon (SOC) is reduced to almost half over the past four decades due to global warming (Lal 2004). The downcoming of SOC has become a matter of worry, as SOC is the main pillar for improved soil physical, chemical, and biological health which further supports higher land and water productivity in the region. Therefore, carbon must be sequestered by adopting one or other ways for mitigating the global warming consequences.

2.8 Conservation Agriculture for Practicing Climate-Smart Agriculture

Different approaches of conservation agriculture help in adoption of climate-smart agriculture in extensive, mechanized agricultural sequence on erosion-prone, structurally deteriorated soils. Furthermore, climate change led to a number of problems that stood in front of sustainable agriculture (Thomas and Twyman 2005). Different traffic technologies and principles of conservation agriculture further provide improvement in the livelihoods (Robertson et al. 2008; Meena et al. 2016a). Furthermore, the adoption of CA will help in improvement of both soil and environment quality at the ecosystem level (Fig. 2.2).

Within India, CA principles within a particular agricultural system remain logical due to the diverse factors that might be social or economic. Generally, conservation agriculture involves the following principles:

1. Crop rotation: This is a must exercise for changing the soil depth explored for the nutrients as rhizosphere area changes with every crop. Therefore, crop diversification, viz., rice with maize, increases livelihoods of the local farmers.
2. Minimum tillage: Minimum tillage not only reduces the bulk density as in the case of zero tillage but also sequesters higher amounts of C and thereby minimizes emission of GHGs. Furthermore, by improving soil organic carbon status, minimum tillage ultimately improves the soil health (Jat et al. 2009) which finally improves the soil eminence. But to have a significant improvement, a certain set of periods of 3–5 years is required (Bhatt 2015).
3. Mulching: Mulching, viz., placement of the crop residues on the soil surface, improves the soil moisture holding capacity (Bhatt and Khera 2006; Bhatt and Kukal 2017; Kumar et al. 2018a), maintains the soil temperature (Singh et al. 2011a), and finally improves the grain yields (Kukal et al. 2014; Meena et al. 2015b). Basically, crop residues hinder the direct contact of the hot sunrays onto the soil, decrease the vapor pressure gradient, and minimizes the vapor lifting capacity of the wind by minimizing its speed near the soil surface.

It is very important to know the interaction occurring between conservation agriculture techniques and the other resource conservation technologies (RCTs) which certainly increase both land and water productivity (Kirkegaard and Hunt 2010; Kumar et al. 2018b). But C-sequestration potential (Chan et al. 2011), GHG minimum emissions (Maraseni and Cockfield 2011), and higher energy usage (López-Moreno et al. 2012; Meena et al. 2017c) are often assumed for zero-tillage systems. Dealing with these illogicalities will be dominant if CA principles are to be functional wisely to exercise sustainable agriculture. Different possibilities, viz., spreading crop residues onto soil surface, zero tillage, etc., delineate important principles of CA which has the potential to mitigate global warming consequences.

4. Technologies to mitigate the consequences of the global warming: One could adopt the following technologies to meet the objective of having improved land and water productivity.

2.8.1 Agronomic Practices

1. Soil test-based fertilization will certainly reduce overfertilization resulting in lower N_2O emissions which further mitigate the global warming consequences. Therefore, farmers must go for soil test-based fertilization instead of deciding fertilizer dose by having a watch on the neighboring farmers.

2. Fertilization timing: Fertilization as per crop need is very important to avoid losses of N_2O to the atmosphere.
3. Use slow-release fertilizers, viz., neem- or poly-coated urea, which certainly slow down the release of the nutrients, thus increasing their N use efficiency, e.g., greater granule size of urea, diminished nitrification rates, and minimized GHG emissions.

2.8.2 Technology to Improve Nitrogen Use Efficiency

Nitrogen use efficiency management practices, viz., fertilizer granule type, time of application, depth of placement, and their interaction with irrigation timings and rainfall events, affect N_2O emissions. Fertilizer applied affected the production of N_2O. Venterea et al. (2005) observed higher N_2O emissions with urea than those with anhydrous ammonia, while Tenuta and Beauchamp (2003) delineated higher magnitude of total emissions with urea than with ammonium sulfate, with that of calcium ammonium nitrate being higher. Proper fertilizer droppings in the rhizosphere can decrease nitrogen losses which on the long run mitigate the global warming consequences. Furthermore, nitrification and urease inhibitors delay transformation of NH_4 to NO_3 and urea to ammonia to match crop demand. S-Benzylisothiouronium butanoate and S-benzylisothiouronium fluroate increased overall land productivity and increased nitrogen use efficiency (NUE) by 4–5% (Bhatia et al. 2010; Varma et al. 2017a). Cover crops may be used on sloppy lands to reduce N_2O emissions, while storing animal waste anaerobically minimizes N_2O losses out of soil. Losses of N through leaching, volatilization, and denitrification decreased on adoption of irrigation on 2-day intervals instead of continuous irrigation in paddy fields.

2.8.3 Adaptation Technologies

Adaptation is one of the most important aspects to stand and perform in the present time of climate change as otherwise crop plants may not be able to yield as per their potential. The following are the techniques which could really help in the adoption:

1. Crop breeding for development of new heat- and low water-tolerant crop cultivars is a major intervention which helps us to practice climate-smart agriculture in the region. Plant breeding has a great potential to develop new more resistant, heat- and salt-tolerant crop cultivars which adapt to adverse climatic conditions. New cultivars have the potential to withstand the more adverse conditions.
2. Proper crop rotation is the next secret and one of the basic principles of conservation agriculture which enables us to sustain land and water productivity. Different crops growing at one time on a single piece of land, viz., intercropping, holds the promise for sustainability even in the era of global warming.

2.9 Research and Development Need

Development of both low water- and salt-tolerant crop cultivars is the need of the time which also provides us reasonable yields by improving both nitrogen and water use efficiency. Furthermore, there is a need for continuous marking of the different adopted tracks against global warming and breeding new crop cultivars with resistance to new diseases and pests which could be recommended to the farmers for growing under the present era of climate change.

Mitigating global warming consequences with or by adopting one or other more suitable integrated approaches is the main challenge in front of agricultural scientists. New incentives should be there for the farmers practicing climate-smart agriculture and adopting its different principles. New encouraging and supporting policies must be there for better adoption of these resource conservation technologies as many of proposed technologies are site and situation specific, and there is a need to specify them as per conditions.

2.10 Carbon and Water Footprints in the Rice-Wheat System

This concept was introduced about a decade ago. The terminology chosen in both the cases was enthused by ecological footprint (EF), which was introduced in the 1990s (Rees 1992). All foot prints delineates human arrogates use of natural resources of this planet's, in different ways. The ecological footprint delineates the use of bio-productive space in hectares; the carbon footprint measures the emission of gases that contribute to heating the planet in carbon dioxide (CO2) equivalents per unit of time or product; and the water footprint measures the consumption and contamination of freshwater resources in cubic meters per year. All footprints can be related to specific accomplishments, produces, and ingesting designs.

A carbon footprint is defined as the total emission caused by an individual, event, organization, or product, expressed as carbon dioxide equivalent. It is difficult to calculate carbon footprint accurately because of inadequate knowledge and data explaining the complex interactions between processes contributing to or influencing the natural processes of releasing or storing CO2. Hence, Wright, Kemp, and Williams have suggested defining the carbon footprint as a measure of the total amount of carbon dioxide (CO2) and methane (CH4) emissions of a defined population, system, or activity, considering all relevant sources, sinks, and storage within the spatial and temporal boundary of the population, system, or activity of interest (calculated as carbon dioxide equivalent using the relevant 100-year global warming potential) (Pfister et al. 2017; Yadav et al. 2018a).

Carbon footprint is more specific than other footprints, since it measures direct emissions of gases that cause climate change in the atmosphere. It is extensively acknowledged and used by the public and describes GHG emission measurement from the narrowest to the widest sense. There are several calculation methods and approaches for carbon footprint accounting that are being used. Carbon trade in developed countries is supported by research in advances in carbon footprint (Hillier et al. 2009). For instance, consumers are guided regarding the different products used by them and their contribution to GHG emissions, thereby an attempt being made to guide them for using low-gas-producing gadgets (Burney et al. 2010; Kakraliya et al. 2018). With the increase in carbon emissions, there is a need for socioeconomic transformation and development of a carbon market and associated management techniques (Röös and Tjärnemo 2011; Zhang and Zhang 2016; Meena et al. 2018a), but insufficient research related to quantifying carbon footprints to support such a management system is making carbon trading difficult.

Greenhouse gas emissions and the relative forcing on global warming have inspired the quantification of the carbon footprint of the economy. It is determined as the GHG emissions in carbon equivalents (CEs) caused by the production of a certain product (Wright et al. 2011). Carbon footprint is meant to denote a degree of the exclusive total amount of carbon dioxide emission that is directly and indirectly caused by anthropogenic activity (Dubey and Lal 2009). For example, the UK Greenhouse Gas Inventory estimates the proportion of the nation's overall carbon footprint due to agriculture to be around 8%, out of which 75% can be contributed by fertilizer use. It is difficult to pinpoint the carbon footprint of a specific activity, but recently thorough studies into the contribution of specific agricultural events during crop production to the global footprint are being conducted (Wiedmann and Minx 2008; Yadav et al. 2017a).

The carbon equilibrium can be an indicator of agricultural fabrication. The agriculture sector has been widely recognized as a significant source of GHGs to the global total GHG emissions (54% of methane and 58% of nitrous oxide produced via agricultural activities which further contribute to global warming). Methane is generally produced by microbial decomposition of organic matter under submerged conditions during rice season. Furthermore, denitrification is responsible for the production of the N2O gas which has 265 times global warming potential (GWP) than CH4. Uninterrupted submergence, advanced organic C content, and use of organic fertilizer in puddled soils improve methane discharge, while burning of crop residues contributes to the global methane and nitrous oxide emissions.

A substantial amount of methane emission has been attributed to enteric fermentation in ruminants. Moreover, nitrogenous nourishments are the source of N2O in inseminated soils, whereas the indigenous N can contribute to its release in unfertilized soil. It has been observed that N2O emission increases following irrigation and precipitation. Carbon dioxide also occurs from agricultural activities, viz., soil organization practices such as tillage that can trigger carbon dioxide emission through biological decomposition of soil organic matter. Fuel use for various agricultural processes and burning of crop remains are the other sources of carbon dioxide productions. Fertilizers and manures are sources of off-site CO2.

The net GHG emission in 2007 in India was 1727.7 million tons (Mt) of CO2 eq. The main foundation was the energy sector, contributing 57.8% to the total GHGs, followed by industrial (21.7%), agricultural (17.6%), and leftover (3.0%) sectors. In the agricultural subdivision with a total production of 334.4 Mt CO2 eq., the chief foundations were enteric fermentation (63.4%), rice agronomy (20.9%), farming soils (13.0%), compost running (2.4%), and on-field burning of crop residues

(2.0%). Thus, the crop manufacture sector (rice cultivation, soils, and field burning of crop residues) underwrote 35.9% of the total emanations from farming (Leach et al. 2012).

Carbon accounting is the assessment of carbon footprint of an individual, a nation, or an organization. Population, financial production, and vigor and carbon strength of the economy are the main influences on carbon footprints. When an organization or an individual aims at reducing its carbon footprint, they target and manage these factors. Production activities require a lot of energy and leave a large carbon print; hence, by decreasing the amount of energy needed for production, the carbon footprint can be decreased most effectively. These are identified as carbon counteracting, a response to carbon dioxide emanations with a corresponding reduction of carbon dioxide in the troposphere (Corbett 2008). Alternative projects such as solar/wind energy (renewable sources of energy), reforestation, etc. can also reduce carbon footprints. Once the size of the carbon footprint is known, appropriate strategies can be devised to reduce it.

Greenhouse gas production caused by the construction of agricultural produce via the use of farm equipment; elements such as herbicides, insecticides, and fungicides; and fertilizer for crop protection and nutrition is referred to as carbon footprint in agriculture. So it is important to identify the carbon footprint of a crop for making agriculture sustainable (IPCC 2006; Singh 2016). Carbon secretion or carbon penalties induced by production practices in a growing season may be termed as a carbon footprint of a crop (West and Marland 2002; Smith et al. 2008; Smith 2013; Meena and Yadav 2014).). The carbon footprint (CF) is assessed by taking into account the total GHG emission in carbon equivalent (CE) through material added and from a mechanical operation performed in a single cycle of crop production (Hillier et al. 2009).

Rice is the principal nourishment for over 60% of the biosphere's inhabitants. About 50% of the anthropogenic emissions of methane are attributed to agricultural activities, out of which 10% is contributed by rice cultivation (Scheehle and Kruger 2006; Dadhich and Meena 2014). In continuous flooding conditions, carbon emission in rice varies from 21.96 to 60.96 Tg C year^{-1} due to variation in urea doses (Pathak et al. 2005). The Intergovernmental Panel on Climate Change estimates that the annual global emanation rate of methane from paddy fields is to average at 60 Tg year^{-1}, with a range of 20–100 Tg year^{-1} (Blengini and Busto 2009) which is nearly 5–20% of the total CH4 emissions from anthropogenic sources. In China, carbon concentration fluctuated from 0.64 t CE ha^{-1} year^{-1} in 1993 to 0.92 t CE ha^{-1} year^{-1} in 2007 in terms of cultivated lands and from 0.14 t CE t^{-1} in 1993 to 0.11 t CE t^{-1} in 2007 in terms of whole production (Bockel 2009). Crop residue burning is a potential source of emission of CO2, CH4, and N2O, plus pollutants such as carbon monoxide (CO), particulate matter (PM), and toxic polycyclic aromatic hydrocarbons (PAHs) (Cheng et al. 2011; Verma et al. 2015c). In Italy, the estimated carbon footprint of rice (sowing to farm gate) was 2.90 kg CO2-e kg^{-1} yield. A study in Japan on over 100 producers which examined five life cycle stages, raw material production, rice polishing, retailing, rice cooking, and waste treatment, showed that the carbon footprint of rice was 7.7 kg^{-6} CO2eq 4 kg^{-1}-1 of polished rice.

Wheat carbon footprint, like rice, also is contingent on grain yield and total GHG releases related to crop construction. Rajaniemi et al. (2011) analyzed greenhouse gas (GHG) emissions from wheat production in Finland. The GHG emissions were analyzed in a conventional production chain, direct drilling chain, and reduced tillage chain. The GHG emissions for wheat were 590 g CO2 eq kg^{-1} (Lemieux et al. 2004). In Canada, the carbon footprint for spring wheat was estimated to be 0.357–0.140 and for durum wheat 0.383–0.533 kg CO2-e kg^{-1} yield (Rajaniemi et al. 2011). A report says that in the case of wheat, CF for conventional tillage is 262 kg CO2 ha^{-1} where grain yield average is 2287 kg ha^{-1} (Gan et al. 2011). Fix and Tynan (2011) delineated that GHG emissions for wheat were 720 g kg^{-1}.

Water footprints were presented in the field of water possessions organization in 2002, as a tool to measure water use in relation to ingesting patterns and indicates the water required to sustain a population. The water footprint of a nation is defined as the total volume of freshwater that is used to produce the goods and services consumed by the people of the nation. Since not all goods consumed in one particular country are produced in that country, the water footprint consists of two parts: the use of domestic water resources and the use of water outside the borders of the country. The water footprint is carefully linked to the simulated water notion. The volume of water required to produce a commodity or service is called virtual water. When assessing the water footprint of a nation, it is essential to quantify the flows of virtual water leaving and entering the country. If one takes the use of domestic water resources as a starting point for the assessment of a nation's water footprint, one should subtract the virtual water flows that leave the country and add the virtual water flows that enter the country.

The total volume of water used worldwide for crop fabrication is 6390 Gm^3 $year^{-1}$ at field level. Rice has the principal portion in the total volume of water used for worldwide crop production (Wanhalinna 2010; Meena et al. 2016b). It chomps about 1359 Gm3 $year^{-1}$, which is about 21% of the total volume of water used for crop production at field level (Table 2.2). The subsequent largest water consumer is wheat (12%). The input of some foremost crops to the universal water footmark in so far as related to food feeding is presented below.

Comparatively on an average, the water productivity of rice is much lower than that of wheat because of required anaerobic conditions (Hoekstra and Chapagain 2006).

2.11 Integrated Approach to Enhance Water/Land Productivity Under the Current Scenario

Rice-wheat cropping sequences prove to be labor, energy, water, and capital intensive which further caused structural deterioration of the soil and decline in underground water (Bhatt et al. 2016; Bhatt and Kukal 2017; Dhakal et al. 2016). As per one estimate, a significant area is already under RWCS prevailing in South Asia, out of which around 85% falls in the IGP (Timsina and Connor 2001; Ladha et al. 2003; Varma et al. 2017b). The output and sustainability of rice-wheat-based systems are in question because of the declining underground water table, rising micronutrient

Table 2.2 Involvement of some major crops in the worldwide water footmark (Wanhalinna 2010)

Crop	Contribution (%)
Rice/paddy	21
Wheat	12
Maize	9
Soybean	4
Sugarcane	3
Cotton	3
Barley	3
Sorghum	3
Coconut	2
Millet	2
Coffee	2
Oil palm	2
Groundnut	2
Cassava	2
Rubber	1
Cocoa	1
Potato	1
Minor crops	26

deficiencies, increasing scarcity of resources especially water and labor, emerging energy crisis, and rising fuel prices (Bhatt 2015). Global water scarcity analysis has shown that up to two-thirds of the world population will be affected by water scarcity over the next several decades (Wallace and Gregory 2002). The fall in water table particularly in central Punjab has been reported to increase from 0.2 m year^{-1} during 1973–2001 to about 1.0 m year^{-1} during 2000–2006. As per Humphreys et al. (2010), majority of the blocks in Punjab are being overexploited for pumping out groundwater. The lowering of the groundwater table in the state has been resulting in an increase in the energy requirement and tube well infrastructure cost and deteriorating groundwater quality (Hira 2009). Moreover, coarse- and medium-textured soils when puddled cause subsurface compaction (Sur et al. 1981; Kukal and Aggarwal 2003a), which causes yellowness in wheat leaves due to aeration stress (Kukal and Aggarwal 2003b). The high bulk density layer at six to seven inches appeared as a consequence of repeated puddling by closing earth pores for rice which restricts the wheat root growth during rabi season (Aggarwal et al. 1995; Kukal and Aggarwal 2003b; Meena et al. 2015a).

In India, per head water availability will decrease to 1000 m^3 up to 2025 if necessary steps will not be implemented (UNEP 2008). Water availability decreased as the region’s population increased significantly over the last half decade (Ali et al. 2012). Climate change impacts cereal production in one or other ways, i.e., either through stress or through weather irregularities (Porter et al. 2014). Summer months reported with excess, while water shortfalls were observed during winter seasons; thereby, adoption of an integrated approach is a must for sustainable agriculture in South Asia (Ali et al. 2012).

Integration of different approaches which could indirectly—viz., soil test-based fertilization, integrated nutrient management, leaf color chart, and slow-release fertilizers (neem-coated urea or poly-coated urea)—or directly, viz., laser leveling, short- or medium-duration crop cultivars, transplantation/sowing time, 2-day intermittent irrigation, soil matric potential-based irrigation, permanent beds, rice without puddling (DSR), transplanting of rice with machines, etc., enhance the so declined land and water productivity in the region is an approach dependent upon the divergent soil and climatic conditions (Bhatt and Kukal 2014; Verma et al. 2015b). Furthermore, to mitigate the global warming consequences, a properly integrated approach by using two or more approaches along with new genetically modified water-stress cultivars in all is very important to improve the declining terrestrial as well as aquatic efficiency under the scenario of global warming (Bhatt and Kukal 2014). Increased soil temperatures because of global warming will cause water stress which is further reported to affect different yield and quality parameters in cereals and grass crops, viz., sugarcane (Sanghera et al. 2018; Sanghera and Bhatt 2018). Moreover, studying the residual effect of adopted resource conservation technologies during the intervening period on the soil moisture dynamics is a must (Bhatt and Singh 2018). Soil management practices, viz., tillage, certainly affect the livelihoods of the farmers (Bhatt and Khera 2006; Bhatt and Kukal 2017; Meena et al. 2017a). It is very well clear up to now from the different studies carried out across the globe that total evapotranspiration losses remain almost the same. If we decrease evaporation somehow with some measure, viz., mulching or short-duration crop cultivars, then certainly a higher fraction of the ET water will partition toward the transpiration (T) component, finally improving the inflow of the nutrients along with water, which further improves the declining water and land productivity. Therefore, there is a need for proper selection, integration, and recommendation of a full package (depending upon the socioeconomic status of local farmers); and follow-up plan will certainly help the farmers to practice climate-smart agriculture in the region. But again, one thing must be remembered: the performance of these RCTs is site specific, and one should be very careful while selecting them. Hereby, we are going to discuss them one by one briefly.

2.11.1 RCTs Cutting Off Evaporation Losses and Their Effect on Land and Water Productivity

2.11.1.1 Short-Duration Crop Cultivars

The shorter the stay of a crop in the field, the lesser the evaporation is, and thus the lesser the total number of irrigations which finally results in higher water productivity. Pusa-44 takes about 160 days and consumes significantly higher irrigation water with comparatively lower yields compared to PR-126 and PR-127 which take about 123 and 137 days, respectively, which further saves about 15–20% of irrigation water along with a cutdown two sprays of insecticides (PAU 2018). Therefore, the farmers of the regions suffering from shortage or scarcity of water, viz., central Punjab, must cultivate short- or medium-duration crop cultivars recommended by state agricultural universities for improving both land and water productivity.

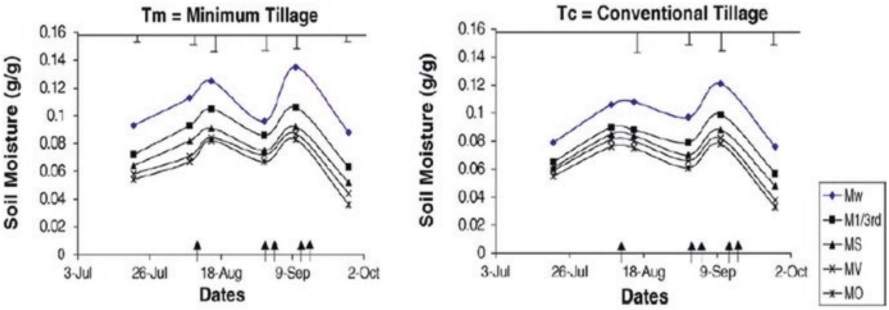

Fig. 2.3 Soil moisture content of surface soil vis-a-vis tillage and mulch application (Bhatt and Khera 2006)

2.11.1.2 Mulching

Mulching is a practice by which the so remained crop residues spread over the bare land which is reported to improve overall livelihoods by avoiding contact of hot radiations, regulating the soil temperature regimes, decreasing vapor pressure difference within soil and ambient air, decreasing lifting capacity of the air, and suppressing weeds (Fig. 2.3) (Bhatt and Khera 2006; Bhatt et al. 2004; Yadav et al. 2017b). Furthermore, Jalota et al. (2007) delineated 7–40 cm of irrigation water savings with mulching; and the benefits from mulch are contingent upon seasonal rainfall, irrigation regime, soil consistency, and kind of mulching material. Mulching reduced soil evaporation component by 15.8 cm in maize and 20 cm in both cotton and sugarcane (Jalota and Arora 2002).

However, improvement in land and water productivity decreased drastically if mulch load was removed which even affected the performance of the resource conservation technologies (Bhatt and Kukal 2017). Bhatt and Kukal (2015a, b) reported that removing mulch loads during intervening periods causes increased soil temperature, lesser volumetric content, and finally higher evaporation losses in the rice-wheat cropping sequence depicting the importance of the mulch in overall improvement of the sustainability of this sequence in the region.

2.11.1.3 Zero Tillage

As far as dealing with crop residues is concerned, almost every option has a limitation. Burning residues in the field then causes air pollution and allows the fixed carbon to go back in air which further causes global warming (Bhatt 2016, 2017; Bhatt and Singh 2017; Ram and Meena 2014). Another option is the incorporation of the residues back into the soil, but this option causes N immobilization and causes yield loss in the next crop. So finally, what should be done? The answer to this very question is Happy Seeder which directly drills wheat seeds in standing rice stubbles. Furthermore, there is no need for pre-sowing irrigation which finally causes around 30% savings in irrigation water (Singh et al. 2008). Experiments carried out at different agroclimatic regions delineated that in wheat, there was more pronounced effect on water conservation observed in dry periods with reduced and no-tillage systems (Rahman et al. 2005; Verhulst et al. 2011). Rice stubble mulch augmented mean wheat grain yield by 17.1%, lessened crop water uses by 3–5%, and enhanced WUE by 38.3% associated with no mulch (Chakraborty et al. 2010; Meena et al. 2018b). Probably due to greater retaining of soil wetness in the more profound layers with mulch, roots grow 25% higher compared to those with no mulch in lower layers (>0.15 m). Happy Seeder allowed sowing of wheat seeds in the standing paddy stubbles without removing rice stubbles outside the field along with sharing the benefits of mulching which decrease the evaporation losses and decrease the amount of water used per irrigation and partition higher fraction of evaporation component to transpiration which ultimately improves land and water productivity in the region.

But at some sites, zero-tillage plots are reported to be having significantly higher weed population. The reason claimed by different scientists is remaining of weeds on the soil surface which further enjoyed the higher availability of moisture and nutrients while under conventional tillage and weed seed placed deeper in the soil depending upon the tilling depth of the instrument used. At deeper depths, both moisture and nutrient availability is cut down which significantly affects their germination and, thus, finally cuts down weed pressure significantly higher than that of zero-tillage plants (Bhatt and Kukal 2017; Bhatt 2015; Singh et al. 2015a, b).

2.11.1.4 Date of Transplanting

Date of transplanting is very crucial for uplifting livelihoods of poor farmers in the rice-wheat cropping sequence as early transplanted crop has highest evapotranspiration losses and lower land and water productivities (Table 2.3), the reason being that in May air is dried and has higher water evaporated by it; thus, we have to apply frequent irrigations to meet irrigation requirements of the plants. With transplanting after June 20, monsoon arrives in July–August, which increases the humidity in air and decreases its vapor lifting capacity; and finally duration in between two irrigations increases and lowers the total number of irrigations, which finally results in higher water productivity. The water productivity is reported to be 17% higher in June 25 transplanted rice than May 25 transplanted rice. Jalota et al. (2009) using the CropSyst model estimated a significant improvement in water productivity by adjusting transplanting date and crop cultivars.

Table 2.3 Effect of transplanting date and variety on yield and water requirements of rice (Jalota et al. 2009)

Transplanting date	Irrigation water (mm)	Grain yield (t ha^{-1})	Irrigation water (mm)	Grain yield (t ha^{-1})
	PR-118 (155–160 days)		RH-257 (110–120 days)	
May 25	2530	7.5	2350	6.8
June 10	2420	6.6	2310	7.3
June 25	2270	7.1	2120	7.5
Mean	2407	7.1	2260	7.2

2.11.1.5 Crop Diversification

Crop diversification plays a pivotal role in decreasing the amount of irrigation water required, and it was revealed that (Jalota and Arora 2002; Arora et al. 2008; Dadhich et al. 2015) particularly diversion from rice helped to increase water productivity for the system as a whole. Evapotranspiration losses decrease if the system is diversified from rice-wheat rotation to cotton-wheat or to maize-wheat rotation as cotton and maize have lesser water requirements (Table 2.4).

Wetland puddle rice must be replaced with other alternative crops to lower ET requirements. The photosynthesis and crop-specific seed composition are two most important factors affecting land productivity (Ali et al. 2012). The exchange between leaf photosynthesis and water loss is comparatively higher in C_4 crops. By substituting rice with maize in the rice-wheat system, the irrigation water is reported to be lower, but productivity of the rice-wheat system is still in question (Gathala et al. 2014; Meena et al. 2017b). The WP_I of rice (5–5.6 kg m^{-3} based on rice corresponding yield) was 8–22 times lower than that of maize. The maize-wheat cropping system had 126–160% higher irrigation water productivity than that of the rice-wheat cropping system.

2.11.2 RCTs Cutting Off Drainage Losses and Their Effect on Land and Water Productivity

2.11.2.1 Direct Seeded Rice

For reducing the irrigation water amounts (in puddling operations) and for improving the degraded soil structure (caused by puddling), direct seeded rice (DSR) is a way out as it neither involves the puddling operations nor involves the standing irrigation water for 15 days (as in AWD and in tensiometers). This RCT sows directly rice seeds into the soil using seed cum fertilizer drill. However, the land productivity often is somewhat lower due to severe iron deficiency; much more weed pressure etc. as it particularly more truely in the zero till DSR plots. Furthermore, it is very important to consider the rice-wheat system as a whole including intervening periods. Bhatt (2015) observed significantly higher irrigation water productivity in conventional tillage DSR than zero-tillage DSR.

In DSR, it was observed that aerobic rice cultivars responded well than the lowland cultivars in terms of grain yield under water-stressed conditions, viz., water-deficient areas; however, under submerged conditions, the lowland cultivars had an edge over the aerobic cultivars (Bouman et al. 2007). Direct seeded cultivars have a lower yield potential than the flooded cultivars but with 50% less consumption of water. Thus, they could be very well cultivated in a region facing scarcity of water and having heavy-textured soils as this technology proves to be a failure in the light-textured soils (Bhatt and Kukal 2015a, b, c, d; Kumar et al. 2017a).

2.11.2.2 Laser Leveling

Among various RCTs advocated for the region for improving land and water productivity, laser leveling is widely accepted and adopted because of the fact that laser

Table 2.4 Diversification for improving water productivity (Jalota and Arora 2002; Arora et al. 2008)

			Land productivity (t ha^{-1})			Water productivities (kg m^{-3}) based on	
Cropping systems	ET (mm)	E_b (mm)	C_1	C_2	Wheat corresponding yield (t ha^{-1})	ET	NWL
Rice-wheat	1030	210	6.0	4.5	9.7	0.94	0.78
Cotton-wheat	980	901	2.0	3.5	8.6	0.88	0.80
Maize-wheat	860	220	3.5	4.5	7.2	0.84	0.67

leveling levels all the dukes and dikes and causes uniform distribution of water and causes irrigation on a large area within a shorter period of time. Around 25–30% of irrigation water could be saved with laser leveling without affecting crop yields (Bhatt and Sharma 2010). Furthermore, Jat et al. (2009) have well documented the crop yield augmentation coupled with improved irrigation water productivity with precision land leveling.

2.11.2.3 Permanent Beds

Permanent beds are recommended for increasing the declining land and water productivity. Jat et al. (2005) observed comparatively higher irrigation water productivity (kg grain m^{-3} water) under permananet beds than in CT (42%) and ZT (35% higher), respectively; but Kukal et al. (2009) have reported no savings in amount of irrigation water under PTR and transplanted rice on permanent raised beds in a sandy loam soil, because of higher cracking of loam in permanent beds when a full-furrow depth of irrigation was applied; but on the contrary, higher water use efficiency (WUE) was observed in bed-planted crops (Brar et al. 2011; Sihag et al. 2015) although with time, the irrigation water productivity on permanent beds decreased as slopes of side beds were compacted due to tractor tire pressure during repeated reshaping (Kukal et al. 2008). But Kukal et al. (2008) further provide evidence that these beds were quite effective initially but year after year due to reshaping operation the side slope of beds got compacted resulting in higher bulk density. Moreover, the surface area of these beds was about 25% higher, resulting in higher absorption of radiant energy which resulted in higher evaporation losses and more water needs; and finally aged beds had lower water productivity.

2.11.2.4 Soil Matric Potential-Based Irrigation

It is the main driving force as water moves from higher energy level to the lower energy level (Bhatt et al. 2014). Tensiometer measures the soil matric potential, thus a quite effective technique to decide when to irrigate a crop based on the soil suction behavior (Fig. 2.4). Kukal et al. (2005) and Bhatt and Sharma (2010) reported that soil matric tension-based irrigation scheduling helps in significant savings of irrigation water with almost similar/higher yields, thus helping in increasing water productivity in the region as it dictates the farmers as when to irrigate. In the absence of the mulch load, tensiometer depicted higher SMP readings than that of the mulched plots indicating higher evaporation losses (Bhatt and Kukal 2015a, b).

2.12 Conclusions

The rice-wheat cropping sequence in South Asia has taken a toll on natural resources, air, water, and soil. Several resource conservation technologies, viz., zero tillage in wheat and direct seeding and mechanical transplanting of rice under different tillage conditions, being advocated in the region, have been studied under isolated conditions for individual crops and are shown to be resource-conserving techniques. Furthermore, changes in rainfall patterns, increasing temperatures, and frequency of

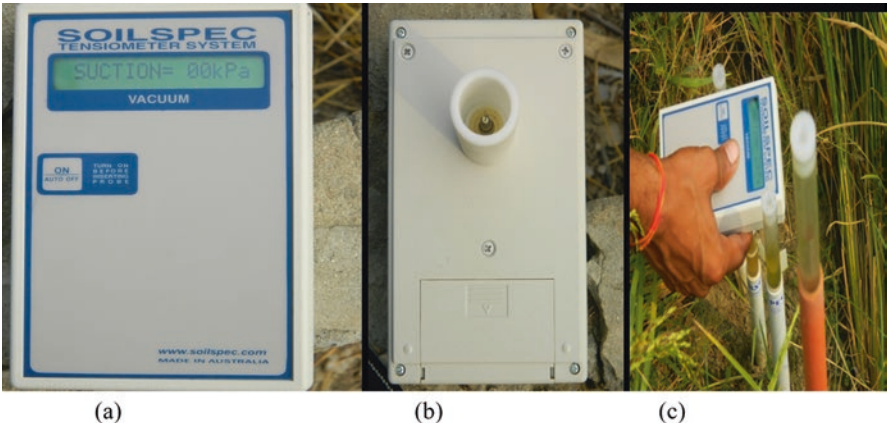

Fig. 2.4 Soil spec front view (**a**), rear view (**b**), and in action measuring soil water tension (**c**)

extreme weather actions, viz., droughts, floods, etc., are expected to slow down the progress toward sustainable agriculture. These consequences of climate change are already having serious impacts on crop yields, especially for the rainfed regions. Therefore, an integrated approach is the requirement of the time (keeping in mind the socioeconomic conditions of the local farmers) to improve the ever-decreasing livelihoods of South Asian farmers in the current period of climate change. CSA is an answer to all these urgencies whose principles help us to fulfill all demands of food in the era of ever-decreasing land resources and when the whole world is facing abrupt change in the weather parameters. CSA also reduces soil degradation by increasing soil organic matter and by reducing soil organic carbon losses through oxidation by advocating the concept of zero tillage and thus increasing resilience to climate change impacts. Scientists must have to evaluate sound scientific resource conservation technologies which have the potential to minimize the emission of CO2, CH4, and N2O gases in the atmosphere. Furthermore, new agricultural programs/schemes/plans provide a good opportunity for CSA practices either by providing some incentives or by creating awareness among the local farmers. One must consider the following points to formulate the new policies:

(a) Enabling policymakers, institutions, makers of legal frameworks, financers, and the government to act for practicing CSA in a better way.
(b) Climate change and opportunity must be studied even at school level for identifying the emergency to apply CSA.
(c) Climate projections and trends must be delineated at regular intervals.
(d) For mainstreaming and scaling up CSA, there is a need to map CSA practices along with capacity building, changing mind-sets, and enhancing regional collaboration.

Therefore, there is a need to identify the seriousness of the present situation by sharing knowledge; facilitating collaborations; setting goals of both improved land

and water productivity; raising awareness among all who could contribute, viz., students, farmers, extension workers, and policymakers; knowledge upgrade as well as technical support, and then finally execution at the farm.

There is a need to check the performance of a particular set of CSA technologies after a certain period of time, thereafter making certain effective changes wherever required after obtaining the consent of the local farmers. Furthermore, adoption of CSA practices largely depends on updating the extension worker inherent knowledge, formulating farmer-friendly political action plans, proper understanding between farmers-extension workers and government bodies, and proper storage facilities for proper storage of surplus grains. Farmers adopting CSA practices thereby emitting lower greenhouse gases will be rewarded, and this practice will certainly encourage the others. Proper crop insurance must be there for maintaining livelihoods even in case of certain uncertainties, viz., floods, droughts, etc. Small farmers generally hesitate to adopt CSA practices generally because of financially limited resources and unawareness toward a new approach as mostly they want to walk on the road of their forefathers without deflecting from it. For financial limitations, governments, different NGOs, NABARD, and other cooperative banks must propose good schemes for CSA farmers, while for improving awareness, national education and research systems should be strengthened.

2.13 Future Strategies

For the upcoming CSA programs to be effective, the following actions must be planned for overall improving the declining land and water productivity in the region:

- By adopting a proper concerted mechanism, improve acceptance of climate change in agriculture by mapping climate change effects and trying to incorporate them in seasonal climate outlooks.
- By involving local people of the area by creating awareness on the influences of global warming on agriculture and its associated sectors, viz., poultry, fishery, dairy, etc., frame different integrated packages for texturally divergent soils.
- Try to frame some common SWOT analysis for countries affected by climate change so that they could develop their own mechanisms to come out from this challenge.
- Appropriate regional platforms either at village, regional, national, or even international level will be established for having healthy interactions between grassroots stakeholders, viz., farmers, scientists, and policymakers.
- The CSA concept will be incorporated in all national reports and communication documents.
- Different committees at state or national level well supported by the policymaking body of the government will be constituted for effective implementation of the CSA programs. Furthermore, more funds will be diverted to CSA activities by the government in different CSA programs.

- New farming techniques, viz., vertical farming, more particularly for the urban areas, are impending for achieving self-sufficiency in food production to meet present food demands.
- Delineation of advocated advanced resource conservation technologies and their interactive effect on declining water and land productivity on a regional scale (using different models joined with environmental information system and remote sensing technique) is a must, which provides us an integrated approach suitable for a particular soil texture and agroclimate.

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