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Agroforestry- A sustainable Tool for Climate Change Adaptation and Mitigation

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ABSTRACT

According to WMO (World Meteorological Organization), 2018 was the fourth warmest year on record and average global temperature reached approximately 1°C above pre-industrial level portraying climate change. Changing weather had an impact on lives and sustainable development especially in developing countries. Agriculture is the human enterprise that is most vulnerable to climate change. Large percentage of the population of developing countries depends upon agriculture for their livelihoods. Agroforestry, is an age old management system practiced by farmers to provide shade, a steady supply of food throughout the year, arrest degradation and maintain soil fertility, diversify, increase and stabilize income sources, enhance use efficiency of soil nutrients, water and radiation and provide regular employment thereby increasing system resilience. Agroforestry, thus provides an example of a set of innovative practices designed to enhance productivity in a way that often contributes to climate change mitigation and can also strengthen system's ability to cope with adverse impacts of changing climate conditions.

Key words: Agroforestry, Climate change, Mitigation, Vulnerability.

Over the past few decades, climate change has become a debatable issue whether it is reality or not and if so, what are the areas to be worst affected and ways to mitigate its impact. Climate in a narrow sense is the average weather over a period of time ranging from months to years. The classical period for averaging climatic variables is 30 years, as defined by the World Meteorological Organization. Climate change refers to a change in the state of the climate generated data by statistical tests that persists decades or longer (IPCC, 2014). United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. Climate change exposes societies, economic sectors and ecosystems to risk. Risks from climate change arise from the interaction between hazard (triggered by an event or trend related to climate change), vulnerability (susceptibility to harm) and exposure (people, assets or ecosystems at risk). Despite the availability of various evidences suggesting climate change, uncertainty regarding the actual nature and consequences of changes in climatic variables makes it difficult to plan adaptation and mitigation strategies. However, it can be reduced and managed using various formal or informal tools and approaches that are often iterative. Agroforestry, the integration of trees and shrubs with annual crops production and livestock, is an age old management system practiced by farmers for its multiple benefits. It provide a steady supply of food throughout year, prevent degradation of soil resources and maintain soil fertility, diversify income sources on farm, increase and stabilize income, enhance soil nutrient use efficiency and provide regular employment thereby, increasing system resilience (Rao *et al.,* 2007). Agroforestry land use offers opportunities of creating synergies between both adaptation and mitigation actions for coping with the adverse impacts of climate change. Thus, agroforestry systems provide a particular example of a set of innovative practices that are designed to enhance productivity in a way that often contributes to climate change mitigation through enhanced carbon sequestration and that can also strengthen the system's ability to cope with adverse impacts of changing climate conditions.

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Current patterns of climate change

According to WMO, (2019), the global mean temperature for 2018 was about 0.99 ± 0.13°C above the preindustrial baseline (1850-1900). The average anomaly for the most recent decade 2009-2018 was 0.93 ± 0.07°C and the average for the last five years was 1.04 ± 0.09°C. The usual effects on precipitation were absent with weak La Nina conditions at the beginning of 2018, later changed to neutral. Unlike other important climate variables, there is no single

indicator that can usefully summarize global precipitation changes. Indeed, some of the predicted changes in precipitation in response to climate change affect the frequency and intensity of rainfall that are not well captured by simple monthly or annual averages. Global mean sea level for 2018 was about 3.7 mm higher than in 2017. The average rate of rise was 3.15 ± 0.3 mm yr^{-1}, over the period January 1993 to December 2018, while the estimated acceleration was 0.1 mm yr^{-2}. Agriculture and climate change are interrelated with each other in various aspects, as climate change is the main cause of biotic and abiotic stresses, which have adverse effects on the agriculture of a region. The land and agriculture are being affected by climate changes in different ways, *e.g.*, variations in annual rainfall, average temperature, heat waves, modifications in weeds, pests or microbes, global change of atmospheric CO_2 or ozone level and fluctuations in sea level. Agriculture is of great importance in Indian scenario because of mythic status in Indian lore as first salvo of satyagraha was fired by Mahatma Gandhi on behalf of farmers. Further it accounts for a substantial part of GDP (16%) and employment (49%) and lastly concern about farmers and agriculture today is to ensure that tomorrow there are fewer farmers and farms but more productive ones (ESI, 2017-18). India's agriculture is more dependent on monsoon from the ancient periods. Any change in monsoon trend and temperature drastically affects agriculture. Environmental extremes and climate variability enhanced the chances of numerous stresses on plants. Climate change affects crop production by means of direct, indirect and socio-economic effects as described in (Fig 3) (Raza *et al.,* 2019).

Agroforestry in context to adaptation and mitigation

Agricultural systems in developing countries are adversely affected by land pressure and climate change, both of which threaten food production despite the relative success of intensive agricultural systems that are promoted in many regions of the world. Sustainable intensification of agriculture underlines the importance of diversification as a way to improve crop and land management by integrating trees in land use systems. There are many ways to achieve sustainable agricultural goals through the combination of increased yields with ecosystem services, but there are few options where agroecosystem diversity and farm productivity are enhanced simultaneously. Agroforestry systems/ Integrated management system (integration of trees, crops and animals) provides a particular example of a set of innovative practices that are designed to enhance productivity in a way that often contributes to climate change mitigation through enhanced carbon sequestration and can also strengthen the system's ability to cope with adverse impacts of changing climate conditions (Chavan *et al.,* 2014).

Effect of elevated CO_2

Carbon dioxide (CO_2) is one of the important GHGs which contribute to change in climate (Reddy and Shankar, 2018). The concentration of carbon dioxide (CO_2) in Earth's atmosphere has reached 405.5 ppm (parts per million) by 2017 (WMO, 2018). This level of atmospheric CO_2 is the result of the accumulation of only a part of the total CO_2 emitted because about 55% of all emissions are removed by CO_2 sinks in the oceans and terrestrial vegetation. Elevated CO_2 impact on rice cultivars in general showed that their development was accelerated throughout the vegetative phase and flowering commenced seven days earlier, resulting in greater yield with change in the chemical composition of the rice grains (Uprety *et al.,* 2010). Agronomic efficiency of N application was higher under elevated CO_2 condition. Under elevated CO_2 condition, growth and yield of rice increases but quality decreases. Similarly, in case of wheat crop increased productivity and

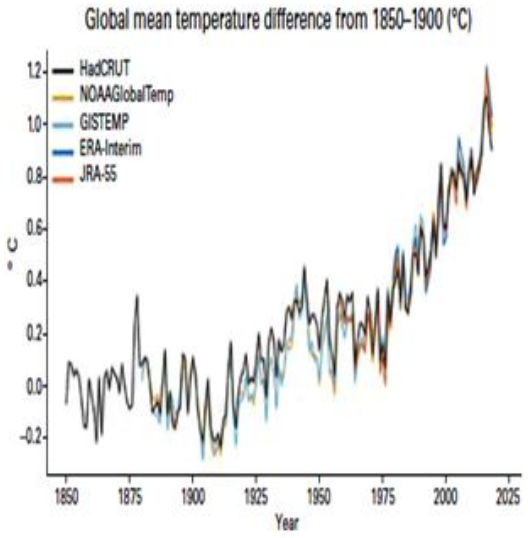

Fig 1: Global mean temperature anomalies with respect to the 1850-1900 baseline for the five global temperature datasets.

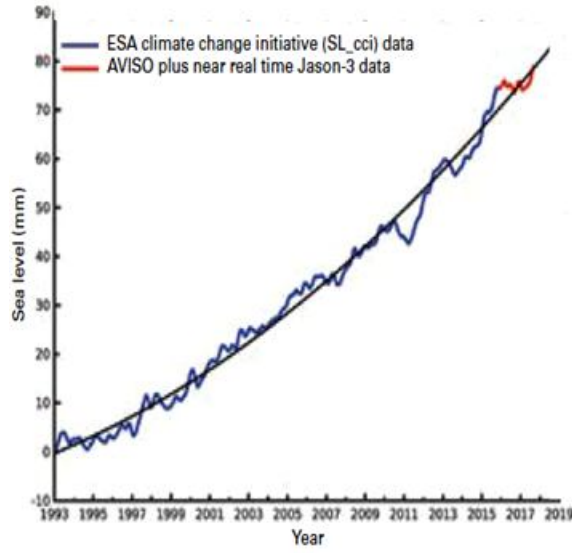

Fig 2: Global mean sea level for the period 1993-2018. (thin black line is a quadratic function representing the acceleration).

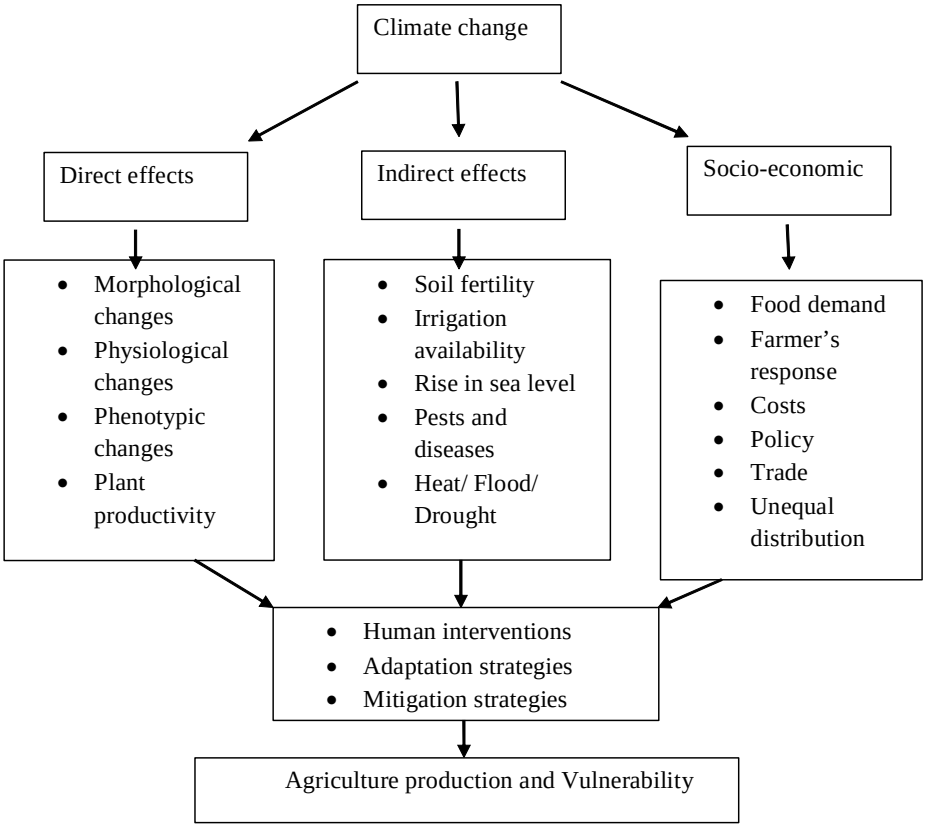

Fig 3: Direct, indirect and socio-economic effects of climate change on agricultural production.

reduced grain quality was reported by Aleminew and Abera, (2020) in Ethiopian highlands. In order to increase grain nitrogen concentration there may be a need to apply higher N doses at elevated CO_2 level (Raj *et al.*, 2019). Agroforestry helps in reducing atmospheric carbon dioxide levels and, hence, mitigates climate change. Carbon stored in agroforestry ranges 0.29-15.21 tonnes of carbon per hectare per year aboveground and 30-300 tonnes up to 1m depth in the soil (Nair *et al.,* 2010). The average carbon sequestered by agroforestry has been estimated to be 9, 21, 50 and 63 $MgCha^{-1}$ in semiarid, sub-humid, humid and temperate regions. Potential carbon sequestration by 2040 in agroforestry is more than 550 megatonnes of carbon per year, which is the highest potential among different land-use and management options (Fig 4). Various agroforestry tree species suitable for Indian conditions are *Morus alba, Melia azedarach, Dalbergia sissoo, Phyllanthus emblica, Tectona gr andis, Eucalyptus spp., Terminalia spp., Tamarindus indica, Mangifera indica, Populus* spp., *Grewia optiva, Cocos nucifera*, Bamboo species, *Ziziphus species etc.* In agroforestry systems, a large amount of biomass is added to soil in the form of leaf litter *etc*. that helps in stabilizing soil organic matter suggesting that agroforestry can increase soil carbon pool that would have a significant impact on reducing the adverse effects of climate change. Biological nitrogen fixation offers an excellent opportunity for drawing upon atmospheric nitrogen in an inexpensive

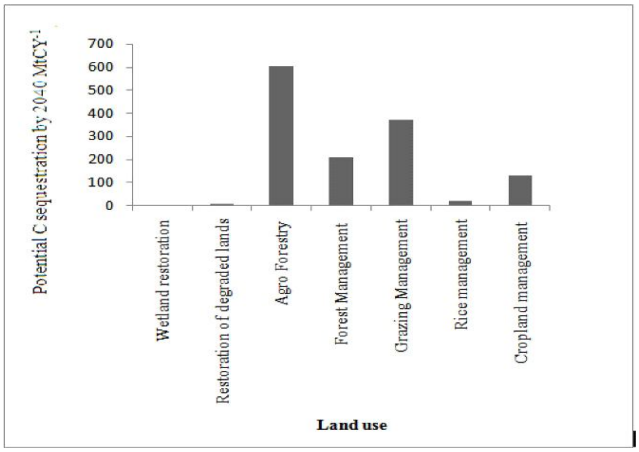

Fig 4: Carbon sequestration potential of different land-use and management options.

and environmentally sound way for meeting the needs of nitrogen which is an important element in agricultural production. Nitrogen fixation rates for most herbaceous legumes are in the range of 40-200 kg N ha^{-1} yr^{-1} (Nair, 1993). Various nitrogen fixing species are *Acacia* spp., *Albizia* spp., *Alnus* spp., *Leucaena leucocephala*, *Bauhinia* spp., *Myrica esculenta, Casuarina equisetifolia, Dalbergia sissoo, Erythrina* spp., *Sesbania sesban, Prosopis* spp., *Cassia* spp., *Peltophorum* spp., *Hardwickia binata etc.*

Effect of increased temperature

Crop production

Despite the beneficial effects of higher CO_2 on many crops, associated increase in temperature would affect crop production considerably with more depressing effects in tropics and subtropics (Neenu *et al.,* 2013). There is possibility of 5-10% decline in wheat production with every 1°C rise of temperature by mid 21st century. IPCC indicated a probability of 10-40% loss in crop production in India with increase in temperature by 2080-2100 (Vyankatrao, 2017). International Rice Research Institute predicted 20% drop in production per degree celsius of temperature rise. Rice becomes sterile if exposed to temperatures above 35 degrees for more than one hour during flowering and consequently produces no grain (Senapati *et al.,* 2013*).* Agroforestry helps in increasing crop production by incorporating trees on the farm through various beneficial effects that trees have on the microclimate and crop. Pardon *et al.,* (2018) found increase in the yield of wheat near the trees as compared to control in poplar based agroforestry system and was attributed to the shading effect of trees during heat waves, thereby buffering maximum temperature. They further found that tree row presence resulted in significant increase in CP concentration of wheat and barley. Increased CP concentration is one of the adaptive capacity of the crop to climate change. Lin (2007) concluded that shade tree use in agroforestry systems may offer an effective coping mechanism to implement in agricultural areas that suffer from climate extremes. Similarly, Craparo *et al., (*2015) found that rising minimum temperature will reduce the coffee yield in Tanzania upto 145 ± 41kgha^{-1} by 2060. They suggested the shade trees as a measure to climate change adaptation.

Crop phenology

Advancement in spring phenology of 2.8 ± 0.35 days per decade has been observed in plants and animals in recent decades in most Northern Hemisphere ecosystems (between 30°N and 72°N). These shifts have been attributed to changes in climate (IPCC 2014). Inurreta *et al.,* (2016) found that agroforestry system reduced the pace of physiological maturity. The phenology of the durum wheat in the two systems-agroforestry system (AFS) and fellow system (FS) was almost the same until anthesis. After this stage, the phenological development in FS was faster until shortly before reaching physiological maturity. Crop ripened about 10-12 days earlier in FS as compared to AFS.

Biodiversity

Number of species projected to lose over half of their climatically determined geographic range at 2°C global warming (from 18% of insects, 16% of plants, 8% of vertebrates to 6% of insects, 8% of plants and 4% of vertebrates at 1.5°C warming (IPCC 2014). Agroforestry innovations contribute to bio-diversity conservation through integrated conservation development approach. It will further help in enhancing the availability of improved planting material, which is a key to the increase in productivity and production at farm level. Biodiversity is the feed stock for a climate resilient agriculture. Agroforestry with components like trees, agricultural crops, grasses, livestock *etc.* provides all kinds of life support system.

Fertilizer use efficiency

Fertilizer use efficiency in India is generally very low (30-50%) and increasing temperature is likely to reduce the fertilizer use efficiency. This will lead to increased fertilizer requirement for meeting increased future food production demand. A large number of resource poor farmers in tropics are not able to apply desired levels of fertilizers. Studies on tropical AFS in nutrient-depleted soils have demonstrated the ability of deep-rooted trees to absorb nutrients that have leached below the rooting zone of agronomic crops and to recycle these nutrients via leaf litter and fine root turnover. Further, pruning of various agroforestry tree species such as *Gliricidia sepium*, *Calli andra* spp., *Sesbania sesban, Azadirachta indica, Pongamia glabra, Cassia fistula, Leucaena leucocephala etc.* act as green manure, thus, improving the nutrient-use efficiency in the system as a whole.

Microclimate modification

Trees on farm bring about favourable changes in the microclimatic conditions by influencing radiation flux, air temperature, wind speed which will have a significant impact in modifying the rate and duration of photosynthesis, subsequent plant growth, transpiration and soil water use. Shade trees in agroforestry system perform an important role in moderating the temperature, humidity, evapotranspir-ation of surrounding area. According to Steffan-Dewenter *et al.,* (2007) the removal of shade trees increased soil surface temperature by about 4°C and reduced relative air humidity at 2 m above ground by about 12%. Soil temperature under the baobab and *Acacia tortilis* trees in the semi-arid regions of Kenya at 5-10 cm depth were found to be 6°C lower than those recorded in open areas (Belsky *et al.,* 1993).

Water (Quality and quantity)

Climate change can alter the availability of water. About 8% of the global population is projected to experience water shortage due to increased warming (1.7°Cover normal) by 2040 and increasing to 14% of the population at 2.7°C in 2043-2071 (IPCC 2014). Lin *et al.,* (2011) found that the VBS (Vegetated Buffer Strips) reduced the transport of both dissolved and sediment bound herbicides and veterinary antibiotics in surface runoff by 58 to 72%. Udawatta *et al.,* (2011) studied the effect of agroforestry buffers on reduction of nonpoint-source pollution (NPSP). They found that grass and agroforestry buffers reduced sediment, total N and total P losses by 32, 42 and 46%, respectively, compared with control treatments and they recommend the design of agroforestry and grass buffers to improve water quality. Schultz *et al.,* (2009) described the water-quality

enhancement benefits of riparian buffer systems and indicated that riparian forest buffers can remove significant amounts of sediment, nutrients and pesticides from both surface and subsurface waters. Climate change is projected to reduce groundwater resources significantly in most dry subtropical regions. In a groundwater-dependent irrigated region in northwest Bangladesh, the average groundwater level during the major irrigation period (January-April) is projected to decrease in accordance with temperature rise (Salem *et al.,* 2017). Agroforestry has potential for improving water use efficiency by reducing the unproductive components of the water balance, *i.e.* run-off, soil evaporation and drainage. Also, agroforestry reduces net water loss through soil evaporation and crop transpiration. In China, Zhao, (2012) evaluated water balance and water competition in alley cropping system and found that in alley cropping, water budget components and water use patterns were improved significantly as indicated by increased evapotranspiration (6-11%) and decreased net drainage (7-45%) and runoff (50-60%).

Agroforestry- In mitigating and adapting changing rainfall patterns

A 2°C rise in the world's average temperatures will make India's summer monsoon highly unpredictable. At 4°C warming, an extremely wet monsoon that currently has a chance of occurring only once in 100 years is projected to occur every 10 years by the end of the century (Reddy and Shankar, 2018). An abrupt change in the monsoon could precipitate a major crisis, triggering more frequent droughts as well as greater flooding in large parts of India. Dry years are expected to be drier and wet years wetter. Limiting global warming to 1.5°C, compared to 2°C, may reduce the proportion of the world population exposed to a climate change-induced increase in water stress up to 50% (IPCC, 2014). Tree component in agroforestry helps to buffer against extreme events by modifying temperatures, providing shade and shelter and by acting as alternative food sources during periods of flood and drought. Tree-based systems have some obvious advantages for maintaining production during wetter and drier years.

Firstly, their deep root systems are able to explore a larger soil volume for water and nutrients, which will help during droughts. Secondly, increased soil porosity, reduced runoff and increased soil cover lead to increased water infiltration and retention in the soil profile which can reduce moisture stress during low rainfall years. Thirdly, tree-based systems have higher evapotranspiration rates than row crops or pastures and can thus maintain aerated soil conditions by pumping excess water out of the soil profile more rapidly than other production systems.

Although many people intuitively link agroforestry with livelihood resilience to floods and drought, Quandt *et al.,* (2017) studied how agroforestry help smallholder farmers for building livelihood resilience to floods and drought. They gave two models, flood model and drought model to represent the resilience potential of agroforestry in extreme conditions. Various attributes of agroforestry that helps in mitigating flood are food, firewood, medicine, construction material, reduction soil erosion and water flow, trees with fast and constant production, wind break, clean air, cover from rain *etc*. while fodder, shade, drought resistance, beautification, prevention of soil erosion, attraction of rain *etc*. helps in combating drought conditions.

Agroforestry for insect pest management

Climate change will indirectly affect crop productivity by changing pest and disease dynamics and ultimately food security. Every 1°C increase in temperature in southwest Europe was associated with an additional migration of 14.4 ± 2.4 species to England. Armyworm, (*Mythimna separata),* reaches outbreak proportions after heavy rains and floods. Outbreaks occurred when rainfall exceeded the average 89 cm. Hamilton *et al.,* (2005) found that soybean grown under the elevated CO_2 atmosphere had 57% more damage from the insects like Japanese beetle, potato leafhopper, western corn rootworm and Mexican bean beetle than those grown under the ambient conditions. However, reduced temperature and humidity fluctuations under shade can also have a suppressing effect on pest and diseases. For example, these conditions tend to reduce the spread of witches' broom disease on cacao. An alley cropping experiment in Rwanda with *Sesbania sesban* found that trees seemed to reduce the incidence of maize rust (*Puccinia sorhii)* (Lin *et al.,* 2008).

Agroforestry for soil fertility

Changing climatic scenario (higher temperatures, increasing CO_2 concentrations, changes in precipitation patterns *etc*.) could increase decomposition of organic matter, nutrient cycling and nitrogen fixation. Keller *et al.,* (2004) reported that climate change will directly affect carbon and nitrogen mineralization through changes in temperature and soil moisture, but may also indirectly affect mineralization rates through changes in soil quality. Agroforestry can be a viable option to alleviate the degradation and loss of soil fertility from agricultural fields. Parkland agroforestry is an important land use system that has a positive influence on maintaining soil fertility mainly due to tree component. Agroforestry helps in maintaining and enhancing soil fertility through organic matter(litter/root decay), nitrogen fixation, throughfall and stream flow, preventing soil and water erosion, nutrient cycling, nutrient pumping, improving soil physico-chemical properties, improving soil biological activity *etc* (Nair, 1993).

Agroforestry for livelihood and food security

Dhyani *et al.,* (2005) have indicated the potential of agroforestry for rural development and employment generation to the tune of 5.763 m human days/yr from Indian Himalayas alone. *Acacia senegal* based agroforestry system in parts of Barmer and Jodhpur districts of Rajasthan is best example of livelihood improvement potential of agroforestry. *Acacia senegal* is a source of gum Arabic which has very

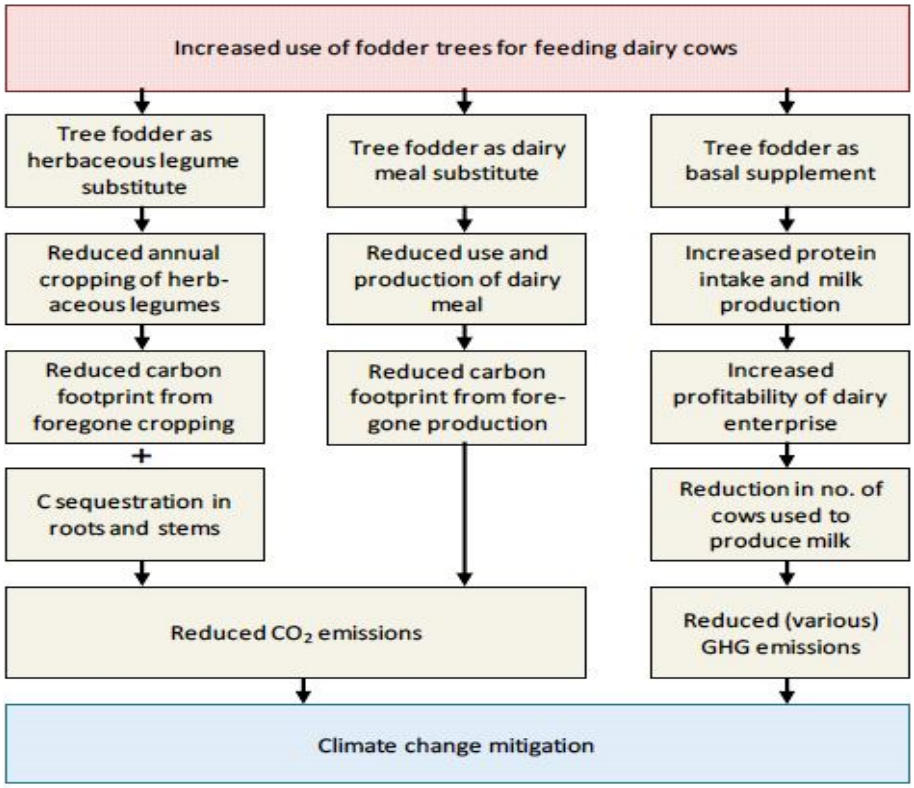

Fig 5: Possibilities of fodder trees contributing to climate change mitigation.

high commercial value. In addition to harvesting crop grain for food and crop straw for fodder, the farmers harvested substantial quantity of gum Arabic through small intervention using gum inducer provided by CAZRI (Roy *et al.,* 2011*).* Leguminous crop (mung bean) sown under ber (*Ziziphus mauritiana)* plantation produced 0.2 t/ha of grain and 0.8 t/ ha quality ber fruits from same land unit even when seasonal rainfall was as low as 200 mm, thus rendering a drought proofing mechanism to the system. The economics of this improved system indicated that in case of sole leguminous crop (mung bean) farming, the net profit per hectare was Rs. 4800/-, however, in case of ber intercropping, the profit was to a tune of Rs. 8000/- /ha (Tewari, 2007; Tewari *et al.,* 2013). Further, results of regression analysis of data on climatic variables suggest negative effect of maximum temperature on food security which require climate resilient technology for its addressal (Kumar and Upadhyay, 2019).

Agroforestry for livestock

Livestock production globally contributes about 9% of total anthropogenic carbon dioxide (CO_2), 37% of methane (CH_4) and 65% of nitrous oxide (N_2O) emissions (FAO, 2009). Livestock-keeping diversifies rural communities' production options and is often adapted to relatively marginal environments, which can promote climate-resilience. Due to deforestation for agricultural expansion access to tree resources from natural forests and woodlands is lost (FAO, 2010). The increased competition between human food and animal feed, the greater demand for animal products globally and the changing environmental impacts, emphasize the increasing importance of agroforestry for livestock sector. Dawson *et al.,* (2014) studied how integration of fodder trees on the farm land helps in mitigating the climate change (Fig 5).

CONCLUSION

The growing awareness of consequences of climate change is real. Being agriculture dominated economies; the impact of climate change on agriculture is of greatest concern to most developing countries. The concepts of resilience and sustainability are well established in integrated management system. Agroforestry systems act as sink for atmospheric carbon while helping to attain food security, increase farm income, improve soil health and discourage deforestation. Thus, agroforestry land use system can be more potent in adaptation and mitigation to climate change by offering a win-win opportunity as compared to agricultural system.

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