Sustainable Agriculture and Food Security

Muhammad Farooq, Abdul Rehman, and Michele Pisante

Abstract Demand of increase in food production to feed the rapidly growing global population has pose serious threat to the agricultural sustainability. Climate change also offers serious challenge to global food security situation as it will negatively affect agricultural yields, particularly in low income countries. The increased agricultural intensification to produce more food from the existing cropland has put the environmental sustainability at stake due to increased emissions, loss of biodiversity, soil health due to increase use of chemical fertilizers and pesticides. Therefore, there is need to develop a multidimensional approach for agriculture sustainability without damaging social, economic and environmental integrity. This chapter highlights the role of social, economic and environmental sustainability in agricultural sustainability and food security. It further describes current food security status and proposes how sustainable intensification can help reduce the adverse effect of intensification on social, environment and economical components of agriculture. It also highlights the mitigation strategies to achieve the food security and safety in changing climate.

Keywords Food security · Agriculture sustainability · Crop intensification · Climate mitigation · Malnutrition

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1 Introduction

The world population according to UN organization estimates will be expected between 8.3 and 109 billion by 2050; however, the existing trend point to the latter figure. This population growth rate will need increase food supply from 50% to 75% depending upon the region (Prosekov and Ivanova 2018). Furthermore, the global climate change will also affect the food production in many parts of the world. Global climate change during the last century lead to heat waves due to rising temperature, atmospheric CO_2 level, frequent spells of drought in some places while higher precipitation on others (OECD 2016). Climate changes and anthropogenic activities have created serious challenges to agriculture sustainability due to natural resource depletion. Furthermore, this situation will lead to lower agricultural yields (Waggoner 1983; Adams et al. 1998; Nelson et al. 2009; Gliessman 2015), threat to the food security and food and feed safety (Miraglia et al. 2009). Food security is physical, social and economic accessibility of healthy, safe and nutritious food to the people at all times, which can fulfill their dietary requirements and food preference for healthy and active life (Fig. 1; FAO 2001). However, to achieve this situation agricultural sustainability is very important as first component of food security is food supply which is linked to agriculture system to meet the food demand which depends on agro-climatic condition of crop and pasture production (Tubiello et al. 2007).

In order to fulfill the increasing food demand, agriculture extension and intensification has helped in increasing food production to achieve the food security (FAO 2009; Tilman et al. 2011; Stevenson et al. 2013). Agriculture intensification without sustainability will result at major environmental costs, as many scientists are expecting stagnant or yield reduction owing to low land expansion and degradation

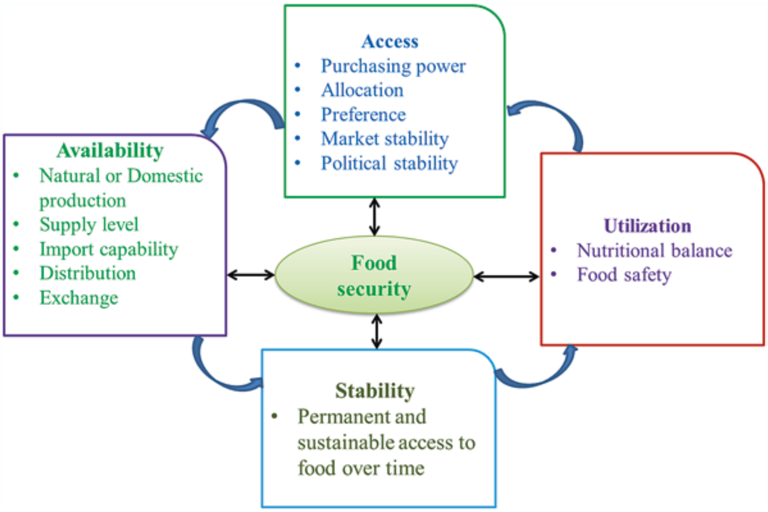

Fig. 1 Components of food security

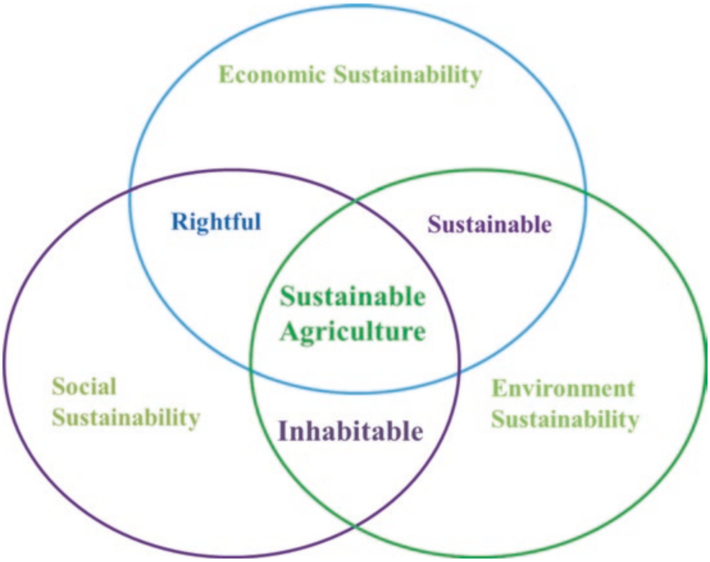

Fig. 2 Components of sustainable agriculture

of land and natural resources due to climate change (FAO 2009; Ray et al. 2012; Stevenson et al. 2013; Eitelberg et al. 2015). Sustainable agriculture holds the key to global food security in view of the oscillating climate, social and market situation. Sustainable agriculture uses integrated animal and plant production system practices that are aimed to improve the farmer income with environmental integrity and social sustainability (Fig. 2). In recent years, the sustainability of agriculture has got ground among academics, policy makers and practitioners due to growing awareness about social and environmental concerns among stakeholders.

This chapter encompasses the work done on agricultural sustainability including social, economic and environmental sustainability, global food security situation and role of sustainable intensification in agriculture sustainability and food security. Furthermore, how climate change mitigation can help in achieving food security will also be discussed.

2 Sustainability in Agriculture

Sustainability is a broader term and pillars of sustainability approach which represent individual indicators linked with a metrics to represent different domains of sustainability (Smith et al. 2017). Sustainability in Agriculture is measured as economic stability, social stability and ecological/environmental sustainability (Smith et al. 2017). In the last several decades, many developing countries have been facing robust population growth, reduced arable land, urban expansion, change in food habits and oscillating global food market pressure (Huang et al. 2009; Qiang et al. 2013; Huang and Yang 2017), which influence the agriculture sustainability (Table 2). The enhanced agriculture production has resulted a conflict between environmental sustainability, food security and safety (Miraglia et al. 2009). The green revolution has resulted in improved economic sustainability of farmers. However, the increased cost of production due to high prices of seed, fertilizer, labor and machinery and yield stagnation has also led to economic unsustainability. The increasing risk of agro-environment from grain production in future can threaten the sustainability of agricultural land use (Qi et al. 2018). To maintain the sustainability of agriculture, a multidimensional approach should be optimized considering the social, environmental and economic sustainability approaches for agricultural production system.

2.1 Economic Sustainability

Economic sustainability is vital component of sustainable agriculture. Green revolution in Asia has substantially enhanced the agriculture production through improved provision and use of inputs (new cultivars, chemical fertilizers and pesticides) (Hazell 2009). The advancement of agriculture technology boosted the grain yield in Asia by 3.57% annually during 1965–1982 (Rosegrant and Hazell 2000). The yield of rice and wheat has increased from 150% to 250% respectively in subcontinent and Indonesia (FAO 2014). This rise in agricultural crop yields lead to many fold increase in per capita income of farmers. For instance, in two provinces of India (Haryana and Punjab) the poverty declined from 35.2% to 8.1% and 28.1–8.4% in 2004/2005. In Pakistan, post green revolution has improved the food security situation as per capita caloric intake has increased from 2462 in 2000 to 1748 in early 1960s (Evenson 2005). Moreover, population density, agriculture credit facilities, market situation, food habits are also key determinants of economic sustainability (Table 2).

The green revolution has resulted in improved economic sustainability of agriculture production system in South Asia. During past few decades, the increase cost of production due to high prices of seed, fertilizer, labor and machinery and yield stagnation has led to economic unsustainability. Recently, Zulfiqar and Thapa (2017) studied the economic, environmental and social sustainability of Agriculture of Pakistan. To study the economic sustainability, they used overall crop production and stability of crop production as indicators, while environmental indicators were crop diversification, soil salinization, fertilizer use (organic and inorganic) and pesticide usage. Moreover, food security and employment of rural labor force were social sustainability indicators. They found regional differences for agriculture sustainability across Pakistan. Their findings revealed the tendency of unsustainable production in all provinces (Punjab, Sindh, Balouchistan and KPK) as the farmers in Sindh and Punjab are using more chemical fertilizers, pesticide and pumping ground water for irrigation purposes. The lack of sustainability in Balochistan and KPK was due to low use of fertilizer and pesticides and even no application in some areas. Furthermore, groundwater pumping for irrigation in coastal areas further increases the unsustainability of agriculture.

Arable landholding and soil fertility also influence the economic sustainability of agriculture. In a study, Wasąg and Parafiniuk (2015) assessed the ecological and social sustainability in Roztocze Region of Poland. They found that bigger holdings 70 ha UAA (utilized agricultural area) have ecological stability due to high organic matter in soil. Although these holdings have high organic matter decomposition but the balance remained positive due to increased addition of manure as these holdings have large scale of animal production. Similarly, social sustainability was also observed in holding >30 ha UAA due to increased mechanization which reduced the workload i.e. <100 man hours per ha UAA (Table 1). Niemmanee et al. (2015) studied the existing agricultural systems cover on the environmental, economic andsocialcondition of Samut Sakhonn Province, Thailand and suggested suitable pattern for sustainable agriculture. The major characteristics of this sustainable agriculture system were use of mixed cropping systems with string bean (most supplementary plants) and chili, less use of pesticides and chemical fertilizers and more use of manures, crop residues and application of knowledge gained through training and its dissemination.

In conclusion; the higher use of chemical fertilizers, pesticides and other inputs along with fluctuating agricultural markets has resulted in increased agricultural production over the years however, there is also indication of economic unsustainability due to increased use of inputs and its high input costs.

2.2 Environmental Sustainability

The global population will rise increase to 9.7 billion by mid of this century, which will result in increased food demand and environmental degradation due to agriculture intensification. The biggest challenge in this situation is achieving food security with agriculture sustainability worldwide. Food security ensures the healthy and continuous food availability over time; whereas, sustainable agriculture ensures the maintenance of agro ecosystem resilience (Table 2; Skaf et al. 2019). Increase in food demand associated with agriculture intensification to achieve food security is posing threat to environmental sustainability. The environmental integrity is at stake due to intensive agriculture which resulted in fertilizer driven eutrophication (Scherer and Pfister 2015), acidification (Tian and Niu 2015) and water scarcity due high use of water for irrigation (Scherer and Pfister 2016).

The rise in food demand has increased the competition for water, land and inputs for food production. Moreover, this competition has resulted in the use of high

Table 1 Effect of sustainable intensification on environmental, economic and social sustainability

Country	Cropping system	Fertilizer use/ crop residue	Description	Reference
India	CA in maize-wheat-mungbean	29.8 t ha^{-1} residue incorporation	↓soil bulk density ↑organic matter (72%),↑MBC (213), ↑MBN (293), ↑DHA (210%),↑ APA (49%), ↑bacteria (28%), ↑fungi (68%), ↑actinomycetes (98%),↑ system yield (39%)	Choudhary et al. (2018)
India	CA in rice-wheat-mungbean	30.95 t ha^{-1} residue incorporation	↑organic matter (83%), ↑MBC (117%), ↑MBN (171%), ↑DHA (140), ↑APA (42), bacteria (26%), fungi (61%), actinomycetes (92%), ↑ system yield (39%)	Choudhary et al. (2018)
India	Rice-wheat-legume crop rotation with CA		Improved carbon sequestration, soil health, with higher grain yield and food security	Samal et al. (2017)
Malawi	Sole maize	No fertilizer	One food crop per year with 12% food sufficiency and profit of USD 188	Snapp et al. (2018)
Malawi	Sole maize	69 kg N/ha 9 kg P/ha	One food crop per year with 96% food sufficiency and profit of USD 935	Snapp et al. (2018)
Malawi	Pigeonpea-maize intercrop	34.5 kg N/ha 4.5 kg P/ha	Two food crop per year with 92% food sufficiency and profit of USD 1054	Snapp et al. (2018)
Malawi	Doubled up legume/Maize rotation	17.3 kg N/ha 2.3 kg P/ha	Three food crop per year with 100% food sufficiency and profit of USD 637	Snapp et al. (2018)
Pakistan	Mungbean-chickpea		Cost effective and sustainable intensification crop rotation for dryland areas of Pakistan	Hassan et al. (2015)
China	Monocropped maize systems		Monocropped maize is effective alternative to wheat-maize system for economic and environmental sustainability in North China plain	Cui et al. (2018)
Europe	Multiple cropping		Multiple cropping by replacing luxury crops with food crops and using zero tillage and water deficit irrigation can help in utilization of 16 M ha land with conservation of 11 m ton soil and 17 billion m^3 H_2O and will ensure the food security of 229 M more people	Scherer et al. (2018)
Spain	Olive oil cropping system		SI increased the olive production from 36.8% to 64.4% with a 40–60% increase in revenue/unit of energy invested with maintained energy consumption	Sánchez-Escobar et al. (2018)

↑ = increase; ↓ = decrease; *CA* conservation agriculture, *MBC* microbial biomass carbon, *MBN* microbial biomass nitrogen, *DHA* Dehydrogenase activity, *APA* alkaline phosphatase activity

Table 2 Factors affecting socio-economic and environmental sustainability

Country	Approaches	Description	Reference
Kenya	Population density	The areas with population density below 600 persons/km^2 showed improved organic matter, better crop residue management with better nutrient use efficiency and availability (N and P), increased crop yield and food security	Willy et al. (2019)
Kenya	Population density below 600 persons/km^2	The areas with population density above 600 persons/km^2 showed high fertilizer and manure use, increased labor and capital cost, soil fertility and low nutrient use efficiencies	Willy et al. (2019)
Finland	Meat replacement with bean	Plant proteins replace with meat due to socio-economic and cultural aspects. Moreover, high bean production and consumptions ensures social and economic sustainability with better food security	Jallinoja et al. (2016)
Ecuador	Improving the ecosystem water management	Improved water management through changing in crop pattern, reduction in virtual water use with high crop water productivity will ensure water and food security	Salmoral et al. (2018)
	Sustainable branding	Creating awareness about food products e.g. organic production, ethical features will encourage consumer to pay for organic produce which will improve the environmental and economic sustainability	Franco and Cicatiello (2019)
Poland	Land holding	Farmers with more arable land (>70 ha UAA) better economic and social sustainability due to increased animal production, mechanization and better soil fertility owing to increase animal manure, relative to farmers with small land holdings (<30 ha UAA)	Wasąg and Parafiniuk (2015)
Mexico	Urban agriculture	Restoration of historic agriculture practices (floating gardens, Aztecs etc.). Improved food production with sound and balanced social, ecological and environmental dimensions	Dieleman (2017)
Brazil	Botanical pesticides	Nano formulations (18%) of essential oil of *Lippia sidoides* (thymol −68.5%) effectively control the population of *S. zeamais* populations	Oliveira et al. (2017)
Pakistan	Allelopathic plant water extracts	Application of crop water extracts of sorghum, mustard, rice and brassica in combination with low doses of Pendimethalin help in weed management with higher yield and environment safety	Jabran et al. (2008), (2010)
England and Wales	Integrated farm management	Use of traditional and modern farming method in integrated manner improves the productivity, with better social and environmental sustainability	Rose et al. (2019)
Lebanon	Cropping system selection	Olive production system is eco-friendly due to energy and agricultural input requirement, while citrus is harmful for economic and environment sustainability due high fuel, energy, water and fertilizer cost	Skaf et al. (2019)

UAA utilized agricultural area

inputs and some farming practices which are damaging the environment and major contributor of anthropogenic GHG emissions (Reilly et al. 1996). Post green revolution intensification of agriculture has resulted in soil degradation in the form of compaction, erosion, loss of organic matter, pesticide contamination, low biodiversity and increased soil salinization and waterlogging etc. (Kibblewhite et al. 2008; Schiefer et al. 2016; Turpin et al. 2017; Shah et al. 2017; Shahzad et al. 2018). Therefore, sustainable agriculture should be able to restore soil quality by use of non-chemical fertilizer and pesticides (organic fertilizers, bio-fertilizers and bio-pesticides), crop rotation with increased diversity to meet the global food production with sustainable environment and soil health (Verma et al. 2015; Zhang et al. 2016). Skaf et al. (2019) studied the environmental sustainability in nine different cropping systems of Lebanon by following the environmental accounting methods i.e. material flow accounting (MFA) (emission and energy accounting and their impact) and gross energy requirement (GER). They found that at farm level, citrus had the highest environmental cost due to high inputs use (fertilizers, water and diesel), whereas, olive production resulted in lowest MFA and labor resulted in less harmful for environment and use of mass is lowest environmental cost (Table 2).

Increasing use of chemical fertilizers and intensive use of arable land has substantially increased the grain production but has seriously deteriorated the upstream of environment of agriculture, farmland and downstream communities (Vitousek et al. 2009; Gomiero et al. 2011; Schreinemachers and Tipraqsa 2012). The use of pesticide has resulted substantial increase in yield globally to meet the food demand of human population growing at rapid pace. Nevertheless, this has resulted in accumulation of harmful substances in food and decline in environmental health with development of pest resistance. For sustainable food security, it is necessary to produce more food which is safe and nutritious, in the era of decreasing arable land and limiting water resources. However, use of alternative substance to synthetic chemicals has got attention due to rapid deterioration and harmful effects of pesticides on human health with increase in food safety. Use of allele chemicals from plant orientation has been effective in controlling the pest in agriculture (Campos et al. 2018; Rehman et al. 2018). Most of the botanical pesticides are developed from the essential oils produced by plants, these oils play many vital role in plant biology as they help in defense against biotic and abiotic stresses, attract pollinators and seed dissemination (Table 2: Isman 2000, 2006; Regnault-Roger et al. 2012; Pavela and Benelli 2016). These plant based compounds can be used as insecticides, fungicides or replants (Isman 2006). Use of traditional and modern farming method in integrated manner improves the productivity, with better social and environmental sustainability (Table 2: Rose et al. 2019)

In conclusion: agriculture intensification associated with high use of chemical inputs is deteriorating environment, soil health, microbial diversity in rhizosphere. However, use of organic fertilizers, botanical pesticides and natural predators can help in environmental sustainability with sustainable agricultural yields.

3 Is Global Food Security Situation Sustainable?

Agriculture faces some serious challenges as it has to address the issue of ~1 billion people who sleep hungry daily, with around an expected addition of ~2 billion people in world population by mid of this century (Rosenzweig and Parry 1994). Globally around 821 million people are suffering from malnutrition in 2017, which make around 10.9% of global population (Fig. 3; FAO 2018). In spite of all efforts the number of hungry and malnourished people is rising. In a recent survey of World Bank around 83 million people in 45 countries were starving. The undernourished population is below 5% in developed countries while it goes upto 13% and 20% in Asia and Africa respectively (Prosekov and Ivanova 2018). The number of unnourished population increased from 218.7 in 2015 to 243.2 million in Africa, while it is 519.6 million (19.7%) in 2016 compared to 508.3 in 2015 (18.3%) (Fig. 3; Prosekov and Ivanova 2018). This number is further escalated in 2017 as 20.4% of the African population is undernourished (Figs. 3 and 4). In 2013, around 19.8% of the African population is undernourished with the rate is alarmingly high in Eastern (31.9%) and Central Africa (40.9%); whereas, in Asia around 12.4% population is undernourished with highest number of undernourished population lives in Southern Asia (15.9%). Likewise, 6.1% population of Latin America and Caribbean is undernourished (FAO 2018). Moreover, the food consumption pattern is changing as the people with high income eat more and nutritious food while the situation is opposite in the developing countries.

According to FAO (2009), with stable population growth, the possibility of hunger eradication by mid of this century is questionable. The major cause of malnutrition and hunger are natural calamities, wars, poverty and high population growth rate. In a recent study, Prosekov and Ivanova (2018) selected the five countries with a decrease or increase in food security index by the end of 2017. They found an

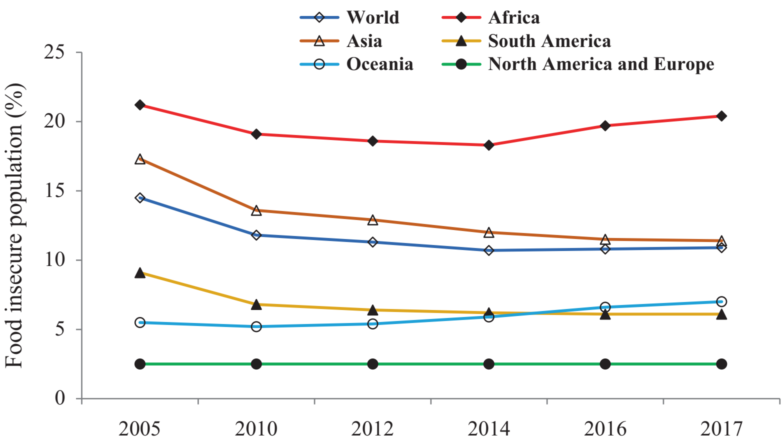

Fig. 3 Global food security situation. (Source: FAO 2018)

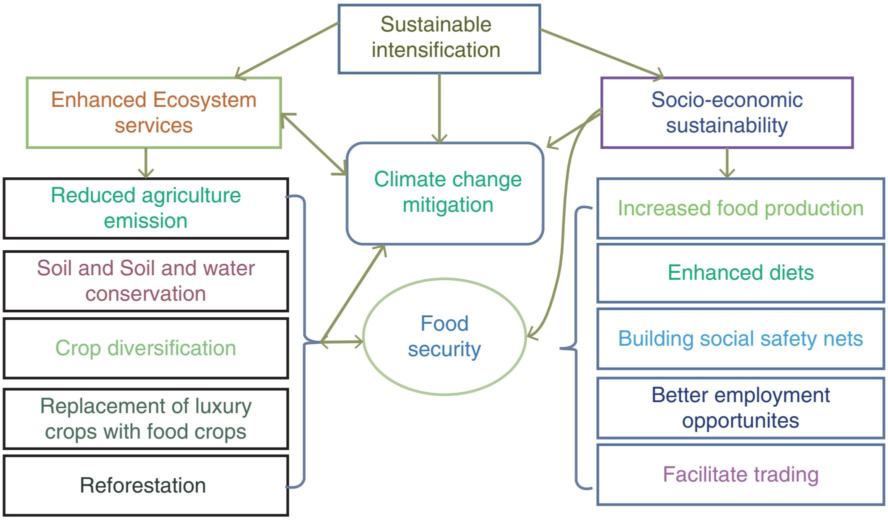

Fig. 4 Role of Sustainable intensification in climate change mitigation and food security

improvement in food security index in Nicaragua/Bangladesh (+1.3), Ecuador (+1.4), Paraguay (+2.0) and Sierra Leone (+2.6); whereas a decrease in food security index was observed in Venezuela (−7.1), Qatar (−6.0), Madagascar (−4.7), Congo (Dem. Rep.) (−3.8) and Yemen (−3.4). The decline in food supply in war affected countries is obvious but the decline in some peaceful countries is due to financial crisis globally.

In order to feed the global population, food production has kept pace by increased agricultural intensification and expansion (FAO 2009; Stevenson et al. 2013). However, in future, some estimates an increase in food production (Ewert et al. 2005), while, others expect decrease or stagnant agricultural yields due to rapidly depleting natural resources, land degradation and climate change impact on natural resource base (FAO 2009; Stevenson et al. 2013; Eitelberg et al. 2015).

Target of global food security has become challenging as on consumer side population increase and change of food consumption pattern, while on the production aspect food production is limited due to less availability of arable land for agriculture expansion and hence resulted in intensification (Scherer et al. 2018). According to UN organization the expected population of world will be between 8.3 and 10.9 billion people at the current population growth rate, which will put pressure for almost 50% and 75% increase in food supply according to some estimates (reviewed by Prosekov and Ivanova 2018). They further stated that the food supply demand will be doubled by 50% in low income countries, while the expected food demand will grow by 60% and 250% in rice consuming and Sub-Saharan African countries.

The projected food demand in terms of calories will increase more than the expected arable land (Tilman et al. 2011). Moreover, the available arable land also provides feed, fuel, fiber, timber, helping in regulating ecosystem through flood control, water purification, carbon sequestration and providing habitat to fauna and flora (Scherer et al. 2018). The potential arable land is expected to be less productive in future compared to current agricultural land as the recent enhancement in food production was attained at the cost of intensification rather than expansion (Foley et al. 2011). There are still some yield gaps in many parts of globe in spite of agriculture intensification (crop cycle) (Mueller et al. 2012) and harvest gaps (cropping frequency) (Ray and Foley 2013; Yu et al. 2017) that could be narrowed.

4 The Sustainable Intensification of Agriculture

The green revolution in 1960s has led to humongous increase in yield of staple crops due to development of input responsive crop cultivars which have come at cost of environmental integrity. In order to minimize the effect of agriculture practices on the environment, many alternative approaches have been put (e.g. organic agriculture, conservation agriculture, agroecology, ecological intensification, sustainable farming systems and sustainable intensification) (Petersen and Snapp 2015). Among these approaches sustainable Intensification (SI) is a relatively new addition and was proposed by Jules Pretty (Pretty 1997). The earlier on SI focused on approaches which can help in improving agricultural yields to meet rising food demand and also ensures environmental integrity (Pretty 1997, 1999).

Sustainable intensification is needed to handle the problem of global food security and environmental change. Local climatic conditions define the potential and need for sustainability of agricultural practices. Nevertheless, the application of these practices depends on social and economic factors, as farmers need to adopt new farming practices while consumer demand affect the economic viability of these adaptation (Scherer et al. 2018). The SI approach deems imperative in low income countries to meet the increasing global food demand (Table 1; Tilman et al. 2011). The SI can increase food and economic sustainability, especially in areas which have more and fertile agricultural land but have lower yields (Drechsel et al. 2001; Pisante et al. 2012; Vanlauwe et al. 2014).

A large number of scholars conceptualize ‘sustainable intensification’ as approached aiming at increasing the food production from the existing cultivated land in such a way with lower environmental impact and sustainable food production in future (Garnett et al. 2013). SI approach is complementary to climate smart agriculture (CSA) as SI it focuses on adaptability to climate change with lower emissions per unit of output. The CSA emphasizes the improvement of risk management, information flows and local organizations/institutes to support adaptation (Campbell et al. 2014). Moreover, CSA serves as basis for encouraging and enabling intensification. However, for adaptation instead of narrow intensification, there is need to include diverse cropping systems along with local planning for adaptation, development of efficient governess system with more asset diversity. Both SI and CSA agriculture are critical for global food security as they are part of multi-deft approach aimed at lowering waste and consumption, development and facilitating social safety net and trade and improving availability of healthy and nutritious diet

(Campbell et al. 2014). Schut et al. 2016 studied the sustainable intensification in African highlands and found that sustainable intensification faces constraints of economic and institutional nature. They further reported that institutional constraints include poor functioning or absence of markets, policies, low capabilities and finance resources and interaction between stakeholders.

In developing countries agriculture intensification is aimed at producing more food and income from existing agricultural resources. In order to attain this target, agriculture intensification can help in improving the sustainable agriculture yields with profit and social sustainability. However, SI requires better and improved agriculture technology and inputs (crop management practices, improved seed and fertilizer etc.), natural resource management (soil fertility, erosion control, reforestation, increase biodiversity etc.) and institutional reforms and innovation (policy, social infrastructure, easy access to finance, inputs, market and services) (Pretty et al. 2011; Vanlauwe et al. 2014). The integrated emergence of these innovations make smart and efficient use of existing agro-ecological, financial and human resource use across levels of different systems in a specific context (Robinson et al. 2015).

Snapp et al. (2018) conducted a participatory action research using four technologies i.e. sole maize with no and recommended fertilizer, pigeon pea –maize intercrop, doubled up legume rotation (pigeoneer intercropping in groundnut) followed by maize with half of recommended fertilizer and visualized the SI performance and tradeoffs using radar charts. They found that pigeon pea-based technologies have more environmental gains than sole maize plantation due to more biomass production, nitrogen fixation and cover duration. The domain for human and social capacity building were better for legume intergradation particularly due to diversity in diet, farmer preference (especially females) and food security over sole maize (Table 1). Furthermore, legume system was more beneficial on marginal soils due to less risk of crop failure than unfertilized maize. Niemmanee et al. (2015) studied the impact of existing agricultural systems cover on the social, economic and environmental condition of Thailand and suggested mixed cropping system with chilli as secondary and string bean as supplementary crop. They further suggested increasing use of manures and crop residues as fertilizer source and reducing the use of synthetic fertilizers and pesticides. Moreover, application of knowledge gained through trainings to the production system management and by sharing it with the farming community can help in sustainable agriculture system.

The crop yield of cereals and oil crops saw a humongous increase of 135% between during last five decades while an increase of only 27% was reported in arable land (arable land expansion varies across region) (Burney et al. 2010). Intensification without sustainability has led to numerous problems globally (Bennett et al. 2014). Furthermore, SI is a pervasive reorganizing of food systems to not only limit the environmental impact but also increase the human nutrition, animal welfare and rural economies with sustainable development (Garnett et al. 2013). In conclusion, food demand should be met through existing farmland as cultivation of new lands will have major environmental effects and costs. Therefore, intensification combined with prices and policies will have positive impact on land sparing.

5 Mitigating Impact of Climate Change in Agriculture for Food Security

Global average temperature has increased by 0.13 °C per decade since 1950s, and a faster increase (0.2 °C) is expected for next two to three decades which will have larger impact on cultivated land area (IPCC 2007). Agriculture production system contributes substantially towards global warming and accounts for 19–29% of total global greenhouse gases (GHGs) emissions, and most of these are directly coming from agricultural activities directly in the form of CH_4 and N_2O and indirectly through agricultural driven change in soil cover (Vermeulen et al. 2012). For instance, Yue et al. (2017) studied the GHGs emission from 26 crops and 6 livestock products in China and found that meat had the highest carbon footprints (CF), while lowest CFs value were observed for vegetables. Furthermore, methane emission from fertilizer and paddy were the major contributor of CFs from crop production. Climate change will have more and in general negative impact on agriculture in areas with lower latitude (Vermeulen et al. 2012; IPCC 2013). It is expected that climatic variation in future will increase the intensity and frequency of droughts, floods and will increase the risk for livestock and crop producers (Thornton and Gerber 2010). Furthermore, climate change will limit the food access to both urban and rural population due to low income, high risk and disrupted markets (Vermeulen 2014). Climatic variation is major contributor towards land degradation and change in soil cover particularly in drylands causing rapid soil deterioration.

Climate change will significantly affect the crop yield and future food availability (Table 2). For instance, Lobell et al. (2011) studied the climate trends with global crop production over three decades and found that climate change has reduced the yield of wheat and maize by 5.5% and 3.8% respectively, whereas the yield gains or losses for rice and soybean balanced out due to losses in some countries while gain in others. Al-Amin and Ahmed (2016) studied the effect of climate change on food security of Malaysia and potential climate change adaptations over 50 year time span. They predicted a 30–35% food sustainability gap below the national baseline in 2015 and the gap widens over time due to climatic change influence on agricultural yields. Nevertheless, application of certain adaptation strategies can narrow the food security gap from 5% to 20% over time. Recently, Agovino et al. (2018) constructed index of sustainable agriculture (ISA) over the period of 2005–2014 according to 16 variables and studied the climate change impact on agricultural production in 28 European Union countries. They ISA provide the ranking of EU countries based on social, economic and environmental sustainability. They found (a) negative bidirectional relationship between agricultural yield and climate change (b) negative bidirectional relationship between SA and climate change and lastly (3) conventional agriculture have negative impact on SA. A decade ago, Ravi et al. (2010) reported that extreme climatic eve-n would increase the incidence of wind and water erosion, which will shift the soil cover at faster rate in dryland areas. Farmers with poor resources, small landholdings are more vulnerable to climate change. Nevertheless, the negative effect of climate change on agriculture production and food security can be ameliorated through sustainable agriculture approaches through minor modifications in crop and livestock production practices, changing the cropping and food systems to ensure socio-economic and environmental sustainability (Table 3).

Agriculture is one of the principal factors affecting climate change by directly contributing GHGs emission through anthropogenic activities (14%) and land use (17%). Moreover, it is expected that low and middle-income countries will be the major contributors of agriculture emission in the future (Smith et al. 2007). Although the industrialized countries have substantially reduced the GHGs emissions, nevertheless developing countries face the problem of high carbon emissions. Climate smart agriculture is a pragmatic option to improve the food security with better climate change adaptations and mitigations. Furthermore, in developing countries, climate change mitigation is a co benefit as priority remains with adaptation and food security (Campbell et al. 2014). Parihar et al. (2018) in a 5 year study observed the diversified crop rotations and conservation agriculture (CA) impact on soil health, GHGs emission and food security in north-western Indo-Gangetic plains and found that CA practices in maize based cropping systems can help in reducing the GHGs emission and reduced the soil degradation. They further reported that CA in maize based cropping systems (maize-wheat-mungbean, maize-chickpea-sesbania and maize-maize-sesbania) improved the carbon sequestration, soil mineral N, with reduced N_2O emission and soil degradation.

In dryland areas, rainwater harvesting can help in mitigating the issue of climate change induced soil degradation in agro-ecosystem (Lal 2001). Maintaining the soil fertility can help in mitigating the problem of food security through increased food production under climatic variations (Wagstaff and Harty 2010). Adoption of eco-friendly sustainable agricultural approach can help in maintaining soil fertility and limit land degradation (Lovo 2016). Several practices such as use of cover crops, intercropping, crop diversification, and agroforestry can help in maintaining the agricultural production and soil conservation (Mensah 2015). Crop diversification can help in mitigating the climate change by providing options of increased diversity of marketable produce, development of innovative approaches and better functioning of agricultural system (McCord et al. 2015). Intercropping with legumes and trees can help in root proliferation which will help in improving water and nutrient uptake (Lithourgidis et al. 2011). Soil fertility holds the key for sustainable management of agricultural systems for improved biodiversity and agricultural production (Ponisio et al. 2015; Garbach et al. 2016). Furthermore, balance crop rotations can also help in improving the soil health, soil organic matter buildup and carbon sequestration (Omonode et al. 2007). Crop rotation also helps in breaking the pest cycle, improve disease resistance and crop yield (Katsvairo and Cox 2000; Krupinsky et al. 2006). Furthermore, integrated livestock and crop production systems help in reducing the land degradation with improved soil health, fertility and better land utilization helping in increased economic benefit and thus can contribute towards social and environmental sustainability by lowering poverty and reduced use of chemical fertilizer and pesticides (Gupta et al. 2012). For instance, Devendra and Thomas (2002) reported that nutrient transfer from pasture to crop land through

Table 3 Climate change mitigation strategies

Region	Strategy	Description	Reference
Andean regions	Biodiversity Quinoa	It is highly nutritious and can grow on diverse climatic conditions and marginal lands with high economic returns	Ruiz et al. (2014)
Tanzania	Soil conservation (Mulching, bund making and terracing) and agroforestry	A large number of farmers use terracing (28%), bund making (46%) and mulching (57%) to enhance soil productivity and replacing coffee with agroforestry to mitigate global warming effect	Mulangu and Kraybill (2013) and Kajembe et al. (2016)
Malaysia	Irrigation scheduling, crop diversification, IPM, Conservation agriculture, better weather and climate information system	These adaptation strategies can help in reducing the negative effective of climate change on agriculture yield and will help in ensuring sustainable food production	Al-Amin and Ahmed (2016)
Ecuador	Conservation payments to international C price	Reduce deforestation and GHG emissions	Ortega-Pacheco et al. (2019)
	Sustainable intensification	Increased yield with reduction in emission of 161 GtC annually	Burney et al. (2010)
India	Sustainable intensification (Rice-wheat-legume) and CA	Increased carbon sequestration, better soil health with higher food production	Samal et al. (2017)
India	Diversified maize rotations	The higher SOC and mineral-N, with lower N_2O fluxes and lower global warming potential with high food security and soil health were found in maize–wheat–mungbean and maize–chickpea–Sesbania than in maize–maize–Sesbania cropping system	Parihar et al. (2018)
Italy	Precision Agriculture (PA) and conservation tillage (CT)	Minimum tillage and no-tillage reduced the soil carbon losses by 17% and 63% respectively than conventional tillage with reduced carbon emission. In addition, PA practices optimized the fertilizer and fossil fuel consumption. Adoption of PA and CT reduced the CO_2 emission by 56%	Cillis et al. (2018)
China	Change of crop cultivar (13%), crop type (9%), soil management (16%) and planting dates (5%)	Crop diversification, crop variety, planting date and soil management were best suited adaption to climate change for better crop production and economic return	Kibue et al. (2015)
India	Efficient fertilizer use Zero tillage Rice water management	Adoption of these cost effective strategies can reduce 50% of GHG emission	Sapkota et al. (2019)
Canada	Organic waste managment	Application of organic waste of food industry to soil can help in reduction the cost of N fertilizer application by soil nitrate recycling and also reducte the GHGs emission	Rashid et al. (2010)

manure substantially helps in maintaining soil fertility and crop yield. Livestock provides cheapest labor and efficient route to intensification through nutrient cycling.

Extensive work should be developed on the topic of climate change and potential implications for food safety, which include developing models (on the basis of the available information and on the generation of reliable new data) in order to obtain more information on the spatial distribution of risk determinants for food systems under different scenarios of climate change (Miraglia et al. 2009).

In conclusion, climatic variation can largely affect agricultural yields globally. However, understanding the previous impact of climate change and devising of new policies, introduction of new crops, crop rotations, crop and livestock integration can help in mitigating the adversities of climate change through reduced GHGs emissions, better soil fertility and agricultural yield.

6 Conclusion

The rise in food demand has led to intensification. The agricultural yields have increased to many folds during last 60 years with a little increase in agriculture land. This intensification has helped in meeting the food demand but it is deteriorating environmental integrity and also poses threat to social and economic sustainability as the agricultural yields will decline in future from the same crop land due to intensification. Sustainable intensification can help in maintaining the agricultural productivity without decreasing agricultural yield and ensuring food security along with social and economic sustainability. It can also help in reducing the GHG emissions from agriculture. Climate change negatively affects food security with increase in GHG emission. However, sustainable crop and livestock intensification, crop diversification, intercropping, carbon sequestration can help in reducing the emissions from agriculture and improving the food security situation.

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