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REVIEW ARTICLE

Climate change and agriculture – An appraisal

B. M. CHITTAPUR, DODDABASAVA AND M. P. POTDAR

Agricultural Extension Education Centre, Koppal
University of Agricultural Sciences, Raichur - 584 101, Karnataka, India
E-mail: basavarajc7@gmail.com

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Abstract: Climate change due to global warming is the phenomenon affecting the survival and composition of biosphere globally which needs to be understood for its impact on agriculture by all particularly those engaged in agriculture to develop strategies for mitigation and adaptation, transfer them to fields/growers or policy makers for sustainability of agriculture and food security of the country which due to its subtropical placement is more prone to vagaries of climate change. The melting Himalayan glaciers, vagaries of monsoon, dependencce of agriculture on monsoon and ever increasing demographic pressures make the issue more important to be assessed and addressed on war footing, and, therefore, the review covering the enigma of climate change, global carbon cycle and role of agriculture, impact on water availability and crop performance, measures for climate proofing is presented in the article with special reference to Indian conditions.

Key words: Climate change, Global carbon cycle, Green house gas, Water availability

Today, the world (the biosphere) in general and agriculture *vis-a-vis* food security in particular is threatened seriously due to global warming and climate change (CC). Food security is defined by the Food and Agriculture Organization (Anon., 2002a) as a 'situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life'. CC in addition to production likely to affect nutritional value of crops. Seventy six percent of the populace receiving most of their daily protein intake from plants may experience protein deficiency due to decrease in crop protein content predicted with elevated CO_2. CC change is defined as any change over the time, whether due to natural variability or from human activity. CC alters the composition of global atmosphere and causes natural climatic variability. Climatic parameters such as atmospheric CO_2 content, temperature, precipitation (rainfall), humidity, light intensity and duration alongwith water and nutrient status of the soil are important to determine the plant growth and agricultural production. Deviation of any of these parameters from their optimum range limits the plant growth and ultimately affects crop yield. Ironically, the climate is changing at much faster than natural rate as a result of dumping more and more green house gases (GHGs) in to the atmosphere by various countries and thereby threatening the global food security for the increasing population (Lal, 2005). CC has already caused significant impacts on water resources, food security, hydropower, human health *etc.*

In the present scenario of changing climate, atmospheric CO_2 concentration is increasing. From pre-industrialization period, CO_2 concentration in the atmosphere of about 280ppm started increasing and reached a level of 315 ppm in 1967, 356 ppm by 1993 (Schimel *et al.*, 1995), and 385 ppm during 2008 which is about 38% higher than the pre-industrial levels (Anon., 2008). It is expected to reach 450-550 ppm in 2050 and 700ppm by the end of the 21st century. India having a total geographical area of 329 mha produces 4.6% of global CO_2 emissions and this figure is likely to grow in future. According to the projection given by World Energy Outlook, CO_2 emissions in India would increase @ 4.3% per year and almost will be tripled between 2005 and 2030 mainly due to energy consumption. Higher concentration of CO_2 alongwith other GHGs like CH_4, N_2O, O_3 and chlorofluorocarbons causing greenhouse effect and have resulted in rise of temperature by $0.74^0C \pm 0.18^0C$ over the past 100 years (Trenberth and Jones, 2007). According to IPCC 4th assessment report (Meehl and Stocker, 2007), average global air warming of 1.8^0C can occur in B1 scenario and 4^0C under A1F1 scenario by the end of 21st century. For Indian region under south Asia, the IPCC has projected 0.5-1.2^{0}C rise in temperature by 2020, 0.88-3.16^{0}C by 2050 and 1.56-4.44^{0}C by 2080 depending on the pace in future development scenario.

India's mean surface air temperature has increased significantly by about 0.4°C over the past century. According to recent climate model projections, India may experience a further rise in temperature of 1°C by the year 2050, about four times the rate of warming experienced over the past 100 years (Rae *et al.*, 1996). Climate variability is one of the most significant factors influencing year to year crop production, even in high yield and high technology agricultural areas. Studies, therefore, on climate impacts and adaptation strategies are increasingly becoming major areas of scientific concern. The expected rise in temperature in higher latitudes will be much more than at equatorial regions and mean annual precipitation will increase in the tropical regions and at high northern latitudes, and decrease in the sub tropics. Amongst the seasons, the temperature increases are likely to be much higher in winter (*rabi*) season than in rainy (*kharif*) season (Anon., 2007).

Global carbon cycle and carbon pool

Global carbon cycle is a budgetary statement of different components including pools and fluxes which play a significant role in identifying sources and sinks of C. In our planet, C is stored in the following major pools, *viz.*, oceanic pool (38000Pg), geologic pool (5000Pg), pedologic pool/soil C pool (2500Pg), atmospheric pool (760Pg) and biotic pool (560Pg) (Lal, 2011). C is stored in ocean in the form of $Ca(HCO_3)_2$ of dissolved C such as $CaCO_3$ and shells in marine organisms. Geologic pools stores the C in the lithosphere as fossil fuels and rock deposits such as limestone, dolomite, and chalk etc. Oceanic pool is the largest C pool followed by geologic, pedologic, atmospheric and biotic global C pools. Although ocean stores most of the earth's C, soil contains approximately 75 per cent of the C pool on land, which is three times more than amount stored in living plants and animals.

Soil plays a major role in maintaining balance between global carbon cycle through sequestration of atmospheric carbon as soil organic carbon. Soil C pool comprises soil organic carbon (SOC) and soil inorganic carbon (SIC) pool. The primary way by which C is stored in the soil is as SOM. SOM is a complex mixture of C compounds, consisting of decomposing plant and animal tissue, various microbes and carbon associated with soil minerals. C can remain stored in soils for millennia, or be quickly released back into the atmosphere. Climatic conditions, natural vegetation, soil texture, and drainage, all affect the amount and length of time C stored. Measured rates of soil C sequestration through adoption of recommended management practices (RMPs) range from 50-1000 kg/ha/year. Estimated global potential of SOC sequestration through RMPs range from 0.9 ± 0.3 Pg C/year which is 1/4th -1/3rd of annual increase in atmospheric CO_2 rate (3.3 Pg C/year). Cumulative C sequestration potential is 30-60 Pg over 25-50 year. SOC concentration is low in the soils of arid region and high in the soils of temperate region and is much more in the organic or peat soil. SOC is more in cool and moist than warm and dry regions (Lal 2004c).

GHGs emission from agriculture

Agriculture is contributing to about 28% of greenhouse gas emissions, primarily due to methane emission, especially in rice cultivation, enteric fermentation in ruminant animals and nitrous oxides from application of manures and fertilizers to the soils. Methane emissions from rice and livestock are estimated at 17.4 and 12.8 Tg/year, respectively (Rae *et al.*, 1996). Different field practices, farm operations and agricultural input used in the process of crop production emit significant amount of CO_2 to the atmosphere (Lal, 2004b). Gifford (1984) classified agricultural practices into primary, secondary and tertiary sources with reference to their C emission capacity. Primary sources of C emissions are either due to mobile operations (eg. tillage, sowing, intercultural, harvesting and transport) or stationary operations (e g pumping water, grain drying and milling). Secondary sources of C emission comprise manufacturing, packaging and storing fertilizers and pesticides. Tertiary sources of C emission include acquisition of raw materials and fabrication of equipment and farm buildings, etc. Therefore, reducing emissions implies enhancing use efficiency of all these inputs by decreasing losses, and using other C-efficient alternatives (Lal 2004b, West and Marland 2002).

Direct and indirect emission of CO_2 takes place during the tillage operations in terms of fossil fuel consumption and due to soil disturbance. Consumption of fuel is the major source of CO_2 emission during seed bed preparation and sowing of the seeds. Many studies carried all over the world reveal that the fuel requirement varies with the depth of ploughing, soil types, nature of operation, type of implement used, horse power requirement and speed of tractor (Schrock *et al.*, 1985, Bowers 1989, Rautray 2003, Lal 2004b). Koller (1996) reported that the diesel fuel consumption was 49.4 l/ ha for moldboard plow, 31.3 l/ha for chisel plow, 28.4 l/ha for disk plow, 25.2 l/ha for ridge plant and 13.4 l/ha for no-till system of seedbed preparation. The average C emission is 15.2 kg CE/ha for moldboard plowing, 11.3 kg CE/ha for sub-soiling, 8.3 kg CE/ha for heavy tandem disking, 7.9 kg CE/ha for chiseling, 5.8 kg CE/ha for standard disking, 4.0 kg CE/ha for cultivation and 2.0 kg CE/ha for rotary hoeing. Each liter of diesel produces 2.698 kg CO_2emission during its combustion and thus the total GHG emissions during the production and combustion of one liter of diesel is 3.15 kg CO_2e. Lal (2004b) reported that C emissions 2-20 kg CE/ha for different tillage operations, 1-1.4 kg CE/ha for spraying chemicals, 2-4 kg CE/ha for seeding and 6-12 kg CE/ha for combine harvesting. Similarly, estimates of C emissions in kg CE/kg for different fertilizer nutrients are 0.9-1.8 for N, 0.1-0.3 for P_2O_5, 0.1-0.2 for K_2O. Thus, intensive land use requires significant energy resources leading to an increase in GHG emissions (Vlek *et al.*, 2003, Chauhan *et al.*, 2006, Maraseni *et al.*, 2010a,b, Maraseni and Cockfield, 2011).

Pumping of water from aquifers requires lot of energy for lifting the water. Emission of CO_2 is mainly through consumption of diesel/petrol. The energy required to pump water depends on numerous factors including total dynamic head (based on water lift, pipe friction, and system pressure), the water flow rate and the pumping system efficiency (Whiffen 1991, Franzluebbers and Francis 1995). The energy use depends on the water table depth or the lift height. The supplemental irrigation used for crop production ranges from 250 to 500 mm per season (Franzluebbers and Francis 1995). The C emission ranged from 7.2 to 425.1 kg CE/ha for 25 cm of irrigation and from 53.0 to 850.2 kg CE/ha for 50 cm of irrigation. Schlesinger (1999) estimated C emission from irrigation at 220-830 kg CE/ha/year. Follett (2001) estimated C emission by pump irrigation at 150–200 kg CE/ha/year depending on the source of energy. Tube wells are commonly used for irrigation in Punjab, India. In comparison, irrigation of winter wheat in Punjab by tube well was estimated to emit 3–25 kg CE/ha (Singh *et al.*, 1999).

Further, the production, packaging, storage and transportation of agrochemicals require energy and thus they contribute to GHG emissions (Bhat *et al.*, 1994). West and Marland (2002) estimated 4.4, 4.6 and 4.8 kg CE/kg a.i. for production, packaging and transport of herbicides, insecticides and fungicides. Lal (2004b) reported C emission in relation to production, packaging, storage and distribution of fertilizers as 0.9-1.8 kg CE/kg N, 0.1-0.3 kg CE/kg P_2O_5, 0.1-0.2 kg CE/kg K_2O and 0.03-0.23 kg CE/ kg of $CaCO_3$. Helsel (1992) reported that out of the total energy used in agriculture globally, 51% is expended in farm machinery manufacturing and 45% in the production of chemical fertilizer. Verge *et al.* (2007) reported that more than 50% of the applied N is either lost through leaching into the soil or released into the atmosphere as nitrous oxide (N_2O) which has 298 times more global warming potential than CO_2 (Anon., 2007).

N_2O is responsible for 6% of observed global warming (Dalal *et al.*, 2003). Most of the N_2O emissions come from N fertilizer usage and soil disturbances. Lack of oxygen or limited oxygen supply in the soil or high oxygen demand due to more carbon food in the soil causes micro-organisms to utilize nitrate (NO_3) and nitrite (NO_2) instead of oxygen. As a result of this de-nitrification process, the applied N-fertilizer is released as N_2O into the atmosphere (Dalal *et al.*, 2003). The IPCC set a default emission factor of 1.25% N_2O–N emissions/kg of applied N. The level of emissions is directly related to N-fertilizer amounts; the higher the N fertilizer use, the greater the emissions of N_2O and thus the higher the CO_2e feed back to the atmosphere.

Climate change impacts on water availability

Water resources play a vital role in human prosperity and crop productivity. Water resources are greatly influenced by warming of climate. In recent decades the rise in global and ocean temperatures is causing widespread melting of snow and ice consequently increasing global sea level. The hydrological cycle is intimately linked with changes in atmospheric temperature and radiation balance. A warmer climate may lead to intensification of the hydrological cycle, resulting in higher rates of evaporation and increase of liquid precipitation. This process in association with shifting pattern may increase frequency of droughts and floods. Agricultural demand particularly for irrigation water is considered more sensitive to CC. A change in field level climate may alter the need and timing of irrigation. De Silva *et al*. (2007) opined that paddy irrigation requirements will increase by 13 to 23%. Inter annual climatic variability will have greater effects on future cropping conditions (Thomas, 2008). It is projected that most irrigated areas in India would require more water and global net irrigation requirements would increase relative to the situation without climate change by 3.5-5% by 2025, and 6-8% by 2075 (Pathak *et al.*, 2014).

Climate impacts on water resources are varied in different river basins in India (Table 1). Due to change in weather pattern there will be acute shortage of drinking water in some parts of the country especially in north and north-west parts of India (Pathak *et al., 2*014). There has been a noticeable increase in snow and ice melting in the Himalayan range, the third largest in the world, and if this continues, it will affect the water supply of much of Asia. Singh and Bengtsson (2004) and Singh *et al.* (2006) indicated that runoff in the glacierized Himalayan region increased linearly with increase in temperature and rainfall. For a temperature rise of 2^0C, the increase in summer stream flow is expected to be about 28%. Changes in rainfall by ± 10% resulted in corresponding changes in stream flow by 3.5%. The changes in runoff are more sensitive to changes in temperature, compared with rainfall, which is likely due to the major contribution of melt water in runoff.

River basins of Sabaramati and Luni, which occupy about one quarter of the area of Gujarat and 60% of the area of Rajasthan, are likely to experience acute water scarce condition. River basins of Mahi, Pennar, Sabarmati and Tapi are likely to experience constant water scarcity and water shortage. Variation in climate, land use, urbanization and water consumption also have profound effects on river runoff. The effect of climate variability on Krishna river runoff was not as profound as compared to water consumption (Bouwer *et al.,* 2006) while,

Table 1. Impact of climate change on water resources during the next century over India

Region/location	Impact
Indian subcontinent	Increase in monsoonal and annual run-off in the central plains. No substantial change in winter run-off. Increase in evaporation and soil wetness during monsoon and on annual basis
Orissa and West Bengal	One metre sea-level rise would inundate 1700 km^2 of prime agricultural land
Indian coastline	One metre sea-level rise on the Indian coastline is likely to affect a total area of 5763 km^2 and put 2.7 million at risk
All India	Increase in potential evaporation across India
Central India	Basin located in a comparatively drier region is more sensitive to climate changes
Kosi Basin	Decrease in discharge on the Kosi river and decrease in run-off by 2-8%
Southern and Central India	Soil moisture increases by 15-20% during monsoon months
Chenab river	Increase in discharge in the Chenab river
River basins of India	General reduction in the quantity of the available run-off, increase in Mahanadi and Brahmini basins
Mahanadi river basin	Increasing intensities of flood
Damodar basin	Decreased river flow
Rajasthan	Increase in evapo-transpiration
Kansabati river basin lateral reach	Increase in transmission losses, soil water content, potential evapo-transpiration, evapo-transpiration and
Lower Brahmaputra	Low flows less frequent and increased peak flows
Sutluj Basin	Little change in total stream flow but substantial change in the distribution of stream flow
Damodar and Rupanarayan river	West Bengal would have more virtual water than Jharkhand

Source: Mall *et al.* (2006)

water availability in Ganga basin is much affected by urbanization (Mishra, 2011). The future trends of lower Brahmaputra indicate low and high flow conditions are likely to occur while very strong increase in peak flows is expected which may, in combination with projected sea level change, could have devastating effects for Bangladesh (Gain *et al.,* 2011). Ashokan and Datta (2008) revealed that the highest increase in the peak runoff (38%) in the Mahanadi river outlet will occur during September, for the period 2075-2100 and the maximum decrease in average run off (32.5%) will be in April, for the period 2050-2076, and thus the river basin is expected to experience progressively increasing intensities of flood in September and drought in April.

Climate change impacts on crop

CC impacts on crop yield are different in various areas, in some regions it will increase, in others it will decrease which is concerned with the latitude of the area and irrigation application (Table 2). Yield is more sensitive to precipitation than temperature. In the event of decreased precipitation, water retentive soils would be better to reduce the impact of drought (Popova and Kercheva, 2005). The positive effects of CC on agriculture are concerned with the CO_2 concentration augment, crop growth period increased in higher altitudes and montane ecosystems; the negative effects include the increasing incidence of pests and diseases, and soil degradation owing to temperature change (Lal, 2005). With CC the growing period will reduce so also crop rotation period in many instances.

Rising atmospheric CO_2 and temperature levels will affect yields, water and nitrogen requirements of the crops in a given region and these changes will possibly have influences on regional as well a global food production. The likely impacts of CC on crop yield can be determined either by experimental data or by crop growth simulation models (Table 2). Oritz *et al.* (2008) suggested that global warming is beneficial for wheat crop production in some regions, but may reduce productivity in critical temperature areas. Averaged over 30 years simulations (CropSyst model), increasing CO_2 concentration from 350 to 700 ppm in maize and wheat, yields were increased by 17 and 57 %, ET decreased by 14 and 3 mm and nitrogen uptake by 12 and 44 kg ha^{-1}, respectively with increased impact in wheat (C_3 plant) than that in maize (C_4) (Kaur *et al.*, 2012). At 350ppm CO_2 with temperature $3^{O}C$ higher than the existing in maize and wheat crops, crop duration of maize and wheat were shortened by 12 and 23 days, ET decreased by 30 and 50 mm, nitrogen uptake decreased by 31 and 27 kg ha^{-1} and subsequently yields were reduced by 37 and 15 %, respectively. The interaction of CO_2 and temperature indicated that even 700 ppm level of CO_2 was unable to maintain the existing maize yield beyond one degree increase in temperature. In case of wheat, yield levels were well maintained at 700ppm level of CO_2 even at higher level of temperature (3°C). Increased levels of irrigation (IW/Pan E ratio of 1.25) and nitrogen (150 and 180 kg ha^{-1}) were not able to outweigh the negative effect due to increased temperature than the existing in these cropping systems.

Response to increased temperature may differ from those of CO_2 levels in some crops. For instance, Shankarayanan *et al.* (2010) reported that at high temperature cotton plants lose their reproductive capacity to a greater extent than their ability to produce biomass and face problems and boll retention. Further, Buttar *et al.* (2012) through simulation studies revealed that with increase in temperature, duration of different stages are shortened. The shortening of duration from sowing to vegetative phase, flowering to boll formation and from boll formation to maturity was 3.2, 3.0 and 2.9 days °C^{-1}, respectively. Reddy *et al.* (1999) also reported decrease in maturation period of bolls and their size with increase in temperature. With increase in temperature from 28 to 32C the total crop duration was reduced by 10.7 days °C^{-1}. With shortening of duration of sowing to flowering by 14 days, flowering to boll formation by nine days, boll formation to maturity by 21 days and sowing to maturity by 45 days the cotton yield was reduced by 236, 140,116 and 75 kg $ha^{-1}day^{-1}$, respectively.

In India, studies under National Project on Climate Change (NPCC) revealed that although additional CO_2 can benefit crops, this effect was nullified by an increase of temperature (Rao *et al.,* 2016). The yield levels of some of the major crops like pigeonpea in kharif and chickpea and sorghum during rabi will be decreased. The reduction in yield of rice, mustard and chickpea at 3-5% per °C increase compared to 5-8% reduction in yield of wheat, groundnut, green gram, soybean and potato when temperatures were raised gradually (1 to 3°C). Among the crops, wheat exhibited highest degree of thermal sensitivity (Rao *et al.*, 2016). The grain yield and biomass of wheat were reduced @ 10-12 and 8-10% per ^{0}C increases in atmospheric temperature. Gradual rise in atmospheric temperature caused gradual depletion in pollen germination of different rice cultivars, while lower temperature caused remarkable reduction in pollen germination of wheat cultivars. Wheat and rice revealed greater thermal sensitivity during reproductive and vegetative growth phases while mustard and greengram registered greater thermal sensitivity during seed filling period.

Increases in temperature (by about 2°C) reduced potential grain yields in most places. For instance increase in temperature by 2°C could reduce pigeonpea yield by about 16% in Kalburagi, Karnataka, India. Regions with higher potential productivity (such as northern India) were relatively less impacted with CC than areas with lower potential productivity (Rao *et al.*, 2016). CC is also predicted to lead boundary changes in areas suitable for growing certain crops. Reductions in yields are predicted to be more pronounced for rainfed crops due to changes in rainfall pattern during monsoon season and increased water demands of crops and under limited water supply situations because there is no coping mechanism for rainfall variability. Eastern regions are predicted to be most impacted by increased temperatures and decreased radiation, resulting in relatively fewer grains and shorter grain filling duration. By contrast, potential reductions in yields due to increased temperatures in northern India are predicted to be off sett by higher radiation, lessening the impacts of CC.

Table 2. Impact on climate change on crop performance

Crop	Model used		Impact	Reference
Wheat	CropSyst-4	South Australia	Elevated CO_2 can reduce the median wheat yield by 25%	Anwar *et al.* (2007)
	CERES-wheat		Increased wheat yield	Eitzinger *et al.*(2003)
	DSSAT 3.5/ CERES-wheat	Southern Australia	Elevated CO_2 increases wheat yields in drier sites but likely to have lower quality	Luo *et al.* (2003)
Maize	CERES maize/ GCCM & GISS climate models		Dry matter can increase by 1.4 – 2.1 t ha^{-1} with GCCM model and 3.5 – 5.6 with GISS model	Cuculeanu *et al*. (2002)
	CERES maize	Brazil	Later planting date will decrease 55% on average yield under rainfed conditions and 21% under irrigated conditions and an accurate forecast can be provided almost 45d earlier than the harvest date	Tojo Soler *et al.* (2007)
	CERES maize	Sofia, Bulgaria	Average productivity will be lower by 60% under drier condition than those of sufficient moisture	Popova Kercheva (2005)
		Limpop Basin, South Africa	Increased temperature and rainfall have positive effect, rainfall is more important than temperature	Akpalu *et al.* (2008)
Rice	RWAP & HadCM3	Volta Basin	Rice yields are expected t o increase by around 45 and 35 % for A2 and B2 scenarios	Droogers *et al.* (2004)
	InFoCrop	Eastern India	Increased CO_2 increase rice yield while higher temperature would cause higher spikelet sterility. Hence selection of cultivar and sowing time are important	Krishnan *et al.* (2007)
	CERES rice	China	Rice yield increase with increased CO_2	Yao *et al.* (2007)
Peanut	GLAM		Yield rise by 19 – 30%	Challinor and Wheeler (2008)
Soybean	IBSNAT-ICASA		Increase yields at high and mid-latitudes and decrease at lower latitudes	Parry *et al.* (1999)
	GLYCIM	Mississippi Delta	Validated model for crop yields due to precipitation, temperature and CO_2	Reddy & Pachepsky (2000)
	PRECIS & GLAM	India	Extreme temperature has a negative impact on crop yield even when irrigation water is available	Challinor *et al*. (2007)
Cotton	CropSyst	India	Decrease in maturation period of bolls and their size with increase in temperature.	Reddy *et al.* (1999)
			High emperature cotton plants lose their reproductive capacity to a greater extent than their ability to produce biomass and face problems of boll retention.	Shankarayanan *et al*. (2010)
			With increase in temperature duration different stages are shortened.	Buttar *et al*. (2012)

Climate proofing

One of the major challenges of 21st century is lowering the atmospheric concentration of GHGs at a certain acceptable levels to mitigate the impact of CC on agriculture and alike sectors due to global warming (Verge *et al.*, 2007, Goyal 2004). Mitigation and adaptation are the prominent strategies to respond climatic aberration. Hulme (2002) defined mitigation as actions taken to prevent, reduce or slow CC, through slowing or stopping the build-up of greenhouse gases in the atmosphere. Adaptation can be defined as adjustments in ecological, social or economic systems in response to actual or expected stimuli and their effects or impacts. This term refers to changes in processes, practices and structures to moderate potential damages or to benefit from opportunities associated with CC (Anon., 2001). Mitigation attempts to cease CC by reducing the GHGs emissions and by improving sink opportunities, adaptation seeks to abstain the adverse impacts through a wide-range of system-specific actions (Fussel and Klein 2002). A superior solution can be sought with the right mix of farm enterprises, diversification in terms of crops and cultivars, livelihood options and, appropriate policy interventions. Scrupulous scientific solutions would impart resilience. Resilience is defined as the propensity of a system to retain its organizational structure and productivity following a perturbation (Holling 1973). Farmers need to consider crop varieties, sowing dates, crop densities and fertilization levels when planting crops (Cuculeanu *et al.*, 2002).

i. Crop production: Emphasis needs to be on cultivation of climate smart crops and practices. Among staples, setaria can produce grains even at 42^0C and hence more resilient and so are other small millets/minor oil seeds (safflower, castor etc.). Breeding heat and drought resistant cultivars, identifying and developing chemicals and practices that impart resilience go a long way towards building food security. Studies under CISSA, CIMMYT India, identified heat stress resistant cultivars of maize for cultivation in north Karnataka where summer temperature often exceed 40^0C (Kuchnur, 2017). The FAO (Anon., 2002b) mentioned that biotechnology can be an approach to improve food security and reduce the environmental pressure. Meanwhile modified crop varieties, resisting drought, waterlogging, salinity and extreme climate, can expand the crop planting area such as in the degraded soils, consequently could increase food availability in the future. With CC the growing period will reduce, and the planting date also needs to be changed for higher production. Therefore, the most cost effective strategy to save field crops from frost/drought is the choice of the optimum dates for crop plantings. As the crop enters flowering stage, their tolerance to climatic extremes is drastically reduced. If the sowing dates are adjusted in such a way that these stages do not coincide during the period of extremities the damaging action can be minimized (Rao *et al.*, 2016). Seed hardening, resorting to transplanting (pigeonpea, cotton) wherever possible, use unconventional/alternate crops (Late *kharif /rabi* pigeonpea), alternate methods of cultivation like aerobic rice (Nagaraju, 2017), direct seeded rice (DSR- Mahender Kumar and Ravindra Babu, 2016), adoption of potential and high water productive cropping system, crop diversification and crop intensification are other options (Chittapur, 2016).

Increase water availability by reducing the wastage of water, increasing water harvesting capacity of the system and increase recharge. Creation of micro-storage facilities in watersheds would not only provide supplemental irrigation but also recharge ground water aquifers. Lining of water conveyance systems in selected reaches where large seepages leading to waterlogging would be occurring is necessary. Holden and Brereton (2006) reported that though higher levels of irrigation can help obtain higher yields, however, farmers need to prevent higher irrigation led high runoff for some of the heavier soil as happening in irrigation commands. In irrigation commands, crop localization pattern and warabandi (on-off system) need be strictly adhered to. Honnali and Chittapur (2014) identified alternate and remunerative crops to paddy in the UKP irrigation command of Karnataka, India. Practices of effluents after properly treating and poor quality water have also been developed for conjunctive use (Vishwanath, 2016; Chittapur and Umesh, 2018; Bhaskar *et al.,* 2018). Such practices would help the use of scarce water more efficiently.

In Tunga Bhadra Project irrigation command conjunctive use of poor quality water revealed that use of saline water up to 4 dS/m in direct mode had no adverse effect on cotton yield. Use of saline water (4-6 dS/m) during canal lean period and then switching over to good quality water wherever available conclusively established that early establishment (June) with available saline water (with 4 irrigations) and later switching over to canal (August) is a best practice (22.1q/ha kapas) compared to a crop receiving good water but sown during August (12.6 q/ha) (Vishwanath, 2016). The salt balance remained favourable and did not cause any concern. Further, measures to enhance water use efficiency need to put in to place. Proper farm leveling could improve water application efficiency by over 20%. Laser leveling may be employed on large scale to level the irrigation layout to improve the water use. AWD (alternate wetting and drying) irrigation technique can increase water productivity in China (Li and Barker, 2004), India (Mahender Kumar and Ravindra Babu, 2016) and many south-east Asian nations (Desai *et al.*, 2018). Drill sown rice which can save up to 30% irrigation water over traditional transplanted puddle rice is gaining popularity (Mahender Kumar and Ravindra Babu, 2016). Aerobic rice cultivation has been demonstrated on large area in Karnataka (Nagaraju, 2017). Farmers are also showing more interest extending SRI (System of Rice Intensification) technology in crops like sugarcane and finger millet in Karnataka, India (Chittapur and Umesh, 2018). Already, work is in progress to standardize micro-irrigation in paddy at many locations (Jagadish, 2017).

ii. Carbon sequestration: Kyoto Protocol affirms that part of the CO_2 emissions from fossil fuel use and from other sources, can be offset by removal of CO_2 from atmosphere via a net increase in the C stocks of the biosphere (West and Marland 2002, Tandon 2008). Sequestering atmospheric C in agricultural soils is one such option (Lal 1999, Lal 2008). C sequestration may be defined as the long-term storage of C in oceans, soils, vegetation and geologic formations. Through the process of photosynthesis, plants assimilate C and return some of it to the atmosphere through respiration. The C that remains as plant tissue is then consumed by animals or added to the soil as litter when plants die and decompose. About 3/4th of the earth's terrestrial C is present in the top one meter of soil. Well managed soils have potential to sequester more C. Some estimates show that 15% of the fossil fuel emissions of CO_2 could be offset by soil C sequestration alone. Lal (2008) reported that soil and crop management now and in the future would play a significant role for sustainable agriculture development. Reduced tillage, crop rotation and agroforestry are potential C sequestering practices.

Tillage generally disrupts aggregation and exposes particulate organic matters (POM) which decompose quickly by microbial action. Reduced C sequestration in chisel till compared to no tillage (NT) is due to differences in aggregates and aggregate associated C. Study revealed that concentration of fine iPOM (intra aggregate POM) was less in chisel till (CT) compared to NT macro aggregates. On a whole soil basis, fine iPOM C was 51% less in CT than NT and accounted for 21% total C difference between NT and CT. The concentration of free light fraction (LF) was not affected by tillage but was on average 45% less in CT than native vegetation (Six *et al.*, 1999). Worldwide studies have suggested significant reduction in GHGs emissions through transforming conventional agriculture to conservation agriculture and use of recommended management practices in agriculture (Lal, 1999, 2008a).

Conservation agriculture plays a vital role in sequestering C in soil-plant system through change in management practices, use of improved cropping systems, less disturbance of soil and hence less disruption of C rich soil aggregates and retention of crop residues in soil (Lal and Stewart 2010, Wang *et al.*, 2010, Honnali, 2017). Conservation tillage alongwith efficient management of irrigation, fertilizer and pesticides may increase SOC by increasing yield and subsequent organic matter (Lal 1999, 2004a, Honnali, 2017). In India, zero-till drills, strip till drills, roto till drills are used for direct drilling of wheat after paddy. In no-till plots, fuel consumption was found to be 11.30 l/ha as compared to 34.62 l/ha by conventional method resulting in fuel saving of 24 l/ha. There was 67 % saving in fuel due to no-tillage as compared to conventional method. Besides, conservation agriculture, based on the use of crop residue mulch and no till farming can sequester more SOC through conserving water, reducing soil erosion, improving soil structure, enhancing SOC concentration, and reducing the rate of enrichment of atmospheric CO_2 (Lal 2004a). Vanden Bygaart *et al.* (2003) found that reduced tillage increases the amount of C sequestered by an average of 320-150 kg C/ha in western Canada and that the removal of fallow enhanced soil carbon storage by 150-60 kg C/ha.

Doraiswami *et al.* (2007) reported that rate of soil erosion was highest with conventional tillage and it reduced with adoption of ridge tillage and consequently ridge tillage increased SOC at the end of 25th year. West and Marland (2002) reported that C emission from conventional tillage (CT), reduced tillage (RT) and no tillage (NT) were respectively 72.02, 45.27, 23.26 kg C/ha in case of corn cultivation and 67.45, 40.70, 23.26 kg C/ha for soybean cultivation based on annual fossil fuel consumption and CO_2 emission from agricultural machinery. Thus there was 67.70% and 65.41% reduction in CO_2 emission as compared to conventional tillage for corn and soybean cultivation respectively. Mosier *et al.* (2006) reported that based on soil C sequestration, only NT soils were net sinks for global warming potential (GWP) and economic viability and environmental conservation can be achieved by minimizing tillage and utilizing appropriate levels of fertilizer.

West and Marland (2002) estimated the average net C flux for U.S. at +168 kg C/ha/year due to CT practices. The net C flux following a change from CT to NT was –200 kg C/ha/ year. Thus, the total change in the flux of CO_2 to the atmosphere, following a change from CT to NT on non-irrigated crops, was expected to be about –368 kg C/ha/year. Ghimire *et al.* (2008) reported that SOC sequestration could be increased with minimum tillage and surface application of crop residue and SOC sequestration was highest in top 05 cm soil depth irrespective of the tillage and crop residue management practices. David *et al.* (2009) estimated annual N_2O and CH_4 emissions from different tillage treatments and their and observed that annual N_2O flux was significantly more from chisel till (CT) (1.96 kg N_2O-N/ha/year than MT (1.82 kg) and NT (0.94 kg N_2O-N/ ha/year treatment. The N_2O emitted were equivalent to 1690, 1825 and 875 kg CO_2 e/ha/year for CT, MT, NT. Net CO_2 emission and global warming potential were in NT was 48 and 52% lower than those from MT and CT respectively.

Crop rotations alone with conventional tillage can increase the rate of C sequestration, and with conservation tillage the rate is much higher than earlier (Gaisera *et al.*, 2009). Ghimire *et al.* (2008) reported that SOC sequestration could be increased with minimum tillage and surface application of crop residue and SOC sequestration was highest in top 05 cm soil depth irrespective of the tillage and crop residue management practices. Franzluebbers (2008) reported that greater soil organic C accumulation under pastures than under annual crops due to longer growing periods, more extensive root system, and less soil disturbance. Lal (2004a) also reported that permanent pasture has the highest C sequestration potential. Suman *et al.* (2009) reported that changes in residue management and incorporation of organic manures may help in carbon sequestration by SOC. Sugarcane cropping (one plant + four ratoons) increased SOC by 2.3–17.1 t/ ha over initial content with different treatments at the end of five years study.

Meyer-Aurich *et al.* (2006a) observed that continuous alfalfa rotation had the highest sequestration rates at 513 kg C/ha/year. Continuous corn and the rotations involving cereals had carbon levels between the highs noted for rotations with alfalfa and the lows for rotations with soybeans. The integration of legumes into corn-based cropping systems provides multiple benefits, including higher yields, cost savings, carbon sequestration, and the mitigation of GHGs. Meyer-Aurich *et al.* (2006b) reported highest carbon storage after 20 years where alfalfa was planted continuously and lowest in the corn–corn–soybean– soybean rotation. Carbon storage of soils in the corn–corn–alfalfa–alfalfa rotation was significantly higher than in the corn–corn– soybean–soybean rotation. Rotations, which included cereals and red clover, had soil carbon levels which were between those observed for continuous alfalfa and a corn–corn– soybean–soybean rotation.

Conversion of woodland to agricultural land depletes terrestrial C stocks by drastically reducing the vegetation C and soil organic carbon (SOC) pools. Agroforestry has the potential to increase soil organic matter (SOM) and store significant amount of C in woody biomass (Unruh *et al.*, 1993). Agro-forestry with perennial crops has importance as a carbon sequestration strategy because of carbon storage potential in its multiple plant species and soil as well as its applicability in agricultural lands and in reforestation (Doddabasava, 2017). Proper design and management of agro-forestry practices can make them effective carbon sinks (Montagnini and Nair, 2004, Bhadwal and Singh, 2002). Average carbon storage by agroforestry practices has been estimated as 9, 21, 50, and 63 Mg C/ha in semiarid, subhumid, humid, and temperate regions. For smallholder agro forestry systems in the tropics, potential C sequestration rates range from 1.5 to 3.5 Mg C/ha/yr (Montagnini and Nair, 2004). Another indirect avenue of C sequestration is through the use of agro-forestry technologies for soil conservation, which could enhance C storage in trees and soils.

Verchot *et al.* (2007) revealed that planting trees and bushes increases carbon sequestered both above and below ground, thereby contributing to GHG mitigation. For smallholder agroforestry systems in the tropics, potential C sequestration rates range from 1.5 to 3.5 t C y^{-1} (Montagnini and Nair, 2004).

For example in Zambia, two to 12 year old trees in Leucaena spp woodlots stored up to 74 t ha^{-1} in above ground biomass and 140 t ha^{-1} 1 in the soil (Kaonga, 2005). Coppicing fallows of *Gliricidia sepium, Senna siamea, Acacia* and *Leucaena* spp. store more C than the short duration fallows of Tephrosia, Sesbania and pigeonpea (Sileshi *et al.,* 2007). Even simple systems such as the glyricidia-maize intercropping recycle substantial amounts of above ground C stocks to the soil via the organic materials. In India, the average potential of agroforestry has been estimated to be 25 t C ha^{-1} over 96 m ha (Sathaye and Rvindranath, 1998) and in this way there is a potential to store about 2400 m t. Albercht and Kandji (2003) opines that 1100 - 2200 Tg C could be removed from the atmosphere over the next 50 years if agroforestry systems are implemented on a global scale. Kursten and Burschel (1993) identified two migratory effects of agroforestry on CO_2 emmissions. The first direct near-term effect is C storage in trees and soils through accumulation in live tree biomass (3 - 60 t ha^{-1}), wood products (1 - 100 t ha^{-1}), and SOM (10 - 50 t ha^{-1}), and through protection of existing forests (up to 1000 t ha^{-1}). Secondly, agroforestry has potential to offset greenhouse gas emission through energy and material substitution, and reduction of fertilizer carbon foot print. About 5 - 360 t ha^{-1} of green house gas emissions are offset through energy substitution, up to 100 t ha^{-1} through material substitution and 1- 5 t ha^{-1} through reduction in fertilizer inputs. In addition, agroforestry can enhance C sequestration by decreasing pressure on natural forests, which are a terrestrial C sink. Therefore, there is growing consensus among scientists that agroforestry is a viable option of enhancing the terrestrial C sink (Lal, 2004a).

Further, microclimatic improvement through agroforestry has a major impact on crop performance as trees can buffer climatic extremes that affect crop growth (Madiwalar, 2016). In particular, the shading effects of agroforestry trees can buffer temperature and atmospheric saturation deficit reducing exposure to supra- optimal temperatures, under which physiological and developmental processes and yield become increasingly vulnerable. Scattered trees in agroforestry farms can enhance the understory growth by reducing incident solar radiation, air and soil temperature, while improving water status, gas exchange and water use efficiency.

Conclusion

CC with growing emissions of GHGs and consequent global warming continues to impact water resources, food security, hydropower, human health etc. Agriculture is both source and sink for GHGs, and warrants strategies to shift this balance towards the latter to reduce global warming and the associated hazards. Apart from breeding/identifying climate smart crops, conservation agriculture, crop rotations involving long season crops, pastures and agroforestry, along with suitable irrigation management practices would go a long way in mitigation and adaptation to CC locally and globally as well.

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