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REVIEW PAPER

Traditional agriculture: a climate-smart approach for sustainable food production

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Abstract Sustainable food production is one of the major challenges of the twenty-first century in the era of global environmental problems such as climate change, increasing population and natural resource degradation including soil degradation and biodiversity loss. Climate change is among the greatest threats to agricultural systems. Green Revolution though multiplied agricultural production several folds but at the huge environmental cost including climate change. It jeopardized the ecological integrity of agroecosystems by intensive use of fossil fuels, natural resources, agrochemicals and machinery. Moreover, it threatened the age-old traditional agricultural practices. Agriculture is one of the largest sectors that sustain livelihood to maximum number of people and contribute to climate change. Therefore, a climate-smart approach to sustainable food production is the need of hour. Traditional agriculture is getting increased attention worldwide in context of sustainable food production in changing climate. The present article advocates traditional agriculture as a climate-smart approach for the sustainable food production and also deliberates the correlation between climate change and agriculture.

Keywords Agroforestry · Climate change · Climate-smart agriculture · Intercropping · Sustainability · Traditional agriculture

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1 Introduction

Climate change is one of the most debated issues of the twenty-first century in the socio-ecological and economic perspectives. Anthropogenic activities are largely responsible for mounting environmental problems such as climate change, environmental pollution and natural resource degradation including soil degradation and biodiversity loss. Human-induced changes are major drivers for current and projected climate change (Solomon 2007; Ramanathan and Xu 2010). Now climate change is a reality and the evidences can be traced through the global warming, glacier melting, sea level rising, ocean acidification, precipitation variability and extreme weather events (Adger et al. 2005; Solomon 2007). Average global temperature is expected to increase through 0.5–8.6 °F by the end of the twenty-first century (IPCC 2013). This increased temperature would affect agricultural production significantly. Agriculture is among the highly sensitive systems influenced by change in weather and climate. In recent years, climate change impacts have been become the greatest threats to global food security (Tripathi et al. 2016; Islam and Nursey-Bray 2017). Climate change results a decline in food production and consequently rising food prices (IASC 2010; Bandara and Cai 2014). Climate change threats are further intensified by growing population. It is projected that global population will touch the historic mark of 9.5 billion by 2050 (Godfrey et al. 2010). To feed this large population, twofold of food production from the present level will be required (FAO 2016). Climate change impacts are more severe in the developing countries due to their agriculture based economy, warmer climate, frequent exposure to extreme weather events and lack of money for adaptation methods (Parry et al. 2001; Tubiello and Fischer 2007; Morton 2007; Touch et al. 2016).

According to Rockström et al. (2009), the boundaries in three systems viz., rate of biodiversity loss, human interference with the nitrogen cycle and climate change have already been overstepped. We are living in the anthropocene era where human-driven environmental changes deteriorate geographical and ecological resilience of the earth system (Crutzen 2002; Steffen et al. 2007; Rockstrom et al. 2009). Agriculture and climate change are correlated as both affect each other significantly (Paustian et al. 1997). It is estimated that contribution of agriculture, forestry and other land use (AFOLU) is about 21% in the total global emission of greenhouse gases (GHGs) (FAO 2016). Green Revolution though boosted agriculture production but at the huge socio-ecological cost such as environmental pollution, biodiversity loss, climate change, land degradation, erosion of traditional agricultural knowledge and decline in human health and livelihood (Redclift 1989; Alteri 2000; Eakin et al. 2007; Phungpracha et al. 2016; Srivastava et al. 2016). Excessive and inappropriate use of agrochemicals, fossil fuels, natural resources, machinery and adoption of high yielding varieties (HYVs) and monocropping patterns are the major causes for such socio-ecological cost (Phungpracha et al. 2016).

Climate change mitigation and adaptation are two foremost needs to reduce global warming impacts (Kongsager et al. 2016; Song and Ye 2017). Achieving the goals of eradicating hunger and poverty by 2030 while addressing the climate change impacts need a climate-smart approach in agriculture. Climate-smart agriculture (CSA) is based on the objectives of sustainably enhancing food production, climate adaptation and resilience and reduction in GHGs emission (FAO 2010). Traditional agricultural practices have regained the increased attention worldwide as climate-smart approach. Traditional agriculture is the outcome of experiences provided by local farming practices through thousands of years (Pulido and Bocco 2003). High productivity, biodiversity conservation, low energy inputs and climate change mitigation are some of the salient features of the traditional agriculture systems (Srivastava et al. 2016). Traditional agroecosystems are recognized as the time tested models of modern sustainable agriculture systems that occur today (Ellis and Wang 1997). Traditional practices like agroforestry, intercropping, crop rotation, cover cropping, traditional organic composting and integrated crop-animal farming have potentials for enhancing crop productivity and mitigating climate change. Indigenous farmers and local people perceive climate change in their own ways and prepare for it through various adaptation practices (Tripathi and Singh 2013).

Farmers due to dogged work and low profit shifted from traditional agriculture towards the modern one. Modern agriculture, however, enhanced food productivity but with the acceleration of several environmental problems such as climate change, food unsafety, biodiversity loss, soil degradation and environmental pollution (Zhang et al. 2017a). Modern agriculture is a major driver for the loss of crop genetic resources in the Third World due to adoption of HYVs and planting the vast fields with genetically uniform cultivars (Altieri and Merrick 1987). Traditional agricultural practices are usually restricted to small farmers. Traditional vegetables grow well in drought-prone areas. Traditional vegetable knowledge is under serious threat due to habitat loss, introduction of new varieties, historical policies, stigma attached to the use of traditional vegetables and altered lifestyle (Dweba and Mearns 2011). In the context of sustainable food production in changing climate, adoption of climate-smart traditional practices is an urgent need. It is right time to rediscover and reimplement traditional practices to improve the socio-ecological integrity of agroecosystems. Integration of traditional agriculture with modern agriculture is the necessity of current scenario. This integration would bridge the huge gap between indigenous and modern peasants. Moreover, it would fortify the human–nature relationships. The aim of this article is to advocate traditional agriculture as a climate-smart approach for sustainable food production. Moreover, agriculture-climate change correlation is also described at substantial level. Authors also stated some recommendations for sustainable food production in changing climate.

2 Agriculture and climate change: a two-way relationship

Climate change is statistically significant difference in either the mean state of the climate or in its variability, continuing for a long period usually decades or longer (VijayaVenkataRaman et al. 2012). It refers to both a shift in mean climatic conditions (e.g. temperature and precipitation) and an increase in the frequency and severity of weather extremes (Tebaldi et al. 2006; Eitzinger et al. 2013; Porter et al. 2014; Mandryk et al. 2017). Economic activities prompted by industrial revolution have been contributed to climate change through increasing GHGs emission (IPCC 2007a). Agricultural activities from cropping to harvesting emit GHGs that cause climate change which in turn disturbs agriculture (Paustian et al. 1997). Therefore, climate change and agriculture are correlated (Fig. 1).

Agriculture is one of the major contributors of global warming through a share of about 10–12% increase in total

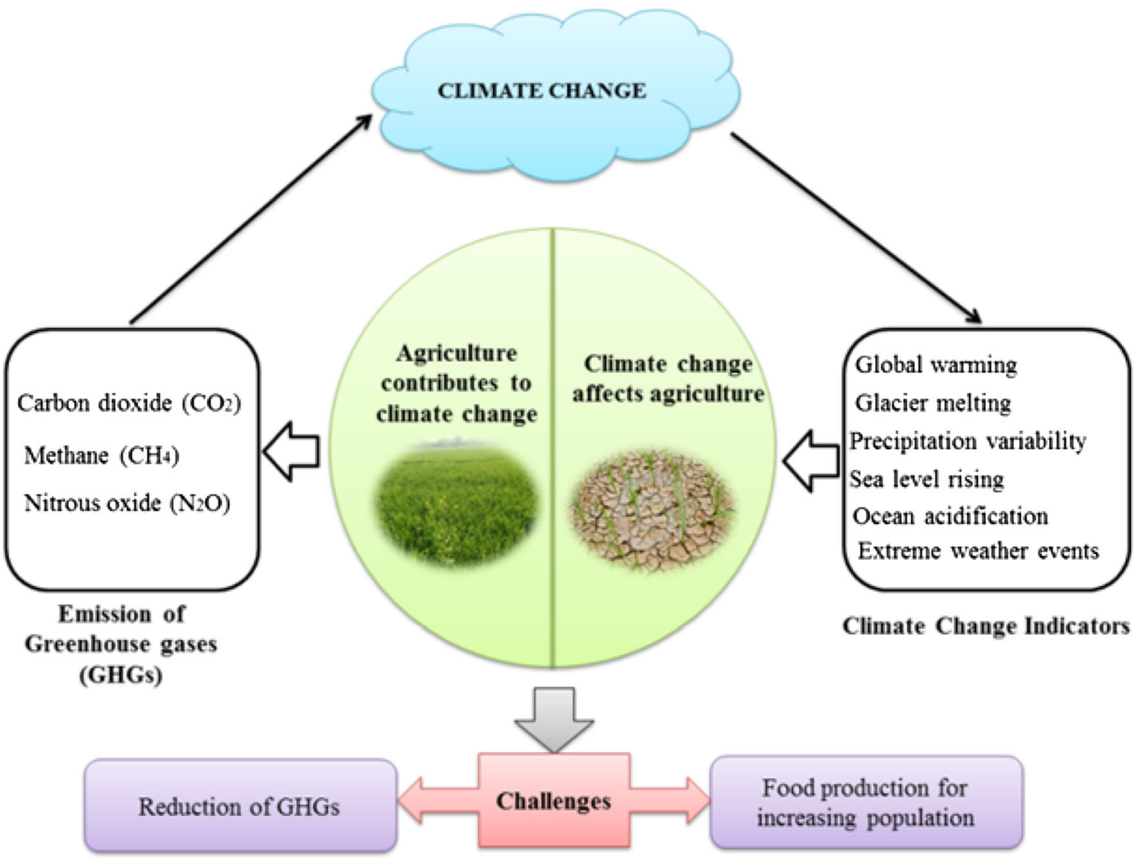

Fig. 1 Correlation between agriculture and climate change

anthropogenic GHG emission (Stocker et al. 2013). Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are major GHGs emitted by agricultural activities (Tellez-Rio et al. 2017). In year 2005, it was estimated that globally agriculture accounted to 50 and 60% of total anthropogenic CH_4 and N_2O emissions, respectively (Liu et al. 2015). Agroecosystems are highly sensitive and vulnerable to climate change (Parry and Carter 1989; Reilly 1995; IPCC 2014). Climate change is a severe threat to both food production and human health (McMichael et al. 2007). It influences agriculture through increased temperature, precipitation variability and amplified intensity of weather extremes. Climate change affects agriculture directly through altering the agroecological conditions and indirectly by increasing demand of agricultural production (Schmidhuber and Tubiello 2007). Climate change is a serious threat to all aspects of agriculture including production, distribution, food accessibility and food prices (Tai et al. 2014; Islam and Nursey-Bray 2017). During 1980 to 2008, there was a 5.5% fall in wheat yields and a 3.8% fall in maize yields globally, compared to their yields in stable climate (Lobell et al. 2011). Climate change also affects the invasive crop pest species (Yan et al. 2017), livestock production (Rojas-Downing et al. 2017) and aquaculture (Porter et al. 2014). Tropical and developing countries are at the greater risk to climate change as compared to temperate and developed countries and this scenario encounters current and future food production (Gornall et al. 2010; Hillel and Rosenzweig 2010; Deryng et al. 2014; Porter et al. 2014; Challinor et al. 2014).

3 Climate-smart agriculture: principles and objectives

Food and Agriculture Organization (FAO) devised the climate-smart agriculture (CSA) approach in order to manage agriculture for food security in the era of global warming (FAO 2010). The CSA approach has three objectives: (1) sustainably enhancing agricultural productivity to support equitable increase in income, food security and development (2) increasing adaptive capacity and resilience to shocks at multiple levels, from farm to national and (3) reducing GHG emissions and increasing carbon sequestration where possible. Sustainable food production while reducing GHG emissions and increasing climate resilience of agricultural system is the foremost objective of CSA (Harvey et al. 2014; Brandt et al. 2015).

Lipper et al. (2014) defined CSA as the strategy that transforms and reorients agroecosystems to produce food in climate change scenario. According to Olayide et al. (2016), CSA is an emerging approach to enhance food production, biodiversity, environmental quality, agroecosystem resilience, livelihoods and economic development while addressing the climate change impacts. Relative priority of each of the objective of CSA fluctuates with locations, for example, small farmers of developing countries need more emphasis on productivity and adaptive capacity (Neufeldt et al. 2013; Campbell et al. 2014). CSA has been getting a mounting attention particularly in developing world due to its capabilities to enhance agricultural productivity and agroecosystem resilience while reducing GHG emission (Grainger-Jones 2011; Long et al. 2016; Mwongera et al. 2017).

4 Traditional agriculture: concept and agroecological features

Traditional knowledge is holistic in nature due to its multitude applications in diverse fields such as agriculture, climate, soils, hydrology, plants, animals, forests and human health (Howes and Chambers 1980; Jungerius 1985; Wilken 1987; Agrawal 1995; Pulido and Bocco 2003). Husbandry and agriculture are among the oldest practices through which human have been interacting with nature and managing ecosystem services (Fisher et al. 2009). Traditional agriculture is the result of the experiences delivered by the local farming practices through thousands of years (Pulido and Bocco 2003). Traditional farming practices contributed a significant role to the building of scientific knowledge in agriculture (Sandor and Furbee 1996; Singh et al. 1997a). These have been nourished a sizeable population for centuries and continue to feed people in many regions of the world (Koohafkan and Altieri 2010).

Farmers throughout the world particularly in developing regions use local, traditional or landraces of both minor and major crops (Jackson et al. 2007). Although modern agriculture has been adopted by farmers in every corners of the globe, but 1.9–2.2 billion people still use traditional methods in agriculture (Altieri 1993; Pretty 1995). Small farmers are stewards of the traditional agricultural practices, and globally about 84% of farms have area less than 2 ha that operate 12% of farmland (Altieri 2004; Lowder et al. 2016). Smallholder farmers adjust to environmental changes through their indigenous knowledge and experience such as changing farming practices and cultivating adapted crops (Lasco et al. 2014). China ranks first in terms of total small farms followed by India, Indonesia, Bangladesh and Vietnam (Altieri 2009). In Sub Saharan Africa, smallholder farmers comprise 80% of all farms and their traditionally cultivated fields are generally more productive than that of large-scale farmers (Stifel 1989; Bridge 1996; Kuivanen et al. 2016). About 70% of Mexican peasants particularly smallholders cultivate their fields with traditional agriculture practices (Aguilar-Jiménez et al. 2013). Farmers in traditional agroecosystems of the Himalayan mountains are largely dependent on the locally available resources and indigenous technology (Nautiyal et al. 2007).

Traditional agricultural landscapes refer to the landscapes with preserved traditional sustainable agricultural practices and conserved biodiversity (Harrop 2007; Lieskovský et al. 2015). They are appreciated for their aesthetic, natural, cultural, historical and socio-economic values (Barankova et al. 2011; Lieskovský et al. 2015). Traditional farming landscape occurs in regions where farming practices either remain same or change comparatively little over a long period of time (Fischer et al. 2012). Some prominent examples of these regions include the Western Ghats of India, the Satoyama landscapes in Japan, the Milpa cultivation systems in Mexico, traditional village systems in Eastern Europe and South-western China's terrace landscapes (McNeely and Schroth 2006; Palang et al. 2006; Ranganathan et al. 2008; Hartel et al. 2010; Takeuchi 2010; Robson and Berkes 2011; Fischer et al. 2012; Liu et al. 2012). The Hani rice terraces of Yunnan Province in Southwest of China are one of the well-known agricultural systems in mountainous regions. These terraces have been designated as Globally Important Agricultural Heritage Systems (GIAHS) in 2009 by FAO and World Cultural Heritage (WCH) sites by United Nations Educational, Scientific and Cultural Organization (UNESCO) in 2013 (Zhang et al. 2017b).

During the last few decades, agrobiodiversity has reduced due to intensive monoculture farming (Matson et al. 1997; Evenson and Gollen 2003; Sardaro et al. 2016). About 80% of the world's arable land is planted with a handful of crops such as corn, wheat, rice, soyabean and others (Adams et al. 1971; Heinemann et al. 2013; Altieri et al. 2015). FAO estimated that 75% of the world's food crop diversity has lost in the twentieth century due to replacement of local varieties by genetically uniform HYVs (FAO 2009; Gonzalez 2011). Worldwide traditional farmers are recognized as the custodians of natural resources including biodiversity (Chhatre and Agrawal 2008). Traditional farmers preserve genotypes through unique and valuable traits within their herds and traditional crop varieties that tolerate environmental stresses including climate change (Boyce 2006; Gonzalez 2010, 2011; Johns et al. 2013). High vegetational diversity and a multifaceted system of indigenous knowledge are the salient features of traditional farming systems in developing countries (Altieri 1993; Gliessman1998; Altieri 2002). Himalayan agroecosystems are rich in crop diversity and traditional agriculture (Maikhuri et al. 1996; Singh et al. 1997b; Kuniyal et al. 2004).

Post-hunter-gather societies have been progressively dependent on extra-somatic energy for food production (McMichael et al. 2007). Food production needs energy in every step from cropping to harvesting and harvesting to distribution. Synthetic nitrogen fertlizers are among the high energy demanding sides of modern agriculture (Pelletier et al. 2011). Local knowledge and locally available resources have been utilized by peasants to develop sustainable farming systems (Altieri et al. 1987). Integration of crop and livestock is a strategy that helps farmers to reduce their reliance on external inputs such as fossil fuels, fertlizers and pesticides (Schiere and Kater 2001; Naylor et al. 2005; Anex et al. 2007). Unlike the modern agriculture systems where the link between agroecosystem and consumer is uni-directional, traditional agriculture systems are linked by bi-directon through recycling of agriculture and other wastes (Ellis and Wang 1997). Agrobiodiversity supplies a range of ecosystem services to agriculture and reduce the need of off-farm inputs. Composting and manuring increase soil microbial and invertebrate communities which improve nutrient cycling (Mäder et al. 2002; Reganold et al. 2010; Kremen and Miles 2012). Indigenous farmers of Asia, Africa and Latin America through continuously farming in extreme weather events have developed farming systems resilient to environmental variability with minimal external inputs (Denevan 1995; Altieri et al. 2015).

5 Traditional agriculture: alternative practices for climate change mitigation

Climate change mitigation is a human-mediated reduction of the anthropogenic forcing of climate system that includes strategies to reduce GHG sources and emissions and enhancing GHG sinks (Halsnæs et al. 2007). Indigenous people are good observers of changes in weather and climate and acclimatize through several adaptive and mitigation strategies (Salick and Byg 2007; Macchi et al. 2008; Salick and Ross 2009). Traditional agroecosystems are receiving rising attention as sustainable alternatives to industrial farming (Fraser et al. 2015). They are getting increased considerations for biodiversity conservation and sustainable food production in changing climate (Selmi and Boulinier 2003). Indigenous agriculture systems are diverse, adaptable, nature friendly and productive (Fernandez 1994). Higher vegetational diversity in the form of crops and trees escalates the conversion of CO_2 to organic form and consequently reducing global warming (Misra et al. 2008). Mixed cropping not only decreases the risk of crop failure, pest and disease but also diversifies the food supply (Sauerborn et al. 2000). It is estimated that traditional multiple cropping systems provide 15–20% of the world's food supply (Altieri 1999a). Agroforestry, intercropping, crop rotation, cover cropping, traditional organic composting and integrated crop-animal farming are prominent traditional agricultural practices. These traditional practices are advocated as the model practices for climate-smart approach in agriculture (Fig. 2; Table 1).

5.1 Agroforestry

Trees are well-known sink for carbon dioxide. They fix carbon through the process of photosynthesis and store excess carbon as biomass (Nowak and Crane 2002). The integration of trees with crops is an age-old practice that dates to the beginning of farming and animal husbandry (Oelbermann et al. 2004). Agroforestry is a practice of planting trees with crops to exploit the ecological and economic interactions of the different components (Lundgren 1982; Nair 1993; Young 1997; Albrecht and Kandji 2003). It is widely adopted as a climate-smart practice due to its potentials for climate change mitigation, adaptation, crop productivity and food security (Nair et al. 2009; Mbow et al. 2014; Luedeling et al. 2014; Coulibaly et al. 2017). Agroforestry enhances soil organic matter (SOM), agriculture productivity, carbon sequestration, water retention, agrobiodiversity and farmers' income (Nyong et al. 2007; Schoeneberger et al. 2012; Zomer et al. 2016; Paul et al. 2017). Carbon sequestration through agroforestry influenced by several factors such as type of agroecosystems, tree species, age of tree species, geographical location, environmental factors and management practices (Jose 2009). Tree components in crop fields reduce the severity of extreme weather events such as floods, hurricanes and tropical storms (Lin 2011; Matocha et al. 2012). Trees in fields serve as the windbreaks and shelter belts (Lasco et al. 2014).

Agroforestry is practised worldwide as a land-use management system but widespread in tropical regions (Pandey 2002). It is a common practice in Southeast Asia, Latin America and Equatorial Africa (Beer et al. 1990; Szott et al. 1991; Herzog 1994). About 1.2 billion people in developing countries depend on agroforestry to sustain their livelihood and agricultural productivity (FAO 2011b; Meijer et al. 2015). The cocoa agroforestry in West and Central Africa is a traditional method of integrating forest component with crops. It is a multistrata agroforestry that provides agroforestry tree products (AFTPs) like high-quality timber and fruits (Simons and Leakey 2004). Dhesa system of Spain is a traditional agroforestry system with animal components. In this system, area under forest canopy is cleared by grazing to use it as cropland (Linares

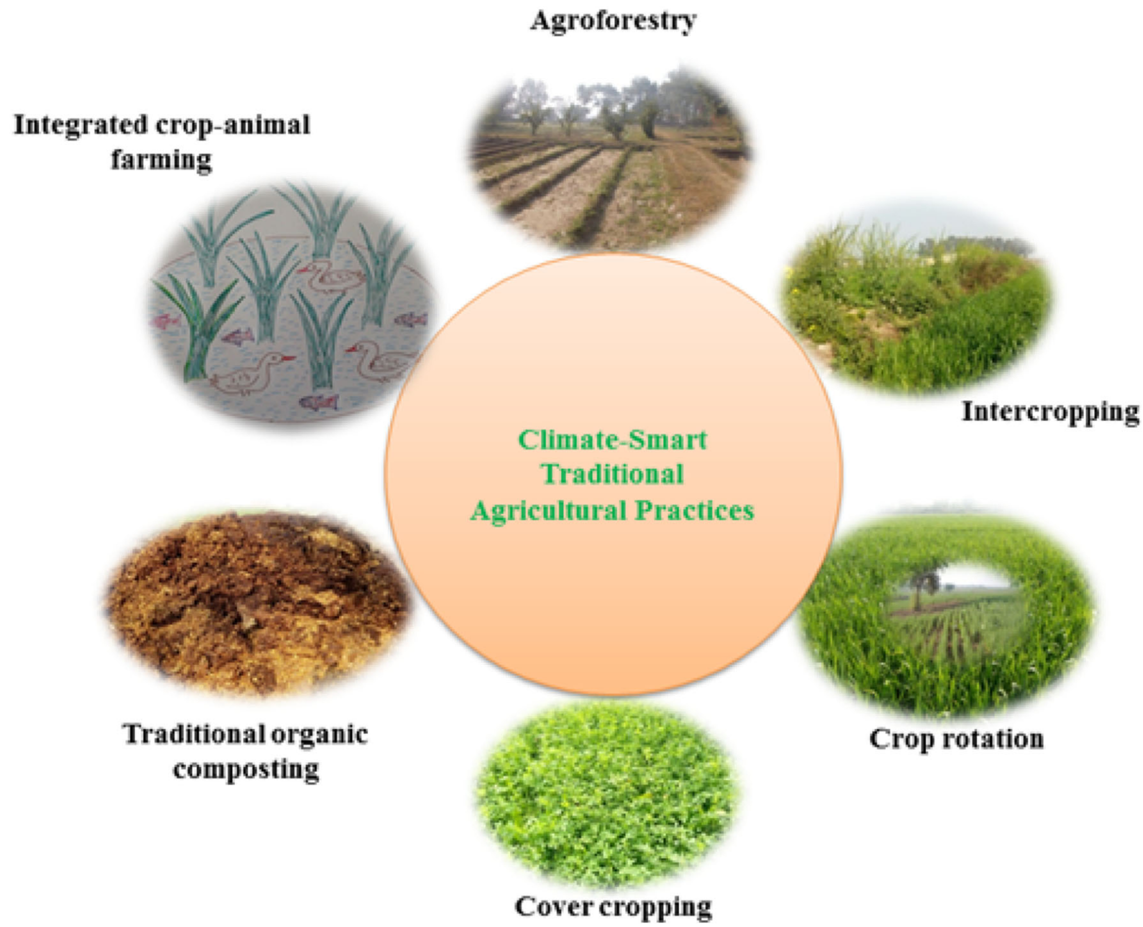

Fig. 2 Climate-smart traditional agricultural practices

2007). Integration of animals into farming systems not only provide milk and meat but also recycle their feed into manure that enhances the carbon sequestration (Altieri 1999b). Agroforestry systems are highly adapted to drought conditions as deep roots of tree explore a larger soil volume for water and nutrients (Verchot et al. 2007). In the current scenario of rising prices of fossil fuels, agrochemicals, food shortages and changing climate, agroforestry has been increasingly adopted as a cost-effective and climate-smart approach for food production (Mbow et al. 2014).

5.2 Intercropping

Intercropping, the concurrent cultivation of more than one crop species on the same field is a practical application of basic ecological principles such as diversity, competition and facilitation (Hauggaard-Nielsen et al. 2008). It is one of the highly productive farming systems (Hu et al. 2017). Intercropping reduces the climate-driven crop failure as variety of crops have different climatic adaptability (Shava et al. 2009). Intercrops efficiently utilize the natural resources such as land, light, water and nutrient and increase biodiversity, productivity, resilience and stability of agroecosystem (Zhang and Li 2003; Mushagalusa et al. 2008; Ning et al. 2017). Analysis of long-term experiments indicated that increasing crop rotation intensity from single crop (corn) to double crop (corn-soybean) enhanced carbon sequestration by 20 g cm^{-2} $year^{-1}$ in humid continental climate at Wooster of Ohio, USA (West and Post 2002). In India, intercropping is an ancient agricultural practice, particularly intercropping of sorghum and pigeon pea (Willy 1983; Wang et al. 2010). Latin American farmers grow their 70–90% of the beans with maize, potatoes and other crops (Francis 1986). Wheat–maize intercropping combined with conservation agricultural practices can be used for reducing CO_2 emission and increasing crop productivity (Hu et al. 2017). Rubber-sugarcane intercropping is a sustainable and environmental friendly method to produce economic benefits while enhancing carbon sequestration (Kumara et al. 2016).

Intercropping of legumes with cereals optimizes the facilitation under nutrient limited conditions (Mao et al. 2015). Legumes make a symbiotic association with

Table 1 Examples of climate-smart traditional agricultural practices and their role in climate change mitigation

Climate-smart traditional agricultural practices				Role of traditional agricultural practices in climate change mitigation	
Traditional practices	Location	Brief description	Reference	Climate change mitigation	Reference
Agroforestry	West and Central Africa	Traditional cocoa agroforestry to sustainably utilize land and natural resources	Simons and Leakey (2004)	Agroforestry systems mitigate nitrous oxide (N_2O) and methane (CH_4) emission	Mutuo et al. (2005)
				Agroforestry mitigates climate change through enhancing the carbon sequestration	IPCC (2000)
Intercropping	Latin America	Intercropping of beans with maize, potatoes and other crops	Francis (1986)	Intercropping enhances carbon sequestration	West and Post (2002)
Crop rotation	Southern Spain	Rotation between drum wheat and sunflower	Pedraza et al. (2015)	Leguminous crops in rotation increase soil's potential to sequester carbon and add nitrogen into soil	Lal (2011)
Cover cropping	Paraguay	Growing grey-seeded mucuna leaves as cover crops	FAO (2011a)	Cover crops enhance soil organic carbon (SOC) pool	Lal (2004)
Traditional organic composting	India	Use of composted farmyard manure (FYM) is a common practice in Indian Himalayan villages	Gopinath et al. (2008)	Organic compost enhances the soil organic matter (SOM) that improves carbon sequestration	Drinkwater et al. (1998), Johnston (1994), Tilman (1998)
Integrated crop-animal farming	China	Duck-rice-fish culture system	Juanwen et al. (2012)	Diversified livelihood and optimum utilization of natural resources in changing climate	Howden et al. (2007)
				Duck-rice culture reduces the external input of nitrogen fertilisers and consequently lowering of N_2O emission	Long et al. (2013)

rhizobium bacteria that help in nitrogen fixation (Duchene et al. 2017). Leguminous crops not only reduce the N_2O emission from agricultural fields but also enhance the release and turnover of mineralizable N-containing compounds in soil (Rochette and Janzen 2005; Jensen et al. 2010; Scalise et al. 2017). Global warming potential of N_2O is 298-fold higher than CO_2 and agriculture alone contributes to about 60% to the total anthropogenic N_2O emission (Syakila and Kroeze 2011; Hauggaard-Nielsen et al. 2016). Intensive application of nitrogen fertilisers has been altered climate system and the global N cycle through emissions of N_2O (Bouwman et al. 2002; Rashti et al. 2015). Legume intercropping help in reducing the external input of nitrogen fertilisers. Intercropped legumes enhance the availability of nutrients (nitrogen and phosphorus), crop growth and nutrient use efficiency (Latati et al. 2013; Lazali et al. 2016; Latati et al. 2017). Intercropping of maize with legumes reduces nitrate leaching and synthetic fertilisers input and enhances agrobiodiversity, soil health and crop yield (von Cossel et al. 2017). Green manure in the form of legume intercrops reduces soil erosion through enhancing soil aggregate stability (Gomes et al. 2009; Forte et al. 2017). They also encourage N-retention in soil (Cherr et al. 2006; Gabriel and Quemada 2011; Forte et al. 2017).

5.3 Crop rotation

Crop rotation refers to the practice of growing a sequence of plant species on the same land (Bullock 1992; Dury et al. 2012). It is an ancient practice that has been used for thousands of years (Bullock 1992; Hobbs et al. 2008). Crop rotation has been recaptured the global attention to solve the increasing agroecological problems such as declining soil quality and climate change resulting from short rotation and monocropping (Liu et al. 2016). Crop rotation is an effective approach for carbon sequestration as compared to growing same type of crop continuously (Triberti et al. 2016). It is a potential practice to reduce the emissions of CH_4 and other GHGs in irrigated-rice fields (Theisen et al. 2017). According to Cha-un et al. (2017), when rice was cultivated in rotation with corn and sweet sorghum in dry season, there was a significant reduction in GHG emission (combined CH_4 and NO_2 in CO_2 equivalent) by 68–78% as compared to double rice cultivation. Crop rotation is a sustainable approach that increases yield and water use efficiency while reducing soil erosion (Huang et al. 2003). In rain fed areas of Southern Spain, rotation between drum wheat (*Triticum drum*) and sunflower (*Helianthus annuus*) is a traditional practice that increases soil fertility (Pedraza et al. 2015). Crop rotation enhances the soil quality and crop productivity through altering soil structure and aggregation, SOC concentration, nutrient cycling and pests and diseases (Jarecki and Lal 2003).

The selection of a crop for incorporating it in rotations is very important. In crop rotation practice, species that enhance N in the soil can increase the phytomass production of the subsequent crops and consequently increasing SOM (Peoples and Baldock 2001; Raphael et al. 2016). Increasing SOM is a sustainable method to enhance crop productivity while increasing carbon sequestration and maintaining global C-cycle. Soil store more organic carbon than that of the atmosphere and global vegetation combined (Lehmann and Kleber 2015). Leguminous crops reduce reliance on N-fertilisers like NPK that emits N_2O and thereby reducing fossil fuel consumption in manufacturing of fertlizers and consequently lowering of CO_2 emission (Zentner et al. 2001, 2004; Wang et al. 2010). Further, such crops improve the soil carbon sequestration (Lal 2011). It is estimated that corn-soybean rotation enhances crop productivity and amount of crop residues as compared to monoculture of corn or soybean (Wang et al. 2010). Cowpea (*Vigna unguiculata*) is an important legume for both human food and livestock fodder. It is a drought-tolerant traditional crop that is well grown in semi-arid tropics Asia, Africa, Central and South America (Singh et al. 2003). Cow pea is an efficient nitrogen fixer that grows well in sandy and nutrient poor soils (Sanginga et al. 2000; Singh et al. 2003).

5.4 Cover cropping

Cover cropping is a sustainable approach for enhancing soil health, soil microbial biomass and agroecosytem services such as nutrient cycling, water storage, weed and pest control and carbon sequestration (Schipanski et al. 2014; Frasier et al. 2016; Pinto et al. 2017). Cover crop refers to the crop that is grown to cover the ground for reducing soil erosion and nutrient loss (Reeves 1994; Dabney et al. 2001). They are usually non-cash crops sown in the autumn to provide winter ground cover (Cooper et al. 2017). Replacement of a bare fallow period through cover cropping is a sustainable strategy for reducing runoff and soil erosion (Reeves 1994; Alvarez et al. 2017). Cover crops can be harvested before planting of the main crops or they can be grown alongside the main crop to provide living mulch (Robacer et al. 2016). Cover crops can be leguminous (e.g. pea, vetch and clover) or non-leguminous (e.g. rye, sorghum and brassicas) (Cooper et al. 2017). Rye, oat, pea, vetch, clover, sun hemp, velvet bean and sorghum are among the prominent cover crop species that are grown to enhance soil fertility and soil carbon sequestration (Wang et al. 2010). Sorghum is a drought-tolerant cover crop (Montgomery et al. 2016). In Paraguay, cover cropping is a traditional practice. In Paraguay, indigenous people grow grey-seeded mucuna leaves which are excellent dead cover that protects soil from erosion and weeds (FAO 2011a). Cover crops are sustainable farming tool that increase SOM and improve soil water dynamics (Steele et al. 2012; Poeplau and Don 2015; Basche et al. 2016; Duval et al. 2016). Basche et al. (2016) found that long-term use of a winter rye cover crop enhanced soil water dynamics such as water content and soil water storage in a maize-soybean cropping system.

Cover crops are recognized as the green manure. They add nitrogen to the agroecosystem either by fixation or by improving the N-mineralization, consequently declining synthetic fertilisers inputs and their resultant GHG emissions (Dabney et al. 2001; Thorup-Kristensen et al. 2003; Fageria et al. 2005; Schipanski et al. 2014; Li et al. 2015; Alvarez et al. 2017). Legume cover crops provide sufficient nitrogen to crops grown in rotation and consequently reducing external inputs of the synthetic fertilisers (Magdoff and Weil 2004; Gselman and Kramberger 2008; Robacer et al. 2016). Grass and legume winter cover crops are recognized as the sustainable tool to supporting nutrient cycling and conserving water and soil resources (Ranells and Wagger 1996; Jahanzada et al. 2017). Legume cover cropping is commonly practised by smallholder farmers in tropics (Mendham et al. 2004). Legume cover crops enhance SOM, biodiversity and carbon sequestration (Uhlen and Tveitnes 1995; Fullen and Auerswald 1998; Singh et al. 1998; Lal 2004). SOC maintenance or enrichment is a key provision for increasing soil ecosystem services including carbon sequestration (Hwang et al. 2017). Cover crops services in SOC pool enrichment has been reported from European countries such as Hungry, UK, Sweden, Netherlands (Johnston 1973; Van Dijk 1982; Nilsson 1986; Berzseny and Gyrffy 1997; Smith et al. 1997; Fullen and Auerswald 1998; Lal 2004). Velvet bean *(Mucuna utilis)* is a potential cover crop for the humid tropics of West Africa that improves SOC pool (Lal 2004). Sainju et al. (2016) reported that SOC increased by 0.4% with rye in momoculture and 3% with vetch and rye in biculture at 0.30 cm.

5.5 Traditional organic composting

Fertiliser-driven GHG emission is the largest source of total GHG emission from agriculture sector (Wang et al. 2017). Inorganic nitrogen (N) fertilisers contribute to approximately 75% of direct emission from agricultural soil (Zheng et al. 2004; Mohanty et al. 2017). Besides contributing to GHG emission, nitrogenous fertilisers decrease soil microbial activity and bacterial diversity (Ding et al. 2017). On the other hand, use of organic compost is a sustainable and climate-smart approach to increase soil fertility. The use of composted organic wastes to enhance soil fertility and productivity is gaining huge attention worldwide (Goyal et al. 2005). Composting is a traditional practice that has been used for centuries (Oudart et al. 2015). Composting refers to the natural process of rotting or decomposition of organic matter by microorganisms under controlled conditions (Misra et al. 2003). It is a biochemical process in which microbial degradation of organic waste results into a product known as organic manure or compost (Onwosi et al. 2017). Composting is a sustainable approach for organic waste management. It not only removes the waste but also transforms waste into nutrient-rich organic product that can be used to enhance soil fertility (Neher et al. 2013). Variety of organic materials are used in composting process such as straw, crop residues, agroindustry by-products, livestock waste, sewage sludge and kitchen waste (Proietti et al. 2016). A simplified model of traditional organic composting is presented in Fig. 3.

Organic composting process begins after putting the organic waste in a pit for several days or months. The heap of organic waste undergoes microbial degradation that converts organic waste into compost. During composting, organic material passes through the thermophilic phase (45–65 °C) that kills numerous pathogenic microorganisms due to release of CO_2, water and heat (Lung et al. 2001; Alidadi et al. 2005; Mehta et al. 2014; Soobhany et al. 2017). Several physio-chemical parameters affect the composting process such as temperature, moisture, pH, particle size, aeration and electrical conductivity (Li et al. 2013; Juárez et al. 2015; Onwosi et al. 2017). Organic compost increases soil carbon sequestration and reduces GHGs emission (Forte et al. 2017). It enriches SOM, soil fertility, soil microbial diversity, soil moisture, cation exchange capacity, soil aeration and reduces soil erosion and crop pests and diseases (Tester 1990; Diaz-Zorita et al. 1999; Peacock et al. 2001; Mäder et al. 2002; Magdoff and Weil 2004; Sun et al. 2004; Fließbach et al. 2007; Ge et al. 2008; Zhang et al. 2012; Liu et al. 2013). It is widely recognized that animal manure and crop straw enhance the SOM and crop yield (Yang et al. 2004).

It is estimated that global average sequestration potential of organic croplands is 0.9–2.4 Gt CO_2/year (Niggli et al. 2009). Organic matter not only makes soils more resistant to drought but also makes them adaptable with low and high rainfall (Lotter 2003; Bot and Benites 2005; Lal 2008). The use of organic manure can increase soil carbon or nitrogen levels in twofold in about 40 years

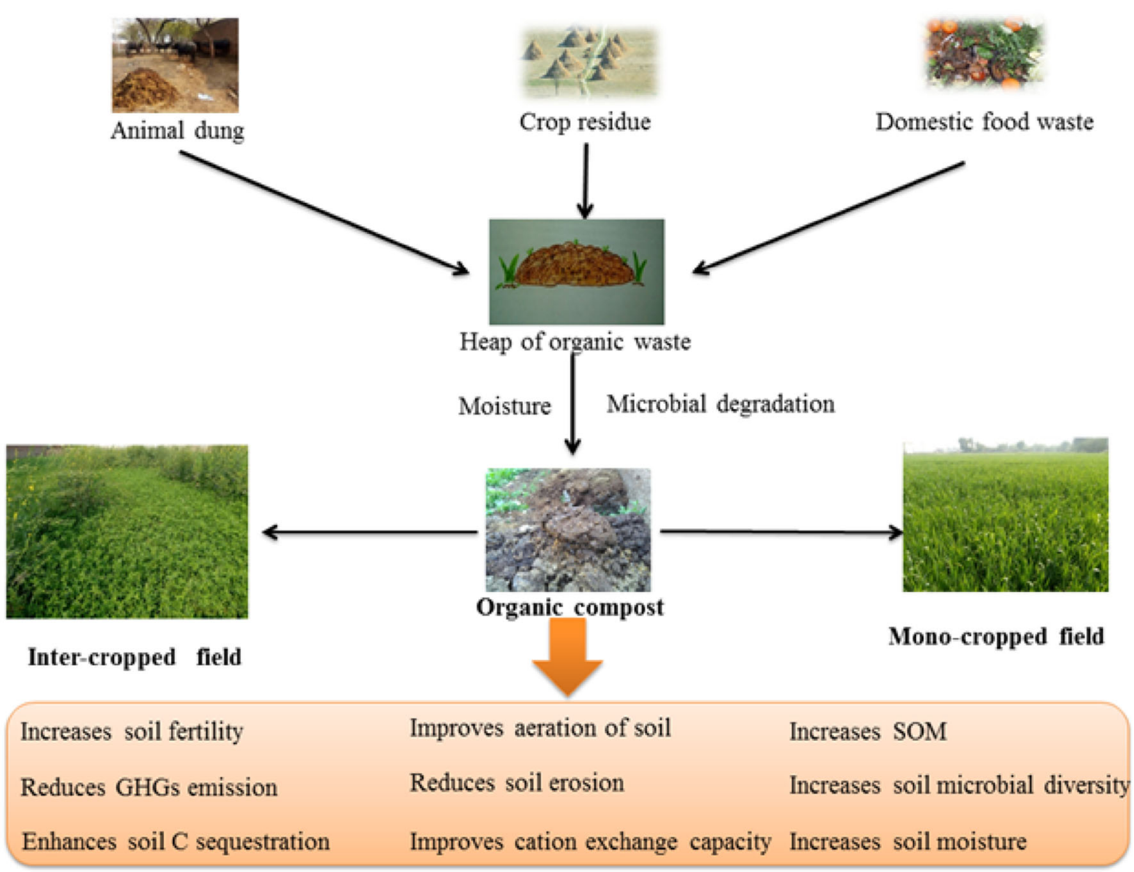

Fig. 3 A simplified model of traditional organic composting

(Jenkinson et al. 1994; Powlson 1994; Tilman 1998). Traditional thermophillic composting is a low-energy, cost-efficient and sustainable approach to address the issues of soil fertility, environmental pollution, waste management and reducing chemical fertiliser inputs (Ndegwa and Thompson 2001; Nasiru et al. 2013; Soobhany et al. 2017). Composting is an important tool to social, ecological and economic sustainability (Scarpato and Simeone 2013; Proietti et al. 2016).

Application of organic resources for soil fertility is a common practice among the smallholder farmers in the tropics due to their inability to purchase costly mineral fertilisers (Palm et al. 2001). Compost preparation is prominent in Asian countries (Yadav et al. 2017). India has a long history of using organic manure to enhance soil fertility (Manna et al. 2003). The use of composted FYM is a common practice in Indian Himalayan villages (Gopinath et al. 2008). Farmers in Jahrkhand state of India use compressed cakes of plant material and flowers to make organic manure. Plant species like madhu (*Madhuca indica*), neem (*Azadirachta indica*) and karanj (*Derris indica*) are used to make cake and then mixed with leaves, flowers and FYM (Dey and Sarkar 2011). The use of organic manure such as farmyard manure (FYM) has been a traditional practice in China (Shen et al. 1997; Yang et al. 2004). In China, organic manure has been used since Shang dynasty 3000 BC (Liu et al. 2013). The use of FYM is a traditional practice in Kilimanjaro region of the South Africa. People in Kilimanjaro make FYM by using materials like livestock wastes including chicken and goat waste and ashes. It is locally called as Samadi or Boru in Kilimanjaro. It increases the soil fertility and prevents crop from insects (Kangalawe et al. 2014).

5.6 Integrated crop-animal farming

Crop-animal integrated farming is a well-recognized practice of smallholder farmers in Asia (Devendra and Thomas 2002a). Although based on crop production, integrated crop-animal farming is a backbone of small-scale Asian agriculture (Devendra and Thomas 2002b). Integrating animal component to crop is supportive for agrobiodiversity, food diversity and land resource management that strengthens the resilience of agroecosystem in changing climate. Rice-fish culture is an important farming practice that increases diversification, intensification, productivity, profitability with sustainable food production (Ahmed et al. 2007; Nhan et al. 2007; Ahmed and Garnett 2011). Further, it increases soil fertility through improving availability of phosphorous and nitrogen and thus decreases external input of chemical fertilisers and consequently lowering the GHGs emission (Giap et al. 2005; Dugan et al. 2006; Ahmed and Garnett 2011). It is a sustainable practice not only for food production but also for climate change mitigation, natural resource management and biodiversity conservation (Frei and Becker 2005; Datta et al. 2009; Jian et al. 2011). Rice-fish culture system is a sustainable method for using land and water resources, generating employment, enhancing farmers' income, providing nutritional security and reducing the risks of rice crop damage by natural disasters (Mishra and Mohanty 2004). After flooding, oxygen is swiftly depleted in the rice fields and this reducing condition promotes the methanogenic process (Liesack et al. 2000; Krüger et al. 2001). Fishes raised in the paddy fields obstruct the methanogenic process during their search of feed and consequently mitigating CH_4 emission (Frei and Becker 2005).

The rice-fish co-culture system in Zhejiang Province, China is an age-old farming practice. It has been used by local farmers for more than 1200 years (Wang 1997; You 2006; Jian et al. 2011). This practice is recognized as the Globally Important Agricultural Heritage System (GIAHS) by the FAO, United Nations Development Programme (UNDP), and Global Environment Facility (GEF) (Jian et al. 2011). Integrated rice-fish cultivation is a traditional farming system in Bangladesh (Ahmed and Garnett 2011). It is based on sustainable utilization of various resources like water and land (Frei and Becker 2005). In India, rice-fish culture is an age-old practice that dates back to about 1500 years (Mohanty et al. 2004; Mishra and Mohanty 2004). Besides fish, duck raising in paddy fields is also a prominent practice. Duck-rice-fish culture is an indigenous farming system in China for sustainable utilization of land and water resources (Juanwen et al. 2012). In paddy fields, fishes are reared which eat plant hoppers and weeds while providing nutrient for rice. Fishes also soften the soil and transport oxygen in water by their movement in rice field. Besides fishes, each household also raises ducks in their paddy fields. Ducks eat insects in the paddy field thus ensuring good rice harvest. Conventional rice culture needs intensive application of chemical fertilisers for enhancing yields. It is widely recognized that fertiliser application is reduced through rice-duck cultivation (Long et al. 2013).

6 Traditional agriculture: a sustainable approach for climate change adaptation

Adaptation contributes a significant role in climate change vulnerability assessment and policy framework to check climate change impacts (Fankhauser 1996; Smith and Lenhart 1996; Smit et al. 1999). Climate change adaptation is an adjustment to reduce vulnerability or enhance resilience in response to observed or expected changes in climate and associated extreme weather events (IPCC 2007b). Climate change adaptation is the need of hour to ensure global food security and environmental quality (Connor and Mínguez 2012; Sayer and Cassman 2013). Farmers in different regions have different perceptions and adaptation strategies to adjust with change in climate. Farmers' perception to climate change play a great role not only to adaptation strategies but also in designing policy and integration of scientific and indigenous knowledge for climate change adaptation (Juana et al. 2013; Ayal and Filho 2017; Woods et al. 2017). In agriculture, climate change adaptation is as old as the agriculture itself. Since the beginning of agriculture, peasants have been continually adjusting their agriculture practices with change in climatic conditions. (Burger 2015). Indigenous farmers have a long history of climate change adaptation through making changes in agriculture practices. The Institute of Advanced Studies at the United Nations University recently identified more than 400 examples of indigenous peoples' contribution in climate change monitoring, adaptation and mitigation (McLean 2010).

Integrating traditional knowledge into climate change policies paves the way for cost-effective and sustainable adaptation coupled with mitigation strategies (Nyong et al. 2007). Without adaptation, climate change is generally challenging for agricultural production. But through adaptation methods, climate change impacts can be minimized (Nordhaus 1991; Easterling et al. 1993; Rosenzweig and Parry 1994; Fankhauser 1996; Smith 1996; Mendelsohn 1998; Wheaton and Maciver 1999). Environmental conditions, geographical location, socio-economic status, cultural differences and diverse knowledge systems influence perceptions of climate change and adaptation approaches (Saarinen 1976; Deressa et al. 2011; Wolf et al. 2013; Touch et al. 2016; Ayal and Filho 2017). Farmers with extensive knowledge about climate change and its impacts are better adjusted (Adger et al. 2003; Kemausuor et al. 2011; Akerlof et al. 2013; Tripathi and Singh 2013; Menapace et al. 2015; Tesfahunegn et al. 2016; Li et al. 2017). Shifting planting and harvesting dates, crop diversification, integrated crop-livestock farming, cropping drought-resistant varieties and high yielding water sensitive crops are some of the sustainable approaches to climate change adaptation (Bradshaw et al. 2004; Di Falco et al. 2011; Di Falco and Veronesi 2011; Moniruzzaman 2015). It has been observed that when compared to monoculture, polyculture systems exhibit a greater yield stability and less productivity decline during drought (Altieri and Nicholls 2008).

Indigenous knowledge should be used in climate change adaptation approaches and policies (Bernstein et al. 2008). Small farmers use several techniques to reduce climate-driven crop failure such as use of drought-tolerant local varieties, polyculture, agroforestry, water harvesting and conserving soil (Browder 1989; Altieri and Nicholls 2008; Chhetri et al. 2012). Indigenous peasnats use various natural indicators to forecast the weather patterns such as changes in the behaviour of local flora and fauna (Kalanda-Joshua et al. 2011; Nkomwa et al. 2014). Farmers in Chagaka Village, Chikhwawa, Southern Malawi use several indicators for climate and weather prediction. According to these farmers, occurrence of grasshoppers and a bird called Chinkhaka flying in household vicinity indicates the drought. Moreover, shedding of leaves by *Adonsonia digitata* (baobab/mlambe), *Cordyla africana* (mtondo) and *Faidherbia albida* (nsangu) indicates the onset of rainfall and well distributed rainfall season (Nkomwa et al. 2014). Farmers of Cameroon use the height of an ant nest in trees or colour of frog to forecast the onset and cessation of rainy season as well as the quantity of rain (Molua 2006; Tingem and Rivington 2009).

Traditional farming systems promote agroecosystem sustainability through conserving soil, harvesting water and cropping varieties of crop under the conditions of water stress, limited resources and low level of technology (Altieri and Toledo 2005). In Ethiopia and South Africa, farmers use several drought adaptation strategies such as changing planting dates, adopting new crop varieties and migrating seasonally (Deressa et al. 2009; Bryan et al. 2009; Lei et al. 2016). Sweet potato is a traditional drought-tolerant and potential food security crop in South Africa (Motsa et al. 2015). In Ethiopia, farmers harvest rainwater through traditional water harvesting pits locally known as zai pits (Chhetri et al. 2012). Farmers of Zimbabwe acclimatize in drought conditions through switching to more drought-tolerant crop varieties (Matarira et al. 1996; Chhetri et al. 2012). Besides their medicinal, commercial and cultural values, traditional vegetables are also important for sustainable food production, climate change adaptation and environmental sustainability with minimum external input. *Cucuminsmelo* var. *agrestis* (kachri) is a drought-tolerant traditional vegetable with short growth cycles and it can survive in harsh climatic conditions of Rajasthan, India (Maurya et al. 2007; De la Peña et al. 2011; Hughes and Ebert 2013; Ebert 2014). Farmers in North-West Cambodia cultivate cassava in their fields. Cassava is a drought-resistant crop that can be grown in different soils and requires less management and generates extra income (Touch et al. 2016).

Framers in Bangladesh make changes in the selection of rice varieties during high temperature conditions. They replace rainfed variety such as Aman rice crop by irrigation based Boro, Aus and other rice crops (Moniruzzaman 2015). Farmers in Sahel, Africa adapt to climate change through making alterations in animal husbandry. They domesticate sheep (Capra) and goat in place of cattle (Bos) as formers have comparatively less feed requirements (Oba 1997). They also include diversity of herds in their husbandry practices to survive under extreme climate (Nyong et al. 2007). Bangladesh is one of the highly vulnerable countries to climate change impacts particularly floods and waterlogging (IPCC 2012). Floating agriculture is an indigenous method of farming in the Southern floodplains of Bangladesh. It is highly self innovated farming technique in which crops and vegetables are grown on floating platforms (beds). These floating beds are built through utilizing locally available materials such as water hyacinth and other aquatic weeds (Chowdhury and Moore 2017).

7 Conclusion and recommendations

Agriculture is one of the leading sectors that contribute to global GHG emission. Utilization of traditional agriculture knowledge for food production is an age-old practice. Traditional agriculture is still a growing concern for widespread use and inclusion in policy framework. This review article advocates traditional agriculture as a climate-smart agriculture approach to sustainable food production. Traditional agricultural practices have potentials to adapt and mitigate climate change through their agroecological features. They increase agrobiodiversity and resilience of agroecosystems. Moreover, they are low-cost, energy-efficient and based on locally available resources. Indigenous people are custodians of traditional agriculture knowledge. Traditional agriculture can be adopted as an alternative method for sustainable food production in changing climate. Besides mitigating climate change, traditional agriculture is also helpful for human health safety, natural resource management, energy conservation and socio-ecological integrity. Agroforestry, intercropping, crop rotation, cover cropping, traditional organic composting and integrated crop-animal farming can be adopted as the model practices for climate-smart approach in agriculture. These practices not only mitigate climate change but also enhance agricultural sustainability.

The necessity for enhancing food production in climate change scenario has been much debated. Traditional practices coupled with modern sustainable farming practices would be a noble choice for climate change mitigation and adaptation. The following recommendations are suggested for the sustainability of food production while addressing climate change issues.

1. Increasing food productivity while addressing climate change impacts needs the integration of traditional and modern agricultural practices. Climate-smart agriculture practices both modern as well as traditional should be encouraged and used widely.
2. Adoption of sustainable practices for socio-economic development would be a better decision to make a balance between environment, society and economy.
3. Indigenous cultures, their languages, rituals, traditions and practices should be respected and campaigned positively for their preservation.
4. Farmers should be given sufficient crop insurance during climate-driven crop failure or during crop damage by natural disasters such as flood and fire.
5. More inclusive research focused on the identification and exploration of traditional agriculture knowledge at larger scale is the need of hour.
6. There is an urgent need to develop a concrete policy framework to protect and utilize traditional agricultural practices.
7. The use of inorganic fertilisers should be minimized and substituted by organic compost to reduce the GHGs emission.
8. Fossils fuels utilization should be reduced and use of biofuels should be encouraged for climate change mitigation.
9. There is a pressing need to enhance the agrobiodiversity for making agroecosystem more resilient to climate change.
10. Cooperation and coordination between various stakeholders such as local people, policy makers and researchers is urgently required to form effective strategies for climate change mitigation and adaptation.

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