Natural Resources Intensification and Footprints Management for Sustainable Food System

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Abstract

The global population are approaching to 10 billion by the year 2050, therefore to encounter the food security of the increasing population it has been anticipated that production of food must be improved by 70%. Despite more food production and increasing the poverty level are the foremost difficulties to fulfil the nutrition and food demand for the emerging world. At the same time, climate change creates a great barrier to improve agricultural productivity. It has been recognized and proved that traditional agricultural practices do not reduce the rural poverty and degradation of the ecosystem. Food production systems are not always environmentally friendly and cost-benefit depends on imbalanced use synthetic fertilizers and pesticides. Therefore, it is indispensable to expand environmentally friendly technologies for sustaining crop yield. Earlier evidence proved that under the future changing climate, the food demand for the growing people across the globe can be only attained through the management of agroecology; since it emphasizes on resource conservation farming practices, reworking small farm enterprises, the participation of more farmers, traditional knowledge of the farming community, improved plant genetic multiplicity, and avoid to use of imbalanced synthetic pesticides and manures. The chapter focuses on the sustainable agroecological based crop production systems without hindering the agro-ecological environment for the nourishment of the growing population particularly in emerging nations of South Asia under changing climate.

Keywords

Agriculture · Agroecology · Climate change · Food security · Sustainability

Abbreviations

ALF	Agricultural Land Footprint
AWD	Alternate Wetting and Drying
BF	Biodiversity footprint
BLF	Built-up Land Footprint
BWF	Blue Water Footprint
CA	Conservation Agriculture
CF	Carbon Footprint
CH_4	Methane
CLF	Crop Land Footprint
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CT	Conventional Tillage
DSR	Direct Seeded Rice
ECF	Economic Footprints
EF	Ecological Footprint
EMF	Emission Footprint
ENF	Energy Footprint
FF	Financial Footprint
FGF	Fishing Grounds Footprint
FLF	Forest Land Footprint
GDP	Gross Domestic Product
GHGs	Green House Gases Emission
GLF	Grazing Land Footprint
GWP	Global Warming Potential

HF	Human Footprint
HYV	High Yielding Crop Variety
IGPs	Indo-Gangetic Plains
INM	Integrated Nutrient Management
LCA	Life Cycle Assessment
LCC	Leaf colour chart
LF	Land Footprint
MI	Maintainable Improvement
N_2O	Nitrous oxide
NF	Nitrogen Footprint
NH_3	Ammonia
PF	Phosphorus Footprint
RCTs	Resource Conservation Technologies
RW	Rice–Wheat systems
RWRs	Renewable Water Resources
SA	South Asia
SD	Sustainable Development
SO_2	Sulphur Dioxide
SOC	Soil Organic Matter
SOM	Soil Organic Matter
SPI	Sustainable Process Index
SRI	System of Rice Intensification
SSNM	Site-Specific Nutrients Management
WF	Water Footprint
WPF	Water Pollution Footprint
WSF	Waste Footprint
ZT	Zero-Tillage

2.1 Introduction

The population across the globe are approaching to 10 billion by the year 2050, therefore to encounter the food security of the increasing population it has been anticipated that production of food must be improved by 70% (de Schutter 2010; European Commission 2011; Ojha et al. 2014). Therefore, to satisfy the food and nutrition in the emerging world, there is an urgent to improve food production. At the same time, agricultural productivity is going to face the extreme event of the changing climate (IPCC 2007). Anxieties are increasing for adaptation of agriculture to the changing climate (Vermeulen et al. 2012), it is due to not only the threat of climate change to agriculture (Aggarwal 2008) but also link to the livelihoods of rural poor across the globe (Mew et al. 2003; Rosegrant and Cline 2003; Parry et al. 2004; Mall et al. 2006).

Several studies already evidenced that changing climate already hits South Asia. (Nelson 2009). For example, Kumar and Parikh (2001) anticipated the damage of about 8.4% of the overall net-returns of farmers in India as a result of the hostile consequences of environment. The people in the region are experiencing the climate change crisis also reported by Ojha et al. (2014), who conducted a study with 303 farm households across three countries of South Asia (SA) (India, Bangladesh, and Nepal) and revealed that 78% farmers are approved that summer day are getting hotter; 66% are approved that winter-time is getting colder and 44% are approved that precipitation during the rainy season is scared as compared to earlier. The agroecological condition of South Asian countries is deteriorating day by day due to traditional agricultural practices. It has been recognized and proved that traditional agricultural practices could not reduce the rural poverty and degradation of the ecosystem. The food production systems are not always environmentally friendly and cost-benefit and depend on imbalanced use synthetic fertilizers and pesticides (de Schutter 2010; European Commission 2011; Ojha et al. 2014; Meena et al. 2020a). Therefore, without considering agroecology, it is impossible to encounter the nutrition safety of the growing people.

Agroecology is the initial frame in the house of worship of the 'Green Revolution', expressed by Dr. José Graziano da Silva, head of the FAO in the closing ceremony of a two days convention, entitled 'Agroecology for Food and Nutrition Security', which was held on 18–19 September 2014 at FAO's headquarters in Rome, Italy. In his new version, Dr. Silva mentioned that agroecology must be well-thought-out as key attention for the rising global substitutions for resolving food safety of the increasing population in the modern era of the changing climate (Gliessman and Tittonell 2015). The benefits of the agroecological farming also urged by organizations (i.e., the FAO, UNEP, and Biodiversity International) included in World Food Security-1 in the year 2012 (de Schutter 2010; European Commission 2011).

Therefore, it is crucial to improve resource conservation, cost-effective, and environmentally friendly technologies for conserving agricultural outputs. The sustainable nourishment for the growing inhabitants can only be attained through the management of agroecology; since it emphasizes on resource conservation farming practices, reworking small farm enterprises, the participation of more farmers', traditional knowledge of the farming community, improved plant genetic multiplicity, and escape to over-use of excessive synthetic pesticides and fertilizers.

The chapter focuses on the sustainable agroecological based crop production systems without hindering the agroecological environment for the nourishment of the growing population particularly in emerging nations of South Asia under changing climate.

2.2 Major Components of Agroecology in South Asia

The term agroecology refers to an integrated approach of ecological and social principles, and their application to design agriculture and allied systems in sustainable manners. It aims to optimum use of natural resources and their interaction with each other to build up a fair and sound farming system. The different components of

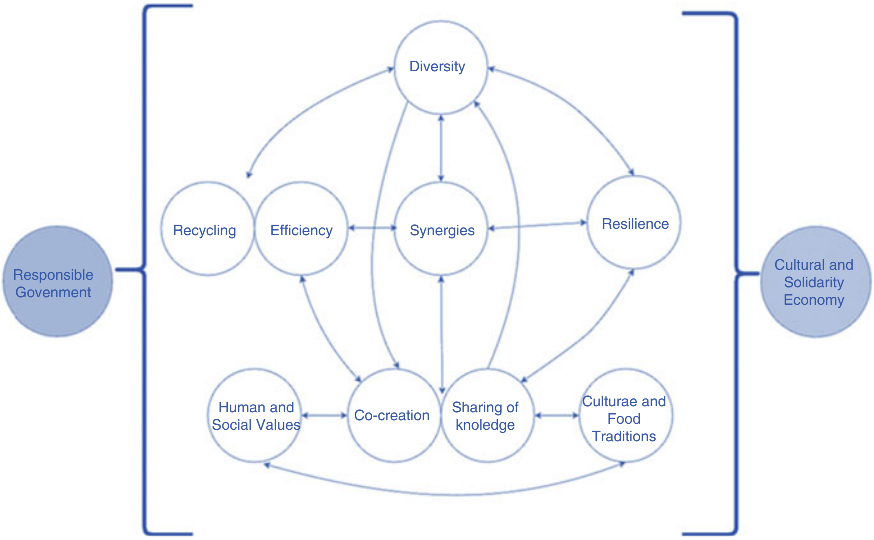

Fig. 2.1 Intra-relationship between the major components of agroecology

the agroecology are intra-related to each other (Fig. 2.1). In this section, we have discussed the major components and their present status in the South Asian region.

2.2.1 Diversity

Diversity is the key component to agroecology that strengthens ecological and socio-economic resilience by understanding the way of conserving and increasing the resource use efficiency. SA comprises of 8 countries and 5 time zones. Hence, a wide range of agro-climatic diversities, cultures, traditions, food habits, and economics exist in this region as follows:

2.2.1.1 Diversity in Land Resources

Huge population pressure and no scope for horizontal augmentation of arable land make it the most crucial resource in SA. Bangladesh uses the maximum land (70%) under cultivation over the total land area, closely followed by India (60%). However, Pakistan, Sri Lanka, and Nepal have utilized 30% of their land only for cultivation purposes (FAOSTAT 2004). Additionally, Bangladesh accounted for the maximum value in irrigation intensiveness (165%), whereas it was 110% for Pakistan (Weligamage et al. 2002).

2.2.1.2 Diversity in Water Resources

In SA countries the maximum rainfall happens through S-W monsoon and winter faces a huge water crisis. Almost 4000 mm precipitation occurs in Bhutan and just 1083 mm is received by India. Pakistan has received only 80 mm of rainfall (Ali et al. 2012). In case of renewable water resources (RWRs), India has the highest RWRs (1911 km^3) next to Bangladesh (1200 km^3), Pakistan (223 km^3), Bhutan (78.0 km^3), and Sri Lanka (52.8 km^3) (FAO 2011). Bhutan is known as the water surplus country, while Pakistan runs in negative in the context of available water resources.

2.2.1.3 Diversity in Climate Change

It has been projected that in SA region 0.5–1.2 °C temperature will rise at the end of this century and 0.88–3.16 °C by the year 2050, and 1.56–5.44 °C by 2080 (reported by IPCC 2007). The effect of global warming would be more in low altitude and dry season in developing countries. Some parts of India such as the west coast, a part of Gujarat and Kerala would be received 6–8% more rainfall than normal in recent future (FCCC 2012). The spatial distribution of temperature change indicates that the central, peninsular, north-east, and west coast India will face the challenge of higher temperate, while north-west and southern India will observe the cooling trend (Kavikumar 2010).

2.2.1.4 Crops Diversification

The diversification of crops refers to the accumulation of different types of crops or systems of cropping into a farming system for getting a higher return. The mono-cropping system has been gradually diversified by the high-value field crops, fruits, and vegetables in SA. Introduction of the dwarfing gene in the agricultural system is a key point for the advancement of diversification in this region. Though the rice–wheat system is the main cropping system for livelihood support in IGPs of SA, but recently rice-maize, cotton-wheat, rice-pulses are being popularized. Among the SA countries, Bangladesh, India, Nepal, and Sri Lanka are most rice intensive countries. Besides the crop diversification, integrated farming, rice cum fish, livestock rearing is gaining attention among the farming communities.

2.2.1.5 Land Diversification

Land diversification refers to the modification of crop establishment techniques, alternate land-use, tillage system, and land management to increase the soil health as well as productive capacity per unit area. Conservation agriculture (CA) is the most promising cost-effective and environmentally friendly technique that includes the least soil-disturbance, soil-cover, and crop diversification. Currently, in SA covers 5 Mha land under conservation agriculture (Friedrich et al. 2012). In India, zero-till wheat cultivation after harvesting of *Kharif* (rainy) rice under the presence of crop residue is most popular conservation agriculture practice in the north-western states. Another approach of alternate land-use system is agroforestry. The most popular agroforestry systems in SA are agri-silviculture and agripastoral system. Poplar and Eucalyptus are major tree species and tea, coffee, black pepper, and cardamoms are also cultivated with perennials trees. The agroforestry not only properly utilizes the spatial and temporal resources but also it is considered as a great source (Jhariya et al. 2015; Singh and Jhariya 2016).

2.2.2 Establishment and Disseminate of Experiences

The effectiveness of farming innovations realizes better when farmers sharing their experiences through a common participatory programme. The co-creation of traditional or indigenous knowledge, practical knowledge blends with scientific knowledge may be very effective to bring the innovation to address the common challenges in agriculture. In SA, farmers' participatory programme, front line demonstration, method demonstration, lab to the land programmes are operated for this aspect (Glendenning et al. 2010).

2.2.3 Government Policies, Institutions, and Public Goods

The effect of Green Revolution in India was realized in 10% of the area with adequate facilities like irrigation system, availability of HYVs, electricity, and nutrient management but most of the area in SA, agriculture systems have been inhibited by the absence of structure. Most of the govt. policies favour urban areas and manufacturing sectors rather than agriculture. Decentralization of government policies and indigenous institutional presentation will be the significant concerns in the progress of maximum agricultural systems. The increase in participation of women in agriculture is another advantage of decentralization.

2.2.4 Synergies

Construction of collaborations in food systems delivers numerous welfares. By improving natural collaborations, agroecological performance boosts the ecological utilities, leading to better reserve use effectiveness and flexibility. As a piece of evidence, incorporation of pulses in the cropping system saves 10 million US $nitrogenous fertilizer in every year (FAO 2016). Crop–livestock interaction provides 15% of nitrogen out of total applied N to crops (FAO 2017). In SA, integrated rice systems in combination with other foodstuffs such as fisheries, duck raring, and trees plantation maximize the synergies in respect to dietary multiplicity, produce, control of the weed, soil properties, and productiveness, as well as providing biodiversity habitation and nuisance control (FAO 2016).

2.2.5 Resource Use Efficiency

Improved reserve usage efficacy is embryonic stuff of agroecological systems that judiciously design and accomplish the assortment to create collaborations between components of diverse systems. As a proof, zero-tillage (ZT) has the potential to save 75% of fossil fuel consumption, and 40–50 US$ over conventional tillage (CT) (Malik et al. 2002; Meena et al. 2020a). Furthermore, zero-tillage (ZT) increases soil C sequestration and converting CO_2 into O_2 as well as enriches

SOC. Bed planting in the rice–wheat system at IGPs saves 18–50% of irrigated groundwater (Jat et al. 2005). Implementation of SSNM technique improves the crop yield by 58% and 42% in the rice–wheat system and accounted for 48% more yield in rainy season rice and 52% in winter rice (PDFSR 2011). Leaf colour chart (LCC) based N application has curtailed 50% of nitrogenous fertilizer ha^{-1} without altering the rice productivity as compared to growers' practice and improved the N usage effectiveness by 20–35% in both maize and rice (Ramesh et al. 2016). The implementation of resource conservation yielded 0.5 MT more wheat and hold back 80 million US$ by lowering fuel consumption, tillage practices, and input use.

2.2.6 Recycling

'Waste' is an anthropological perception—it does not be present in natural environments. By emulating natural ecology, agroecological accomplishes and biological procedures that initiate the recycling/reusing of nutrients, biomass and water within production systems, the natural reserves utilization ability can be assessed. For example, deep-rooted crops in agroforestry system hold the nutrient leaching beyond the root zone that enhances the soil available nutrients (Buresh et al. 2004). In SA, recycling of 668 t rice residues has the potential to generate 708.70 lit of bio-ethanol (Kim and Dale 2004).

2.2.7 Resilience Building

Resilient building in agriculture and ecosystem is the key component for sustainability. In recent years, climate-resilient is the major focus in all over the world. SA countries are situated in the diverse agro-climatic region. Hence, location-specific and cost-effective adaptation and mitigation strategies are essential. Aerobic rice cultivation and livestock management can help to reduce 9% of total anthropogenic CH_4 emission (Smith et al. 2007; Meena et al. 2018). Location-specific conservation agriculture enhances C sequestration up to 1.0 t ha^{-1} (Corsi et al. 2012). However, the lower adaptation of CA (4.72 Mha) and awareness are the major constrain in SA (Friedrich et al. 2012). Furthermore, micro-irrigation such as sprinkler does not release any CH_4 (Pathak et al. 2011). They also observed that if the flooded rice field can be adjusted to mid-season drainage the global warming potential (GWP) will be reduced to 5.6 MT CO_2 eq. and would mitigate GWP by 16.7%. LCC based N application has reduced the N_2O emission by 16% and CH_4 by 11% in rice (Bhatia et al. 2012) in SA. For small holding farmers, adoption of agroforestry can sequestrate 1.5–3.5 t C/ha per year (Montagnini and Nair 2004). Other land management practices like contour farming in a hilly area cover cropping reserved 20–40% more top-soil, agonized fewer destruction, and skilled inferior monetary losses than conventional farming practices (Holt-Giménez 2002).

2.2.8 Social and Human Values

Agroecology poses robust importance on human such as self-respect, fairness, addition, and impartiality to entirely the level of society engaged in the farming activity for improving livelihood dimension. Agroecology encourages gender equality to create opportunities for women as they contribute almost half of the agricultural workforce. Agroecology also provides promising sources of income generation in various ways that are knowledge-intensive, eco-friendly, socially acceptable, innovative, and economically viable.

2.2.9 Tradition of Culture and Food

Human heritage, culture, and food habits are the considerable component of location-specific agricultural planning, as the demand for the foods in the market depends on those aforesaid components. When scientific management practices are merged with indigenous knowledge and culture, wealth agroecological solutions become visible. As an example, India is the origin of more than 50,000 indigenous rice varieties (NBPGR 2013), famous for their taste, nutrient content, disease and pest-fighting ability, and their adaptableness to a wide assortment of situation. Cooking strategies and food habits build up based on those properties of indigenous cultivars. Taking this accrued body of outdated experiences as a controller, agroecology can help to realize the prospective of regions to sustain their peoples.

2.3 Impacts of Intensive Agriculture and Climate Change on Agroecology

Agroecology is the foundation of sustainable agriculture. It provides a robust set of solutions to environmental and economic pressures. Intensive agriculture refers to involvement of heavy tillage, lots of labour and capital, injudicious application of water and fertilizer, crop residue, and fossil fuel burning to obtain higher productivity and profitability without concerning ecological sustainability that degrades natural agroecological system (Poppy et al. 2014). Thus, resource-rich agriculture has been shifted towards resource-poor agriculture day by day. Additionally, climate change poses a predominant threat to humankind. Altering rainfall pattern and temperature fluctuation changes the activities of agricultural landscapes in overwhelming and often destructive ways (Rani and Maragatham 2013). The agriculture sector has been contributed 24% of the total anthropogenic emission (IPCC 2007) which is consisted of CO_2, N_2O, and CH_4, the three major greenhouse gases. Rigorous energy uses in farming activity and land management are the broad anthropogenic sources of GHGs emission. From the aforesaid, it has accredited that intensive farming activities to meet the food demand and climatic variability during the twenty-first century have been affected by the existing agroecology in several avenues.

2.3.1 Global Warming and Weather Migration

Climate change, a consequence of the rising GHGs emission, particularly upper level of CO_2 emissions will lead to increase the global average temperature by 2–6 °C within the year 2100, which is almost more than doubled as compared with the existing temperature, predicted by IPCC (Calzadilla et al. 2013; IPCC 2020). The average global temperature rising will lead to the shifting of weather patterns 300–500 km away from the equator and towards the poles, thus changes the existing agroecology, cropping pattern, pest infestation, etc. Higher CO_2 concentration and soil temperature lead to a higher C:N ratio, which may reduce the decomposition rate, and thereby lowers the nutrient mobilization.

2.3.2 Land Value Degradation

Rising ocean temperature, glaciers, and ice sheets melting are attributed as major reasons for the contemporary sea-level change. It was estimated that at the finishing of the era, the average sea level would be raised by more 1 m and consequently the frequency of the cyclonic events and storm surges would likely to be increased (IPCC 2007). It was evidenced that rice yield has declined by 1.6–2.7%, accounted for US$ 10.6 billion financial losses from last 45 years (Chen et al. 2012) only due to the land value degradation.

Major rice exporting countries like Myanmar, Vietnam, and Egypt are expected to shift as importer countries. Intensive agriculture such as heavy traffic movements in the crop field, bare soil, and frequent tillage operations makes soil vulnerable to erosion. In India, an area of 174.2 m ha is hypothetically unprotected to several degradations such as water (153.2 m ha) and wind (15 m ha) erosion and as a consequence, the per capita land availability has been declined from 0.32 ha to 0.19 ha from 2001 to 2050 (Table 2.1). Furthermore, soil acidity and alkalinity cause 25 m ha and 3.6 m ha of land degradation in India, respectively. It is estimated that only 141 m ha land is available for agricultural practices and a very little scope exists

Table 2.1 Available resources and projected resources in future

Land resource	Total area (Mha)	Per capita availability (ha)		
		2001	2025	2050
Total land area	328	0.32	0.23	0.19
Net sown area	150	–	0.11	0.09
Gross cropped area	250	0.19	0.18	0.14
Net irrigated area	87	0.06	0.06	0.05
Gross irrigated area	100	0.08	0.07	0.06
Area under forest	75.5	0.07	0.05	0.04
Total area covering greenness	120	0.12	0.08	0.07
Total area that can produce biomass	270	0.26	0.19	0.15

Data source: State of Indian Agriculture (2009) for further increase in agricultural land (Manivannan et al. 2017; Meena and Lal 2018).

2.3.3 Deterioration of Soil Quality

Both intensive farming and climate change affect the soil physical, chemical, and biological properties. Rapid tillage accelerates soil erosion and hardpan formation. It was reported that intensive practices lower the soil organic matter (SOM) by 61.7%, devastation of soil construction 27.0%, and cause soil destruction 4.3% (Kughur and Audu 2015; Meena et al. 2020b). The most significant impact of climatic variability is the changes in CO_2 concentration in the atmosphere and this gaseous component has acknowledged as the key element of plant photosynthesis. However, the excessive level of CO_2 concentration supplemented with other climatic anomalies may deprive the production ecology below the existing level (Khan et al. 2020a, b). Root surface area is mostly affected by belowground climate change than other factors. Additionally, studies regarding the influence of soil biological environment due to climate change have strongly associated with the changing the soil temperature and CO_2 concentration. This situation significantly influenced the N mineralization process and increased the concentration of solution-phase N (Pendall et al. 2004; Meena et al. 2020c). Nevertheless, it is very problematic to forecast the behaviour of other macronutrients like K in soil solution as its availability does not considerably regulate by soil biological environment. The SOM has a vigorous function for sustaining the fertility of the soil by holding the macro and micronutrients for plant growth. The SOM also plays a significant role for holding the soil particles together as stable aggregates, improvement of soil physical possess ions including water-holding capability, and delivers gaseous interchange and growth of plants root (Lal 2004; Jat et al. 2018). It is also the food source for soil microorganism and acts as a balancing agent for toxic materials by sorption of this heavy metal. Currently, human-made forest firings for horizontal land intensification, clean cultivation, and continuous mono-cropping and fallow land mainly in the dry season are lowering C sequestration for the prospect of farmland. When the presence of this organic carbon in soil increases, the chances of storing to the atmosphere will reduce; as a result, the potentiality of global warming will be alleviated. It was estimated that for Indian soil the optimum soil organic carbon (SOC) should be in between 1 and 1.5%, while its value has come down to 0.3–0.4% (Singh et al. 2014). It was reported that almost 46% of the soil of India has a deficiency of nutrient because of the poor inherent fertility of soil aggravated by the imbalance fertilizer dose. The tendency of marginal farmers of SA to use higher amount N in comparison to P, K, and other secondary and micronutrients creates a nutrient imbalance and widening N:P:K ratio (White et al. 2012; Shew et al. 2019). Nutrient imbalances, immense deforestation, lower SOC, least cultivation of soil restorative crops are measured as the chief causes for the destruction of soil biodiversity.

2.3.4 Worldwide Water Scarcity

Recent reports regarding the climate change revealed that the weather uncertainty has mostly affected on global hydrological system. Arnell (2004) reported that more than 900 million people would be experienced with the severe water shortage in the 2050s. In future, the doubling in CO_2 concentration may not be a cause for a key alteration in precipitation patterns but may result in a huge growth in evaporation and a reduction in water restoration. In India, the intensive farming practices lead to over-extraction of groundwater resources mainly in the agriculturally developed zone, such as northern and eastern India appeared as major hotspots of groundwater depletion as more intensive cultivation of wheat and rice, respectively, demarcated as 'dark zone'. Climate change in terms of maximization of temperature can affect the water quality in various ways such as lowering the dissolved oxygen levels, increasing algal blooming, and most importantly saltwater illustration in the coastal ecosystem. Pollutants transport through the river also likely to be increased as a result of higher rainfall intensity. It is projected that global net irrigation requirements would increase by 3.5–5% by 2025, and 6–8% by 2075 irrespective of climate change (Döll and Siebert 2001; Fischer et al. 2001). Not only water scarcity, but water quality has also been affected for injudicious application of pesticide, fertilizer, and other chemicals to fulfil the aim of intensive agriculture.

2.3.5 Impact on Crop Production and Associative Environment

Crop productivity in agriculture is influenced by climate change either directly, by affecting the factors such as precipitation, temperature, or CO_2 level that directly related with plant growth and development mechanisms or indirectly influenced on associative factors. In general, increasing CO_2 concentration may positively be influenced by photosynthesis rate in C_3, while C_4 type plants show neutral response in a higher concentration of CO_2 as they have a higher affinity on CO_2 (Pep-carboxylase). At a higher level of CO_2 concentration, C_4 plants survive easily in less water than C_3 because of the higher rate of CO_2 uptake and greater stomatal resistance to water loss (Sarkar et al. 2016; Brahmachari et al. 2019). Therefore, the consequence of global warming may not always negatively influence the overall. Apart from CO_2, crop phenology is expressively exaggerated by fluctuations in high temperature. A 1 °C rise in mean temperature shrinkages the grain yield of C_3 plants like rice by 6% and 3–7% in wheat, soybean, mustard, groundnut, and potato (Saseendran et al. 2000). But the leguminous pulse will be less affected in the changing climate scenario because it was established that higher CO_2 level rises the N_2 fixation. Moreover, the pulses can be grown under resource scare condition. The similar impact has followed in oilseed crops. Additionally, the sensitivity of crops towards climate change has differed with their growth stages such as maize is extremely thoughtful to night temperature during pollination and to the shortage of available water.

Environmental change is considered as a foremost cause of weed flora shifting from the tropical and sub-tropical zone to temperate climate and enhances the number of weed species presently limited to the temperate climate of higher altitude (Sarkar 2015; Silberg et al. 2019). Weeds are highly responsive to a small increase in temperature in the tropical region and several reports are available for a substantial increase in weed growth with an increase in temperature. Agricultural intensification through higher input use to get better yield without concern about sustainability is considered as a serious threat to building up some obnoxious weeds, as a glaring example heavy infestation of *Phalaris minor* in rice–wheat cropping system in SA countries (Banerjee et al. 2019).

In the perspective of higher temperature, it would also influence the insect pest population in a complex way under changing climate. Changing the flowering time in the temperate countries due to global warming leads to the addition of different insect species and reaching of a pest status by non-pest insects. Host plant and insect interaction will alter in reaction to the consequence of CO_2 on nourishing superiority and secondary metabolites of host plants. Both direct and indirect effect of moisture stress on field crops make them more susceptible to be damaged by the pest, more precisely in early stages. Precipitation also influences the insect pest infestation, i.e. in winter cereals, aphid population rate could lower under the drought stress condition. However, higher rainfall area may be affected by severe disease pest infestation because of the presence of more relative humidity. Along with climatic variability, intensive farming involves the utilization of excess amount of insecticide without considering the economic threshold level (Saha et al. 2016). Integrated pest management is also negligible in intensive farming. When these chemicals are used, they not only destroy their intended target pests and parasites but also kill beneficial insects which contribute to biodiversity loss.

2.3.6 Occurrence of Extreme Events on Human

Fluctuations in the climatic distribution in the larger area will enhance the frequency of extreme events like drought, floods, heat waves, torrential downpour, and cyclonic events. The occurrence of uncertainties like an extreme growth in temperature (of 6 °C and beyond) is a consequence of higher CO_2 emission suddenly, due to a forest fire. However, the causes for occurring of extreme events are closely related to each other like occurrence flooding mostly depends on heavy rainfall (more intensified) and glacier melting. Globally, the number of severe flooding is being doubled during the last decade and among the extreme events, droughts are taken into consideration as the most detrimental one. The drought is resultant of erratic rainfall distribution, drastic use of groundwater, lowering moisture storage capacity, or the combination of all factors. Modern intensive agriculture aims to produce higher yield per unit area with the adoption of the mechanized farming system. This makes very hard for traditional farmers to compete. Also, this mechanized intensive farming does not create a lot of job per unit of food produced which likely to increase joblessness and farmers have to migrate from agriculture for searching a better livelihood.

2.4 Natural Resources and Footprints in South Asia (SA)

Natural resources of South Asia (SA) comprise mainly of land and water, which must be used sustainably with advanced resource conservation technologies. Coming over to land resources increased population and urbanization had adverse effects on the land resources. Further, problems of water logging, soil salinity, alkalinity, erosion, brick making put an adverse effect on the land resources as they are shrinking, while on other hand, there is a need to produce more from the less land as world's population.

2.4.1 Natural Resources of South Asia

Seven countries of SA including India, Bangladesh, Pakistan, Sri Lanka, Afghanistan, Nepal, and Bhutan are contributing to 23.7% of the population across the globe, but they comprise merely about 4.6% of world annual renewable water resources. At certain locations, conditions become quite serious as in Punjab, India where more than 114 blocks out of total 142 blocks declared as dark zone which means that farmers of those block will have to think seriously by adopting resource conservation technologies. Agricultural contribution continuously decreased in the gross domestic product (GDP), even because of extensive research and the highest share of people to this sector for earning their livelihoods (FAO 2016). That might be because of many sustainability issues, viz. shrinking water resources, the outbreak of insect pest attack, deteriorating soil vigour, arising micronutrients shortage, etc. (Bhatt et al. 2016). From the last few decades, water demand in the other competitive sectors, viz. household, industrial, and hydropower shaping the way the upper reaches of major river systems in SA. Downstream parts of basins facing severe pressure because of escalating water demands particularly under environmental flows and species biodiversity. Shallow water trends showed decreasing trends in Asia as a whole (Fig. 2.2), where experts of NASA, highlighted the drought in each week concerning groundwater and soil moisture; which is derived from GRACE-FO satellite data. In Fig. 2.2, the drought pointers labelled existing wet or dry situations, articulated as a percentile presentation the possibility of incidence for that specific locality and period of a year, where inferior standards (warm colour) sense dryer than regular, and greater standards (blues) sense damper than standard.

The information of the satellite data confirmed that the shallow water trends in Asia are a decreasing trend as a whole. The interactions of climate, topographical, land-use, and socio-economic factors are responsible for the water availability in the South-Asian countries per capita water resources abundant in Bangladesh, Bhutan, and Nepal, whereas rest observed stressed conditions. Total water extractions in SA signify about one-quarter of the accessible renewable freshwater. Experts already

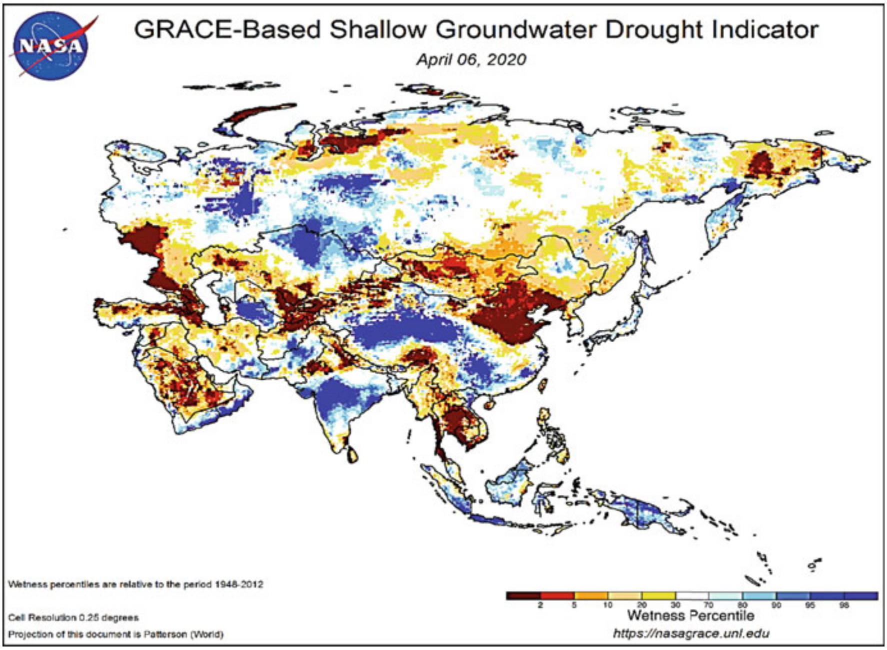

Fig. 2.2 NASA highlights the drought in each week concerning groundwater and soil moisture; which is derived from GRACE-FO satellite data (Source: https://nasagrace.unl.edu/)

predicted that SA is a hot-spot of water-related threats, secretarial for some 40% of natural calamities documented worldwide predominantly under global warming including floods, drought, hike in sea-water level, landslides, and land destruction, specifically in hilly and semi-arid areas. There is a need to predict future climatic conditions, to reduce their impacts as far as possible.

Besides drought, salinity is an additional difficulty in >60% of the area of the Indus-irrigation system, while soil erosion is also detrimental to soil quality in the sub-mountainous tracts where highly intensive rains on the soil with poor organic matter de-attach soil particles. However, eight SA countries, namely India, Bangladesh, Pakistan, Sri Lanka, Nepal, Afghanistan, Bhutan, and Maldives are possessing almost identical land resource and crop types (Fig. 2.3). Different crops cultivated in the South-Asia depending upon the different factors, viz. soil texture, climate, underground water status, availability of the better cultivars, etc. During the recent decades, land productivities of RWCs systems decreased in the IGPs due to numerous problems such as shrinking underground water, deteriorated soil health, micronutrients insufficiencies and wide-spread insect pest infestations, and climate change (Bhatt et al. 2016).

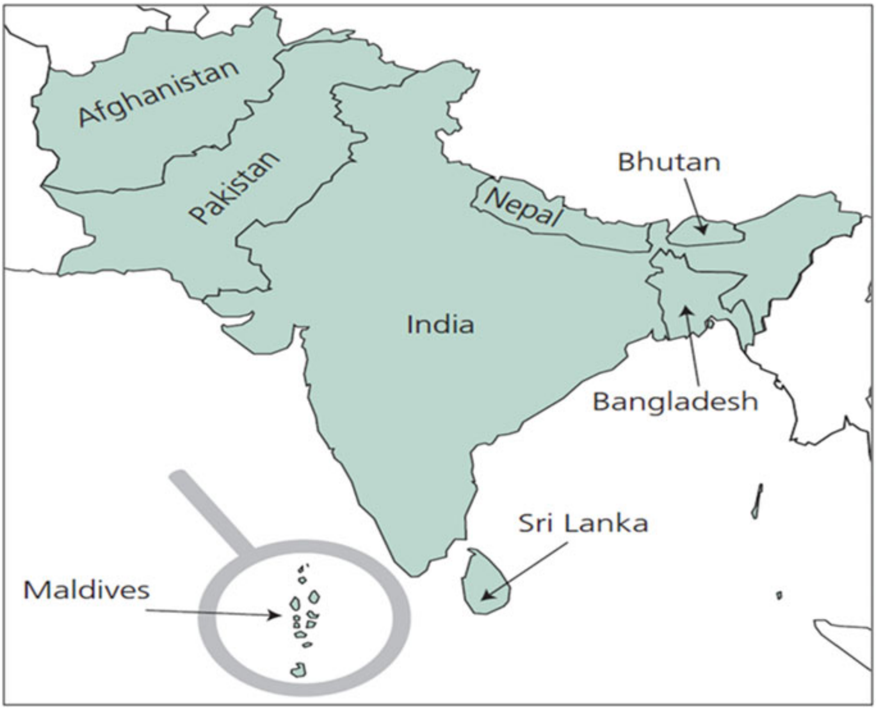

Fig. 2.3 Geographical distribution of these crops in South Asia

2.4.2 Different Footprints

Different footprints (Fig. 2.4) have been recognized and discussed in the following sub-heading:

2.4.2.1 Carbon Footprint

Carbon footprint (CF) from the last few years represents one of the most important environmental protection indicators (Lam et al. 2010; Galli et al. 2012) which deals with CO_2 quantities and other GHGs, viz. CH_4, N_2O, etc. released during a particular procedure or produce (UK POST 2006; BSI 2008). The global warming potential (GWP) (European Commission 2011) used as a pointer for quantifying the CF which is directly linked with climate change leads to global warming (Høgevold 2003). As per another definition shared by European Commission (2011) , CF is because of 'Life-Cycle-Thinking' is linked to global warming. Further, based on land area utilization, CF might be represented by the area prerequisite to confiscate released CO_2 by fossil-fuels through afforestation from the atmosphere (De Benedetto and Klemeš 2009). However, CF related to the estimation of direct and indirect emissions of CO_2 in an action/over the lifespan of a product and delineated in units mass (Wiedmann and Minx 2008).

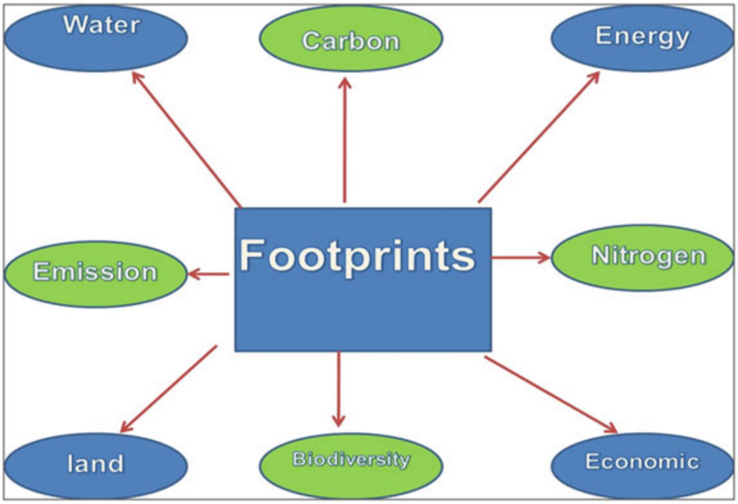

Fig. 2.4 Different footprints which are linked to the agroecology

2.4.2.2 Water Footprints

Water footprints (WFs) represent the total volume (direct and indirect) of freshwater used, consumed, or polluted and are closely linked to the concept of virtual water (Hoekstra and Chapagain 2006; Galli et al. 2011, 2012). Further, WF consists of green, blue, and grey water footprints (comprises of surface and underground water, rainfall consumption, water volume required to dilute polluted water to standards) (Mekonnen and Hoekstra 2010; Klemeš et al. 2009).

2.4.2.3 Energy Footprint

Energy footprint (ENF) may be well-defined as the total amount of lands utilized to afford non-food and non-feed energy; for example, the sum of the land including land for fuel crops, forest land, C uptake land, and hydropower land (European Commission 2011). Further, ENF may be delineated as the total land required for sequestering CO_2 produced for energy usage (Palmer 1998; De Benedetto and Klemeš 2009), without the fraction involved by the oceans, and the part employed by hydroelectric barriers and lakes for hydraulic-power (WWF 2002). ENF also includes fossil (Stoeglehner and Narodoslawsky 2009), wind (Santhanam 2011) nuclear (Stoeglehner et al. 2005), solar (Brown 2009), and renewable ENF (Chen and Lin 2008), as its sub-footprints.

2.4.2.4 Emission Footprint

Emission footprint (EMF) might be termed as product or service quantity-wise responsible for creating emissions, viz. SO_2, CO, CO_2, water (e.g., nitrogen and phosphorus, demand for chemical oxygen), and soil (through emission in the soil) in the atmosphere. Normally, calculations of EMF were done, based on per unit of land required. Lower land intakes' emanations may be degenerate without disrespectful the standard that anthropogenic mass movements must not change the potentials of indigenous sections (De De Benedetto and Klemeš 2009).

2.4.2.5 Nitrogen Footprint

The nitrogen footprint (NF) is an indicator for the measurement of the quantity of volatile compound, which is freed into the environment as a consequence of anthropogenic actions. It is articulated in entire units of Nr (Nr express all types of nitrogen species excluding N_2) (N-Print Team 2011; Leach et al. 2012). The NF symbolizes the disturbance of the provincial to universal N succession and its penalties. NF mainly covers the following Nr emissions: NOx, N_2O, NO_3, and NH_3 which are inter-exchangeable since one Nr form to a different (Galloway et al. 2003). Lack of data and its uncertainty is the major weakness of the NF (Leach et al. 2012).

2.4.2.6 Land Footprint

The land footprint (LF) comprises sub-footprints, including forest (WWF 2002), agricultural land (Kissinger and Gottlieb 2010), the built-up land (Chambers et al. 2004), the grazing land (WWF Japan and GFN 2010), and the crop-LF (Van Rooyen 2005).

2.4.2.7 Biodiversity Footprint

Biodiversity losses such as the result of the land renovation, land convention fluctuations, the unjustifiable usage of carbon-based possessions, the over-misuse of oceanic ecological capitals, and the invasion of unfamiliar living organisms are being measured by biodiversity footprint (BF) (Oteng-Yeboah 2009; Burrows 2011).

2.4.2.8 Economic Footprint

Economic footprints might be conferred by financial footprints (FFs) and economic footprints (ECFs). Clear definitions of both till now not available. Further, FF represents the expenditures made by a human, while ECF represents over-all straight and incidental economic influences of particular procedures, produces, or actions, an area or a whole nation. The FF emphasizes withdrawal, reserves, assurance, duty, and plantations (BMFG 2008) and is well-defined in terms of the financial components solely, business, nation, or period, while ECF signifies the extent.

2.4.2.9 Composite Footprint

Composite footprint is dealing with composite evidence in a particular index and permitting establishments or nations to be categorized in terms of their overall sustainability. These basic assessments are mass-media sociable and are utilized rather likewise to an educational score (OECD 2008). The complex footprints are discussed details in the following sub-sections:

Ecological Footprint

The EF is a compound pointer associated with numerous footprints (Toderoiu 2010; Galli et al. 2012). Humankind's anxieties on surroundings nature, viz. land and water bodies determined by EF (Wackernagel and Rees 1996) which further used to measure environmental sustainability. EF also compares resource consumption behaviour of humans with waste absorption with the environmental capability to rejuvenate (GFN 2010). EF delivers an amassed valuation of numerous anthropogenic forces (Wackernagel et al. 2006; Galli et al. 2012).

Sustainable Process Index

The defensible economy solely depends on solar-radiation as the natural revenue. This solar-radiation is the basic assumption of the Sustainable Process Index (SPI), which is associated with the EF (Kettl et al. 2011) and dealings the over-all region indispensable to implant human actions sustainably within the environment. The whole area is divided by the system units known as a specific area which measures sustainability. Lower the SPI, lesser is the effect of given properties or facilities on the ecosphere (Sandholzer and Narodoslawsky 2007). Further, SPI and EF have the same limitations. Limited data, unsurely of data, time intensiveness related to SPI when results of suitable provincial/regional data achieve a comprehensive intention (Hall 2008).

Despite above footprints, there are also some important footprints recognized and discussed by several researchers including phosphorus footprint, which is dealing with the unevenness of phosphorus in relation with growing crops (Lott et al. 2009); the footprint of fishing-grounds, which linked to catching the various fish species (WWF Japan and GFN 2010), also explained the sea area essential to harvest appropriate fish and sea-food for human beings (Van Rooyen 2005); the footprint of human, which deals the quantity of energy, properties, and harvests inspired by human being throughout the lifespan (National Geographic Channel 2011); the footprint of waste, which deals with the quantity of waste formed by obtaining constituents and ingredients, industrial and processing, and carriage (United Soybean Board e Thinking Ahead 2011).

2.5 Management of Footprints for Sustainability

Footprints management is an advanced concept and its proper management is particularly important for environmental sustainability. The foregoing overview of environmental footprint indicates that they are not yet consistent. Environmental footprints definition often varies, as per their measurement units. From the definition point of view, Hoekstra (2008) delineated that a 'footprint' is a measurable quantity that labelling the assumption of natural assets through human beings. He also endorsed how human actions execute diverse categories of problems and effects on inclusive sustainability. Life Cycle Assessment (LCA) used to outline the environmental influences which highlight the 100% utilization of all kinds of left-over materials (Zaman 2013). Normally, LCA is linked to ecological impressions

(Von Blottnitz and Curran 2007) , while maintainable improvement (MI), also taking care of financial and communal apparatuses. Ilskog and Kjellström (2008) reported five-dimensional design which comprises practical, financial, social, ecological, and organizational sustainability. Further, as per Ilskog and Kjellström (2008), MI goal is to come out with a balanced approach among all the objectives, viz. socially equitable, social multiplicity respect, environmentally comprehensive, frugally conceivable, science-based, technologically suitable and intended to authorize and extend capacity and potential of human beings. Sustainability valuation considered into three major groupings, viz. pointers, assessments connected to products, and cohesive valuation implements. Over recent years, tools have emerged known as footprints or individual contribution which further used for appraisal of sustainability along with its components. The present section entitled, 'footprints management for sustainability' covering with footprint definitions, measurement units, and management of various footprints, which are described details in the following sub-heading:

2.5.1 Management of Carbon Footprints

For reducing/managing the C-footprints from individuals, assessment of CF from individual contribution i.e. a farmer, industrialist, politician or even a student is very important. Pre-industrial Revolution near to about 1750, the CO_2 and other greenhouse gas concentrations were 270 ppm to 280 ppm which further increased to 405 ppm in 2017. Not only GHGs concentrations but annual growth dynamics are also escalating. Further, as per Bartoli et al. (2011), today's CO_2 concentration is highest than the last 2.1 million years. Fossil fuel burning worldwide is the largest source of GHGs generation, which increased from 6.8 PgC in 2001 to 9.8 PgC in 2015 (National Oceanic and Atmospheric Administration 2017). Further, deforestation, urbanization, and natural fires are responsible for 1/5th of global emissions (Smith et al. 1993). Oceans are the biggest sink for the C as absorbed 1.8 PgC year^{-1} to 2.9 PgC year^{-1}. Thus, 4 PgC to 6 PgC of emissions stay behind in the atmosphere each year. The research conducted by Gifford (1994) shows that non-deforested terrestrial ecosystems store 2.5 GtC year^{-1} ± 2.7 GtC year^{-1}. Already many recommendations there, viz. agroforestry, afforestation, minimum tillage, changing of dietary habits from non-vegetarian to vegetarians, use of gypsum with fertilizers, usage leisurely of relief manures, viz. neam-coated or poly-coated urea, intermittent irrigations instead of continuous flooding, DSR, incorporation of crop residues as mulch materials or biochar on the soil-surface, green manuring, use of short duration cultivars, etc. will resolve the determination. Subsequent are discussed other practices for management of CF, though C management is a significant concern for alleviating the adverse effects of global warming.

2.5.2 Crop Residues as Mulch

For the management of the CF, crop residues after crop harvesting must be integrated into the soil or spread on the soil-surface as mulch. Crop residue hinders hot sun-rays to penetrate the bare soil-surface which further lessens the soil-surface temperatures, vapour-pressure gradient, wind speediness and ultimately reduces the soil moisture evaporation. Application of crop residue mulching is indirectly helped to reduce the diesel or electricity consumption by lessening the irrigation demand by the crops. Thus, an efficient crop residue mulching practices are not only helpful to reduce the CF but also beneficial for managing water footprint. (Bhatt and Khera 2006; Arora et al. 2008; Busari et al. 2015; Bhatt and Kukal 2017).

2.5.3 Tillage Modifications

Earlier, tillage rather intensive tillage is done to prepare seed-beds and to get ride-off from the weed seed bank. But later, scientists revealed that conventional intensive tillage as intensive tillage breaks the aggregates and thus makes the organic matter once protected available to the soil micro-organisms, which oxidizes it to CO_2, which is not good for carbon footprints. Therefore scientists across the globe recommended ZT as an important resource conservation technology (Bhatt 2017; Bhatt et al. 2017), but its performance too decreased if all the mulch loads of the previous crops removed from the soil (Bhatt and Kukal 2015a, b).

2.5.4 Need to Change Dietary Habits

In the current era, there is a significant change in nutritional lifestyles as from vegetarian nourishment to a non-vegetarian diet. Further, attention on animal stuff is possibly going to jump to >70% globally between 2005 and 2050. In animals, enteric ageing is an abdominal connected process in herbivorous living being, viz. cow, wild oxen, goat, and sheep have a rumen, a huge four-compartment stomach with a multifaceted microbial population which procedures compound sugars with a final product as CH_4. The discharges decrease potential in Brazil, India, the USA. Additionally, the EU solely increases up to 350 Mt CO_2 per annual. There are several recommendations, viz. enlightening the nature of scrounges, fixing feedstuffs to recover absorbability, and adding grain-based essences to domestic animals, enrichments and addition of substances which could shrinkage CH_4 emissions and manage CF.

2.5.5 Reduces Wastage of Food

Globally, if nourishment production target is reduced anyhow, then the pressure on the food producers will be significantly decreased and that is possible through decreasing the wastage of food which is a vital, but typically un-attended concern. Harvest more by using minimum agricultural lands, pressure anyhow decreased and thereby implementations of different approaches of conservation agriculture seem to be practical which further reduces the emissions of the GHGs. As per FAO measures, about 33% of all human utilization diets is projected to lose. The C imprint of nutrition surplus is measured at 3.3 Gt CO_2. Cereals comprise the greatest share of hardships by calorie and ejections (individually 53 and 34%), whereas green-vegetables comprise the top percentage of hardships by weightiness (44%). In the UK alone, 64% of nourishment wastage is 'avoidable' (Parfitt et al. 2020). Therefore, reducing food wastage will help a lot in managing the C-footprints.

2.5.6 Reducing Methane Emissions from Rice Cultivation

Certainly, there is a role of paddy cultivation particularly conventional paddy cultivation conditions, viz. under puddle standing water conditions (Matthews et al. 1991; Gaihre et al. 2013). Around 55% of the yearly CH_4 emission comes from the paddy growing areas from July to October (Matthews et al. 1991). The average CH_4 discharges varied from 0.65 to 1.12 mg m^{-2} h^{-1} (Mitra et al. 1999) and >90% of which to the atmosphere is through rice plants (Banker et al. 1995). Around 100 g of CH_4 is discharged for producing 1 kg of rice grains. The defaulting CH_4 zero-emission factor is 1.3 kg CH_4 ha^{-1} day^{-1}, in non-stop flooding rice cultivation (IPCC 2006). The decay of fertilizers and crop residues in inundated rice farming mainly responsible for CH_4 emissions (Aulakh et al. 2001). Therefore, preventions submerged conditions by DSR or through alternate wetting and drying or using tensiometers helped in the management of the C-footprints.

Further, in general, WHO (2008) also recommended some practices for daily life as prefer walking, cycling, car-pooling, public transport. On average, every litre of fuel burnt in a car produces >2.5 kg of CO_2. Drive slowly as driving quicker >120 km h^{-1} escalations of fuel in gestation by 30% compared with driving at 80 km h^{-1}. Upper gears (4th, 5th, and 6th) are the greatest cost-effective in the relation of fuel ingestion. Further, reduce, reuse, recycle environmental and health benefits also serve the purpose. Waste is a vital donor to C discharges. The dropping waste can lead to huge emission reserves which help in the management of the C-footprints.

2.5.7 Management of Water Footprints

In the South-Asian countries, except for Bhutan and Nepal water resources are limited and shrinking because of overloads of population pressure. Agriculture sector consumed around 90% of all water available for South-Asia, whereas the rest world used 70% for irrigation. Further, out of these total requirements, around 60% depends on the surface water, while the rest 40% explored from below the ground using submersible pumps. Moreover, paddy cultivation adds to it as around

4000 l of irrigation water used for producing 1 kg of rice. As water is declining throughout the SA and that particularly true where rice-based cropping systems being practiced. Hence, researchers recommended certain resource conservation technologies for the better utilization of the water resources for enlightening the water utilization and hence water use efficiency in the South-Asia. Amongst them, the short lifespan of crop cultivars, timely replacement of rice seedling, use of laser land levelling, judicious application irrigation on the based on tensiometer and adoption of inproved crop production techniques like DSR, mechanical transplanting, crop residue mulching, raised beds, double ZT, etc. are improving water as well land productivity. But, there need to rethink as these RCTs are not universal and are in reality are site and situation-specific. As in the case of DSR, under light-textured soils, it is a great failure. Light-textured farmers often seen to till their DSR crop because of the severe Fe insufficiency and considerably greater weed-pressure, though it is a success under heavy textured soils. Even there is lack of location specific recommendations of the RCTs depending upon the texturally divergent soils and divergent agro-climatic conditions (Bhatt and Kukal 2017). Rapidly declining groundwater quality causing severe health issues needs to be identified, e.g., south-western parts of Punjab, where special rivers diverted for providing irrigation water and people used only filtered water for drinking.

2.6 Natural Resources Intensification for Agroecology Sustainability

The term ‘sustainable intensification’ is used to define the forthcoming path of development of crop cultivation, to meet the requirement of ever-growing food demand vis-à-vis maintaining the food security and combating the adverse effect of global warming (Pearce et al. 2015). Despite this magnificent progress in the agriculture sector during the last few decades, we cannot ignore the forbidding-side of the story as well. The SA countries occupy miserably a low place in respect of yield in contrast with other countries. Organizers, policy-maker, scientists, and economists are seriously concerned about the sluggish development rate of the crop production in current years. The population has been escalating at an alarming level, while the average growth level of total food grain production is not at all satisfactory. So, there is no other option except to produce more and more (Ghosh et al. 2017; Meena and Lal 2018). There is, therefore, an urgent need for massive well-planned action programme for improving input use effectiveness and output to sustain the tempo of agricultural growth in this region. Increasing productivity with a decrease in production cost for the advantage of the agricultural community as a whole and maintenance of soil health are newly emerging challenges for the agricultural scientists (Ray et al. 2020). Modern agriculture practice is highly inputted intensive agriculture. This input-intensive agriculture uses a considerably higher amount of agricultural input such as plant nutrients, seeds of high yielding crops variety (HYV), plant protection chemicals, irrigation, etc.

On the other hand, with the increasing cost of cultivation in the modern input-intensive agricultural practices and no appreciable additional benefits in income, the growers in overall and small and marginal in specific are finding it extremely difficult to earn their livelihood and a large number of them are below the poverty line. Thus, it must be kept in mind that at this juncture we should not emphasize on our production need alone; we must have to consider the ecological health as well to keep the sustainability of our production unaffected.

As sustainable ecological intensification and production maximization are directly related to the efficient utilization of the precious natural resource, thus there is essential to reflect ecological conservation such as the maintenance and regeneration of natural assets and the possible output of the ecosystem services (Lampkin et al. 2015; Raj et al. 2020; Banerjee et al. 2020; Jhariya et al. 2019a, b). Agroecology, an approach for sustainable farming, creates the best use of natural resource to meet the present demand without hampering the future need (AGF 2020). The farmers maintaining agroecological sustainability not only improve food yields for balanced nutrition but also maintain soil and environmental health vis-à-vis healthy ecosystems. Natural resources can be intensified for agroecology sustainability in different ways. Scientist used number of agroecological indicators (Lampkin et al. 2015). We also identified such five agroecological indicators as suggested by (Lampkin et al. 2015; Pearce et al. 2015) (Fig. 2.5).

In Table 2.2, we have summarized the different practices that are directly related (synergistically antagonistically) to agroecological sustainability. Integration of input-intensive agriculture with organic and natural low input-intensive agriculture practices is the most efficient and eco-friendly natural resource management techniques for agroecological sustainability. This system can supply enough plant nutrients in the available form to crops and recover the quality of the agricultural products.

But sole adoption of such organic natural resources intensification strategy alone cannot meet the high nutritional requirement of the crops. For this reason, in the recent past, it has been a convention of applying different sources of nutrients, e.g. chemical fertilizers, organic manures, green manures, crop residue, bio-fertilizers, different soil amendments, etc. in combination to the similar crop in the similar piece of land; that means in an approach of INM (Kesavan and Swaminathan 2008; Balasubramanian et al. 2017). Besides this practices, adoption of integrated pest management, biological pest control, the introduction of legume-based diverse cropping system, livestock-based integrated farming system, and agroforestry system has a direct positive impact by optimizing the use of natural resources intensification for agroecology sustainability and environmentally friendly.

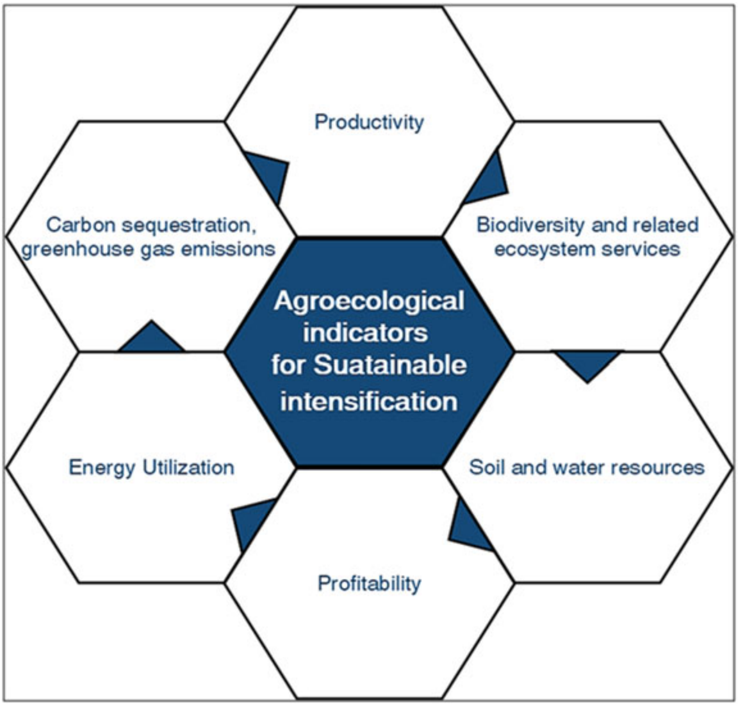

Fig. 2.5 Indicators of performance relevant to sustainable intensification

2.7 Agroecology for Food Security

The demand for food is continuously rising with growing population and farmers are adopting conventional farming practices for augmenting the food production by using higher amount of agro-chemicals as a form of fertilizers and pesticides. However, due to repeated intensive farming practices and higher application of external inputs, the production system showing its limit as the ecosystems have reached saturation and degradation level (Lecomte 2012). The reducing food production capability of the agricultural lands results in a risk to food safety. For most of the major crops, the average yields have improved over the past 50 years (Tilman et al. 2011); nonetheless, the improvement is not equal across the world. The productivity is lower than its need in the poorest provinces of the world particularly in developing countries (Vijikumar 2010) due to insufficient agricultural development models in addition to higher population densities that led to dreadful condition of the natural resource base in SA. Besides, climate change and its consequences have also affected food production and made it difficult to eliminate the food insecurity in this region (European Commissions 2011; Wickramasinghe 2014). In agroecology, simple farming techniques such as traditional practices of the agricultural system linking

Table 2.2 Involvement of diverse agroecological performs and methods to distinct and viable crop diversification. Source: Lampkin et al. (2015) and Pearce et al. (2015)

Practice	Productivity	Non-renewable energy use and GHG emissions	Biodiversity and related ecosystem services	Soil and water resource protection	Profitability
Improve soil fertility through the inclusion of legumes	+	+	+	++	−
Carbon-based soil improvements	+	+	++	+	0
Zero-tillage	+	+	+	+	+
Fewer usage of synthetic fertilizers and pesticides	−−	+	++	++	−−
Rotations	+	0/+	+	+	+/−
Poly-cultures	++	0/+	+	+	+/−
Variety-mixtures	+	0/+	+	0	0/−
Field margin and other refugia	+/−	0/+	+/++	0/+	+/−
IPM	+	0/+	+	0	+
Various grasslands	+	0/+	+	+	0/+
Diversified crops and livestock	+	0/+	+	+	+/−
Mixed livestock species	+	0/+	+	0	+/−
Integrated crop/ farm management	0	+	+	+	0/+
Organic farming	−−	+	++	++	0
Agroforestry	+	++	++	++	+/−

− = worse than conventional, 0 = similar to conventional, + = better than conventional

with biodiversity are adopted to increase the crop yield and to promote natural interactions among crops, soil, nutrients, pollinators, and livestock (Tittonell 2014). Additionally, these techniques and practices are less costly and improve the soil health and fertility which reduces the dependency of farmers on external inputs and state subsidies; therefore, that will help to alleviate poverty and will contribute to food security. However, for effective transformation to the agroecological farming active participation of farmers with their own experiences as well as initial investment by governments for rural infrastructure and expanding existing projects are very crucial (European Commissions 2011).

Agroecological practices reintegrate the food production system with the natural growing course of plants and manage the nutrient cycling in soil with dead plant parts of the same ecological unit persistently. Besides this, it increases carbon sequestration, conservation of soil as well as water and its efficiency, thus restore the agricultural biodiversity and reduce biotic and abiotic stresses on crops (Vijikumar 2010; Sharma and Hansen-Kuhn 2019). Therefore, different approaches to sustain agricultural diversity include crop rotations, intercropping, cover crops, polyculture, mixed and/or integrated farming, ZT technology, agroforestry systems, organic farming, green manuring, and composting, integrated nutrient and pest management, and so on and these have several common and positive influences on agroecosystems and food production (Carrol et al. 1990; Tolentino and Tolentino 2019). Regeneration of the natural ecosystem through these agroecological practices is the sustainable way to long-term food security because it will satisfy several needs of farmers as well as society at large.

In SA, most arable and permanent croplands are lowlands situated at arid- and semi-arid zones and these have higher potentiality for increasing agricultural productivity (Devendra 2012; Tolentino and Tolentino 2019). Though intensive monocrop cultivation particularly rice is more prevalent in lowlands, integrated cropping systems and different mixed farming approaches should be adopted by the farmers to improve the biodiversity (Viczianya and Plahe 2017) and to maintain agroecology which ultimately increases food production as well as whole resource efficiencies. Now it is established that if rice is grown along with *Alzola*, fish, duck, and/or other boarder plants in a complex agroecosystem, it will reduce the application of external inputs but augment the production of rice and other components of the system and the farmers' income along with the empowerment of farming family (Xie et al. 2011; Khumairoh et al. 2012; Liang et al. 2012; Long et al. 2013).

Food sovereignty is also a vital context to directly improve the food safety and its sustainability and it can be attained by considering food sovereignty strategies such as localization of food production by allowing the involvement of the producers in innovations because they know the micro-environment in which the crops are grown, avoidance of dependency on international market and trades and improvement of immunity of populations (Lecomte 2012; Viczianya and Plahe 2017). Hence, agroecology is an approach to maintain diversified agroecosystems and this is the vital time to choose the suitable strategy for ecological resource management of SA for sustainable agricultural productivity which results in long-term benefits and food security to the poor populations.

2.8 Adaptive Measures for Soil Ecology

Soil is the unique essential natural assets for agriculture and can improve livelihoods of agricultural communities when it is managed effectively as it is the main regulatory centre of natural as well as managed ecosystem processes (Barrios 2007;

Bukari 2013). It also acts as a prime reservoir of carbon along with different plant nutrients, buffering medium of precipitation extremes and habitats for several living organisms (Montanarella 2015; Coyle et al. 2016); hence, soil health is very crucial for sustainable agriculture. However, in spite of the continuous application of different agricultural inputs, soil health is gradually deteriorated and the agricultural productivity is being affected after intensive use of it during several years. Due to intensive cultivation reduced soil fertility, soil compaction, erosion, and salinization are also being prominent which result in unstable soil ecology and depreciation of the environmental sustainability and food security (Lal et al. 2011). In SA, crop straws are commonly used as fodder and fuel, not as a basis of carbon-based substance; hence, soil organic carbon is continuously decreasing (FAO and ITPS 2015). Now, higher chemical fertilizer application although does not show higher yield but it is also destroying organic matter and population of organisms in the soil; therefore, it is very important to take measures for maintaining soil ecology for the long run and this is possible only through adopting agroecological practices (Lecomte 2012).

During selection and adaptation of agroecological approach, characteristics of the practice and the target environment should be considered and then the suitable management practices for carbon sequestration, nutrient cycling from the deep soil profile, maintenance of soil structure, and biological population should be allowed to impose along with desired crop species and inputs (Barrios et al. 2012; Wade 2014). The C repossession is the imprisonment and storing long term of atmospheric CO_2 in soil (Jain et al. 2012). Generally, the atmospheric CO_2 is converted into different inorganic carbon compounds by chemical reactions in soil and the quantity of C deposited in soil shows the equilibrium between the mechanisms of C fixation in soil and release from soil (Benbi and Senapati 2009). The soil C sequestration directly depends on climate, vegetation, soil parent material, soil water content, and land management methods of the particular location (Jimenez et al. 2007; Lal et al. 2007; Ontl and Schulte 2012; Abdullahi et al. 2014).

Higher C sequestration improves and maintains the soil physicochemical properties and soil quality and also increases microbial growth and activity (Hu et al. 2001; Chakraborty et al. 2014) which outcomes in enhanced soil structure, the water-holding capacity of soil, infiltration and reduction in soil erosion, and leaching loss of nutrients (Ontl and Schulte 2012). Mainly conservation agricultural practices along with different agroecological strategies can raise the C stock in soil and induce soil stability. Hence, different agricultural technologies such as ZT, crop rotation, mixed cropping, cover crops, crop residue management, mulching, agroforestry system, ley farming, contour farming, grazing management, organic farming, green manuring, integrated nutrient management, etc. have the efficiency to effectively increase the soil C sequestration (Benbi and Senapati 2009; Gami et al. 2009; Nayak et al. 2012; Ontl and Schulte 2012; Sapkota et al. 2017). Therefore, the aforementioned strategies also directly influence the nutrient cycling in soil, plant nutrition, organic matter decomposition, soil aggregate formation, soil erosion, and nutrient loss (Bhojvaid and Timmer 1998; Kaur et al. 2000; Mishra et al. 2003; Nosetto et al. 2007; Jarvie et al. 2017) by increasing the microbial activity due to higher C content in soil (Hu et al. 2001). This microbial biomass mineralizes the soil nutrients for plants and maintains the nutrient cycle (de Deyn and Van Der Putten 2005); besides, it neutralizes toxins, maintains gas and water flow in the soil around the plant roots, and stimulates soil aggregation (Reynolds and Skipper 2005; Kibblewhite et al. 2008) as the soil organisms like bacteria can produce cementing agents among the clay particles and fungal hyphae and its metabolites enmesh the soil aggregates (Reynolds and Skipper 2005; Kibblewhite et al. 2008; Totsche et al. 2018). Additionally, the addition of pulses in cropping system has several positive impacts on soil ecology such as it fixes atmospheric nitrogen, increases the soil phosphorus mobilization, acts as a cover crop and reduces soil erosion, uptakes nutrients from the deeper layer of soil due to its deep root system which results in less leaching loss (Wade 2014).

About 52 Mha areas in SA are salt-affected (Sharma and Singh 2015) and in coastal areas of India and Bangladesh, salinity along with inundation is inherited problem (Burman et al. 2013). Therefore, utilizing these areas for food production after reclamation sustainable food security can be enhanced and in this situation, different land shaping practices can be useful. It was found that crop yield and soil nutrient status have enhanced as compared to non-land shaping situation due to rainwater harvesting, improved soil drainage, salinity reduction, less leaching loss of nutrients, and cultivation of several plantation crops as well as fish (Burman et al. 2013). Besides this, phytoremediation can also be adopted for salinity situations as it is environment friendly and cheaper than chemical reclamation procedures (Sharma and Singh 2015). *Eucalyptus tereticornis*, *Populus deltoides,* and *Tectona grandis* in saline soils; *Acacia nilotica*, *Casuarina equisetifolia*, *Leptochloa fusca, Prosopis juliflora,* and *Tamarix articulata* in sodic soils; *Acacia farnesiana*, *A. nilotica*, *A. tortilis*, *Casuarina glauca*, *Parkinsonia aculeata*, *Prosopis juliflora,* and *Tamarix articulata* in waterlogged saline soils can be planted in agroforestry based cropping system for phytoremediation and for increasing the land productivity (Singh et al. 1994; Dagar and Tomar 2002; Qadir et al. 2007).

2.9 Adaptive Measures for Crop Ecology Under Changing Climate

At present, the changing climate is the primary intention for biodiversity loss which leads to insecurity in food production (Raza et al. 2019). In SA, the crop production system is very sensitive to periodic weather inconsistency, mainly in rainfall and temperature dissimilarities (Aggarwal et al. 2009; Knox et al. 2012; Pitesky et al. 2014; Ali and Erenstei 2017; Khatri-Chhetri and Aggarwal 2017) because 70% of total production directly depends on monsoon rains (Wickramasinghe 2014). Due to climate change, most of the rice and other cereal varieties can lose up to 15–30% of its yield potential across the SA (IFAD 2008) and by the end of twenty-first century, the total cereal production will face around 4–10% reduction (Khatun and Hossain 2012). Therefore, different adaptive measures at farm level are very crucial for sustained crop production system by alleviating the consequences climate change and it depends on the adaptive capability of a particular farming community (Rosenzweig and Parry 1994; Mendelsohn and Dinar 1999; Smit and Skinner 2002; Gbetibouo 2009). Furthermore, combined strategies of adaptation along with mitigation have more impact in declining climate change vulnerability. Some useful crop adaption strategies which can be taken against global warming at the farm level are as follows:

2.9.1 Adjustment in Sowing Time and Method

Altering the sowing as well as harvesting time of crop, detrimental impacts of changing climate can be alleviated (Challinor et al. 2014; Ali and Erenstei 2017; Raza et al. 2019). This approach saves the crop from unpredictable climate before sowing and after harvesting as well as during crop growth. In this state, contingency crop planning according to stress can also be very beneficial for crop adaptability. SA shares the highest methane emission in Asia and yearly emission of methane only from rice cultivation takes third position globally (IRRI 2018; Aryal et al. 2020). But simultaneously, the rice production needs to be augmented for the increasing population of SA. Therefore, replacing the conventional flood rice method with DSR, the system of rice intensification (SRI), and other alternative wetting and drying (AWD) approaches of rice cultivation where puddling is not needed can be adopted. These alternative rice cultivation methods not only reduce greenhouse gas emissions and crop duration but also increase input use efficiency, yield and make rice cultivation possible in water scarcity condition (Siopongco et al. 2013; Sapkota et al. 2015; Aryal et al. 2020).

2.9.2 Stress Tolerant Cultivars

In addition to alteration in sowing time, selection of suitable crop species and cultivar scan also decrease the influences of changing the global climate in crop ecology. Under different climatic stress, drought-tolerant crops like millets instead of other cereals, short duration and/or early maturing crops, salinity tolerant crops, and their varieties can be grown (Raza et al. 2019). This approach is very useful to diminish the impacts of climatic erraticism on the crops (Aggarwal and Mall 2002; Smit and Skinner 2002; Howden et al. 2007; Ali and Erenstei 2017).

2.9.3 Cropping System

Mono-cropping is very popular in SA and this conventional cropping system is very sensitive to climate variability. Therefore, the adaptation of crop rotation, mixed cropping, intercropping, cover cropping, the addition of pulses in the cropping system, etc. is essential to reduce the crop loss and increase the production and farmers' income (Kassam et al. 2009; Ali and Erenstei 2017; Duku et al. 2018).

These adaptive practices also reduce the crop loss due to pest-attack which is also exaggerated due to the changing global change and improve the soil health (Bradley et al. 2010).

2.9.4 Conservation Tillage

Climate change can also reduce the production of food capacity of soil through erosion and declining soil productivity and fertility (Lal et al. 2011); hence, conservation measures should be adopted to minimize these threats (Pitesky et al. 2014). Implementation of conservation tillage such as ZT along with residue management rises the SOM content which improves the soil aggregation and its water-holding capacity and reduces the soil erosion (Sapkota 2012; Pitesky et al. 2014). Besides this, ZT improves soil quality and nutrient status which ultimately increase crop production and decrease the influences of global warming on crops (Lal 2004; Gathala et al. 2011).

2.9.5 Nutrient Management

Application fertilizer is very critical for food production next to the selection of crop varieties (Aryal et al. 2020) but in SA, fertilizer use efficiency is very low (30–40%) (Farnworth et al. 2017; Tewatia et al. 2017). Additionally, intensified use of synthetic fertilizers significantly affects the environment and only crop production system contributes over 60% to nitrogen pollution (Sapkota et al. 2016). Thus, the rational use of fertilizers is very important for reducing pollution and improvement of crops' adaptability to climate variations (Challinor et al. 2014; Raza et al. 2019). Besides, the optimum application maintains soil as well as food quality (Aggarwal and Mall 2002; Raza et al. 2019). In this context, possible adaptation actions such as integrated nutrient management involving both organic and inorganic nutrient sources and/or SSNM potentially can diminish the effects of changing climate which results in increased fertilizer use efficacy, crop yield, and growers' income (Majumdar et al. 2000; Pitesky et al. 2014; Aryal et al. 2020).

2.9.6 Water Management

Under the changing climatic situation, water management is one of the further most indispensable adaptive practices in the agricultural production system (Smit and Skinner 2002; Challinor et al. 2014; Ali and Erenstei 2017) as numerous crops are very subtle to drought during their certain growth stages. Hence, water management practices are crucial techniques to handle the special effects of changing climate on crop ecology. Several adaptive practices of water management are harvesting of water, watershed management, lifesaving irrigation, on-farm water storage, soil water conservation through crop residue management, micro-irrigations, groundwater recharging, contour farming, land levelling, etc. (Aggarwal and Mall 2002; Howden et al. 2007; Gleick et al. 2011; Aryal et al. 2020). Moreover, effective transportation of water to drought-prone areas and management of water erosion and water logging at heavy rainfall areas are also essential for regulating crop ecology (Howden et al. 2007).

However, these adaptation strategies are highly confined to specific locations or crops, i.e. all practices may not be directly adaptable in all regions and/or agricultural fields (Tiwari et al. 2008; Porter et al. 2014; Ali and Erenstei 2017). But, selection and adaptation of suitable practices that enhance crop yield yet deal with climate variability will potentially mitigate the negative effects of global warming as a consequence of the changing climate and sustain the crop ecology (Howden et al. 2007).

2.10 Conclusion

From the discussion of the present study, it is well-noted that food production and increasing the poverty level are the major difficulties to meet the food and nourishing safety of the developing world. At the same time, climate change also creates a great barrier to improve farming productivity. Traditional agricultural technologies are not environmentally friendly and cost-benefit where farmers use imbalanced synthetic fertilizers and pesticides. Hence, it is crucial to improve ecologically friendly technologies for preserving crop productivity. The sustainable food production can be achieved through management of agroecology; since agroecological based agricultural production system generally emphasizes on RCTs, reworking small farm enterprises, consider the participation of more farmers' and their traditional knowledge, include improved plant genetic multiplicity, and avoid to over-use of imbalanced synthetic fertilizers and pesticides.

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