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Climate Change, Carbon Offsets and Low Carbon Technologies in Agriculture: A Review

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Abstract

Climate change is posing serious threat to agriculture and food security at global level. Problems faced by agriculture are further exacerbated with serendipitous climate changes, majorly through emission of greenhouse gases (GHGs). Agriculture, including livestock is a significant contributor of GHG emissions like carbon dioxide(CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs) and ozone (O_3) etc. A sustainable reduction in GHG emissions from agriculture is one of the objectives of Climate-Smart Agriculture (CSA) through use of low carbon practices. The present review focuses on the problems of climate change, major GHGs, reasons for GHG emissions, efforts at international level to mitigate GHGs and major treaties involved etc. The concept of carbon offsets, types of carbon offset projects were also discussed. Further, statistics on global trends in GHG emissions, its major contributors were also reviewed. The importance of low carbon patterns in agriculture and their role in significant reduction of GHGs, the key tradeoff issues while adopting low carbon practices, concepts of win-win solution and triple-win situation are thoroughly discussed. The application aspects such as how farmers benefit from the carbon markets and the key policy considerations for making low carbon society through policy implementations at both domestic and international level are also part of our present review.

Keywords: Climate Change; Greenhouse Gas Emissions; Low Carbon Agriculture; Carbon Offsets; GHG;

Introduction

Climate by its very nature has to be studied across national boundaries. Even though the beginning of 19^{th} century witnessed several international collaborations among meteorologists, not till the possibility of global warming was pointed out, researchers and policy makers realized the intensity of the situation and greater need for international negotiations. This led to elaborate network of research organizations and greater efforts to work out a consensus of reasonably certain conclusions about climate to guide policy makers [51]. In the past three decades, quantity, depth of knowledge and awareness on enhanced greenhouse gas emissions and their contribution to climate change increased in scientific community, policy makers and human population in general. Along with increased awareness, these decades were also filled with lot of unknowns, concerns and relatively active efforts around the globe to design and adopt policies that mitigate climate change.

The first world Climate Conference, held in Geneva in 1979 was one of the first major international meetings on climate change. This conference was attended by researchers from around the globe and organized working groups to focus on climate data, identification of climate topics, integrated impact studies and research on climate variability and change. This conference led to the development of Inter-governmental Panel on Climate Change (IPCC) and United Nations Environment Program (UNP) in 1988. IPCC was first established in 1988 by UNEP and the World Meteorological Organization (WMO) with an objective to provide the world with scientific view of climate change and its political and economical impacts [46]. The second world climate conference was held in Geneva, 1990 which is important towards a global climate treaty. At this conference, IPCC first assessment report was ready and this led to the identification and highlighting of risk of climate change by scientists, which eventually led to the establishment of Global Climate Observing System (GCOS), the United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol. GCOS was established in 1992 to ensure availability of observations and information needed to address climate related issues to all potential users. The GCOS is co-sponsored by the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the United Nations Environment Program (UNEP), and the International Council for Science (ICSU).

UNFCCC, an international environmental treaty was negotiated at the Earth Summit in Rio de Janeiro in 1992 with an objective to "stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" [49]. Under the UNFCCC, climate change is recognized as a global challenge which requires effective international response grounded in the principles of cooperation and common but differentiated responsibilities. Major events since the advent of UNFCCC are Kyoto Protocol (first adopted in 1997 June, Tokyo, Japan but came into force in 2005), European Union Emission Trading Scheme (EU ETS) (launched in 2005) and Paris agreement (first adopted on December 12, 2015 and came into force on November 4, 2016) etc.

Kyoto protocol follows main principles agreed in the original 1992 UN framework convention. The main objective of the Kyoto Protocol is to control emissions of the main anthropogenic GHGs in ways that reflect underlying national differences in GHG emissions, wealth, and capacity to make the reductions [24]. Kyoto Protocol primarily puts obligation on participating developed countries to reduce GHG emissions while encouraging developing countries to reduce GHG emissions. It establishes a structure of rolling emission reduction commitment periods. Kyoto Protocol's first commitment started in 2008 and ended in 2012. A second commitment period started in 2012 as part of Doha amendment to the protocol which will end in 2020. The Kyoto Protocol was the first vehicle for emissions trading in greenhouse gases—or what we will call carbon markets.

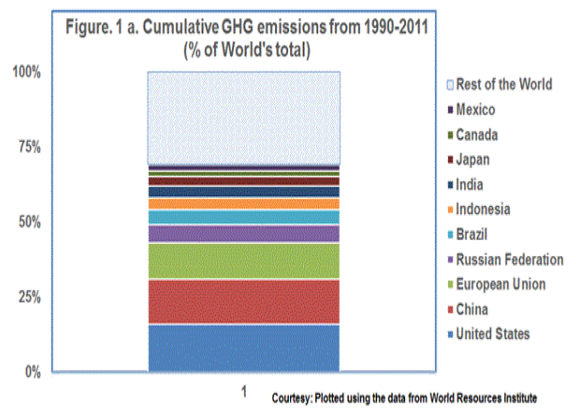
EU ETS was the first large greenhouse gas emissions trading scheme in the world and was launched to fight global warming [15]. This trading happens based on cap-and-trade principle under which a "cap" or maximum limit is set on total amount of GHG Assigned Amount Units (AAU) or allowances that can be emitted by participants; and conversely if they performed well at reducing emissions, they can "trade" or sell off their left over allowances thus turning pollution cuts into revenue). Each unit of AAU is equal to one metric tonne of carbon dioxide equivalent (CO_2e) calculated using global warming potential of greenhouse gases. One carbon offset is also equal to 1 metric tonne of CO_2e. However, AAU are permits to emit, while offsets refers to a unit of carbon dioxide equivalent (CO_2e) or greenhouse gasses (GHG) that is reduced, avoided, or sequestrated to compensate for emissions occurring elsewhere (anywhere in the world, even away from the source, as they mix uniformly in the atmosphere) [23]. EU ETS scheme is divided into "trading periods", with the first trading period from January 2005 to December 2007; the second trading period from January 2008 to December 2012; and the third trading period from January 2013 to December 2020. Kyoto Protocol and EU emission trading scheme are primarily responsible for existence of carbon offset markets, as the participating entities use these markets to achieve compliance with obligations under Kyoto Protocol and EU ETS regulations. There are several offset programs that operate within ((The Clean Development Mechanism (CDM), Emissions Trading (ET) and Joint Implementation (JI)) or outside Kyoto Protocol ((New South Wales Greenhouse Gas Reduction Scheme (NSW GGAS), Regional Greenhouse Gas Initiative (RGGI), Western Climate Initiative (WCI) etc.) [9]. The Third World Climate Conference was held in Geneva, Switzerland in 2009 to focus on climate predictions and information at seasonal to multi-decade time scales for decision making. The main objective of this conference was to to create a global framework that will link scientific advances in the area of climate predictions to meet the needs of their users for decision making to better cope with changing conditions.

In 2015, at 21st Conference Of the Parties (COP 21) to the UNFCCC, under Paris agreement (entered into force on November 4, 2016) 189 countries representing 96 percent of global GHG emissions committed to reducing GHG emissions and reducing global average temperature raise (from pre-industrial levels) to well below 2ºC and pursue efforts to hold the increase to 1.5ºC. Through this Paris agreement, participating countries also agreed to "increase their ability to adapt to the adverse impacts of climate change, foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production". Signatories also agreed to make "finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development" [48, 50]. Intended nationally determined contributions (INDCs) under Paris Agreement refers to the individual national emission reduction targets determined by the respective countries in order to achieve the worldwide goal of GHG reduction. Other initiatives and commitments taken at various Conference of Parties of UNFCCC have also been playing substantial role in making policies that work towards mitigating climate change.

Global Warming

Major contributors to Global Warming

According to the World Resources Institute, ten countries produced around 70 percent of global GHG emissions from 1990 to 2011; and almost half of these emissions are from the United States, China, European Union and Russian federation (Fig. 1a).



From 1990-2011, the U. S. is the highest cumulative GHG emitter (16% of the World's total) followed by China (15% of the World's total) compared to the other countries.

Effects of global warming

According to IPCC working group II report, people, societies and ecosystems throughout the globe are vulnerable to climate change although the degree of vulnerability is different in different places [29]. Effects of enhanced GHG emissions include wide spread raise in global surface temperature over the globe (global warming), raising sea levels, changes in precipitation patterns, expansion of deserts, increase in area affected by drought, changes in snow, ice, increased tropical cyclone activity etc [26].

Greenhouse Gas Emissions, trends, effects on climate

Both natural and anthropogenic gaseous constituents of the atmosphere that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself and by clouds are referred to as greenhouse gases. Primary natural greenhouse gases in the earth's atmosphere include CO_2, N_2O, CH_4 and ozone (O_3). Halocarbons, chlorine and bromine containing gases/substances that are known to have global warming potential are entirely anthropogenic.

Greenhouse gases of primary concern included under Kyoto Protocol are CO_2, CH_4, N_2O, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). Since the advent of the industrial age, human activities (including agriculture) contributed to the enhanced production of greenhouse gasses. Reasons for emissions of these GHGs can be multi-fold; however, combustion of coal [8]; oil products [4]; and natural gas combustion [1], oil and natural gas extraction/refining/processing [1, 33]; transport by road, rail [32]; electricity generation [53]; biomass burning [2]; industrial sectors such as cement manufacturing units [57]; bricks manufacturing [3]; from agriculture sector [19] etc. are the major ones. Waste sector emissions can be from landfills [45] and waste water disposal [12]. Even though there is a fair degree of uncertainty about the precise contribution of various sectors (especially those that include biological processes such as land use change and agriculture) to GHGs; several international organizations (World Resources Institute, IPCC etc.) have been monitoring global GHG emissions. CO_2 equivalents are generated based on 100-year Global Warming Potential (GWP) estimates produced by the IPCC [31].

Global Trends

According to World Resources Institute estimates, a total of 41,755 Mt CO_2 (million metric tons) (41.76 Gt CO_2) equivalent in the year 2000 [5] and 44,153 Mt CO_2 (44.15 Gt CO_2) equivalent in the year 2005 [6] and 49 gigatonne of CO_2- equivalent per year in the year 2010 [30]. were emitted from major emission sources (transportation, electricity & heat, other fuel combustion, industry, fugitive emissions, industrial processes, land use change, agriculture and waste). (Fig. 2a).

In the year 2010, at the global level, the key greenhouse gases emitted by human activities are CO_2 (65% from fossil fuel and industrial processes) (11% from forestry and other land use 11%), CH_4 (16%), N_2O (6%) and 2% of fluorinated gases that include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6) [30]. (Fig. 2b)

Fig. 2a. Global Greenhouse Gas Emissions by Economic Sector in 2010

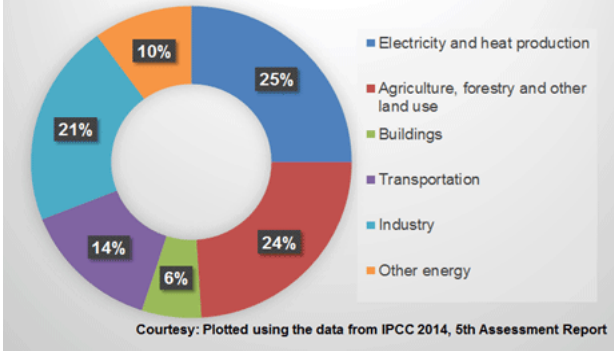
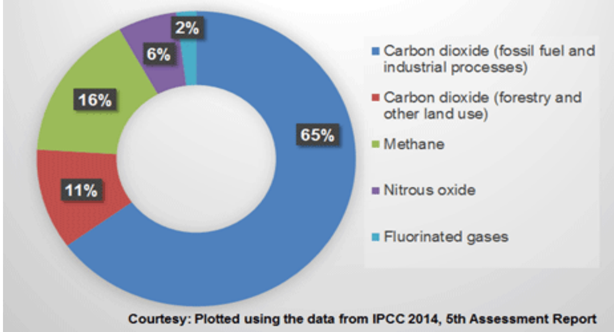


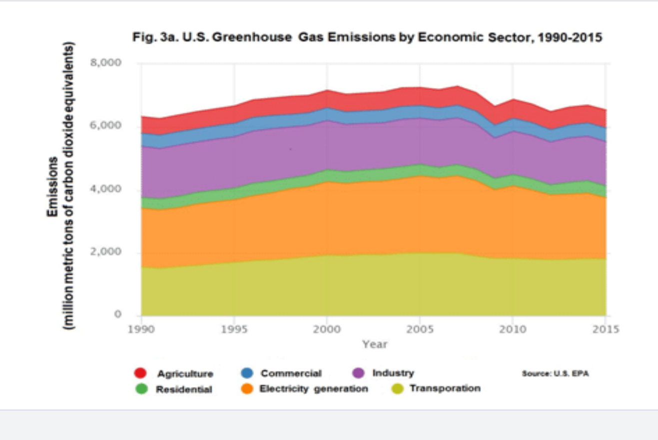
Fig. 2b. Global Greenhouse Gas Emissions by Gas in 2010

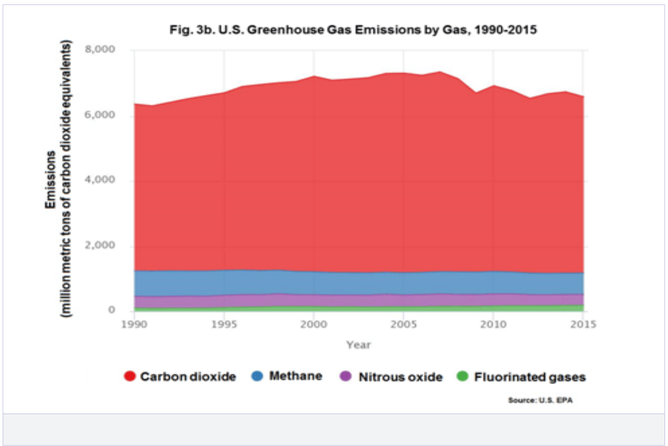


U.S. trends

Since 1990, the U.S. greenhouse gas emissions have increased by about 7 percent. From year to year, emissions can rise and fall due to changes in the economy, the price of fuel, and other factors. The U.S EPA (Environmental Protection Agency) tracks the total U.S. GHG emissions. The primary source of GHG emissions in the U.S are electricity production, transportation, industry, commercial and residential areas, agriculture agriculture, land use and forestry land use and forestry. Total GHG emissions in 1990, 2000, 2010 and 2014 from the U.S are 6397, 7258, 6985, 6870 Million Metric Tons of CO_2 equivalents respectively [16]. Total GHG emissions from various economic sectors in the U.S. from 1990 to 2015 are presented in Fig. 3a From this data, it can be observed that highest GHG emissions are from electricity generation (30%) followed by transportation (26%)

According to the U.S. EPA data, major greenhouse gas emissions from 1990-2015 constitute, CO_2 (81%), CH_4 (11%), N_2O (6%) and fluorinated gases (3%) (Fig. 3b).





Greenhouse Gas Emissions from Agriculture

Agriculture is a major contributor to global greenhouse gas emissions with GHGs being produced at all stages of the system; farming, food distribution, consumption and the disposal of the waste [20]. Agriculture accounts for about one-fifth of the anthropogenic greenhouse gas emissions [30]. During the plant growth, plants uptake atmospheric carbon dioxide (CO_2) and soil nitrogen (N), and redistribute them among above and below ground living biomass, dead residues and soil organic matter. Later, GHGs such as CO_2, N_2O, and CH_4 will be released into the atmosphere by respiration, decomposition of dead plant biomass, soil organic matter and by combustion [41]. Agriculturally induced changes in land use (eg. deforestation) also causes GHG emissions [19]. Annual GHG emissions from agricultural production in 2000-2010 were estimated to be at 5 to 5.8 Gt CO_2eq/yr while annual GHG emissions from land use and land use change activities accounted for approximately 4.3 – 5.5 Gt CO_2eq / yr [41].

Various farm management activities such as fertilizer application, methods of irrigation, tillage etc. lead to production and emission of N_2O. Livestock produces methane as part of their digestion (enteric fermentation) which represents around one third of the methane emissions from the agriculture. The way livestock manure is managed also contributes to CH_4 and N_2O

Carbon Offsets

Technically, one carbon offset represents a token/certificate for reduction of one metric ton (2,205pounds) of carbon dioxide emissions (CO_2e) into the environment. A carbon offset is a reduction in emissions of anthropogenic GHGs or carbon dioxide (CO_2) made in order to compensate for or to offset an emission made elsewhere [23]. Carbon offsets are measured in metric tons of carbon dioxide-equivalent (CO_2e) or greenhouse gases. Carbon offsets play a key role in achieving low carbon economy and are an alternative to direct reductions for meeting GHG reduction targets. There are several kinds of carbon offset projects. Bio sequestration projects (when trees/plants grow, CO_2 removed from the atmosphere will result in carbon credits), energy efficiency and renewable energy projects that prevent or reduce CO_2 emissions into the atmosphere, methane capture projects, carbon capture and storage projects etc. are some of the categories of carbon offset projects (10).

There are two markets for purchasing carbon offsets; compliance market (regulated by carbon reduction regimes such as Kyoto Protocol and European Union's Emission Trading Scheme) and voluntary market (outside of regulations) [11]. It was estimated that the value of carbon markets has increased to USD 142 billion by 2010 [55, 56]. Each member state under the Kyoto Protocol has a greenhouse gas emission quota. The countries that exceeded their quota can purchase quotas (or compliance carbon credits) from those that have not used up theirs. Through these compliance credits, members operate an international emission control system to mitigate greenhouse gas emissions at national level. United Nations Clean Development Mechanism is the most active compliance carbon offset market and is the source of offsets for Kyoto Protocol Signatory countries and buyers in the European Union Emissions Trading Scheme [14]. Trading volumes in compliance markets are much higher and more expensive than in the voluntary markets. However, voluntary market is fast growing and much of the demand for voluntary markets come from the developed and more environmentally aware markets in North America and Europe [25]. Historically, voluntary carbon markets served as a source of experimentation and innovation and more accessible to small communities in developing countries as they lack bureaucracy and transaction costs of regulated carbon offset markets [25]. Small scale emitters offset emissions within the voluntary offset market. Some countries rely on voluntary markets due to lack of national level compliance markets. For example, California is the only state with functioning compliance carbon market in the United States. So the U.S firms are largely depending on voluntary market thus making the U.S a global leader in voluntary market with a global share of 40% in 2011 [17]. Even though, United States of America is not official signatory of the Kyoto Protocol and till recently not implementing Federal cap and trade system, several U.S firms have been purchasing carbon offsets voluntarily, largely motivated by corporate social responsibility and public relations.As a major step towards combating global climate change, in September 2016, the U.S. (top 2nd contributor of GHG emissions with up to 18% global GHG emissions) ratified Paris agreement. This might bring welcoming changes through new compliance mechanisms or regulations in this area at subnational or national level in the near future.

Policy Issues related to Carbon Farming

Carbon farming is a term used to farming methods that reduce greenhouse gas emissions, and capture carbon in vegetation and soils. Low carbon society is the order of the day and for this, there is an urgent need in urban and rural societies especially in developing countries to devise strategies and prepare road maps for achieving this goal. In this context, promotion of low carbon agriculture and popularization of its practices among yeoman community assumes significance. One of the focal points of Climate Smart Agriculture (CSA) is to eliminate or reduce GHGs emissions, especially by promoting and adopting low input and organic agriculture. Though, the concept of organic agriculture is not new, achieving the targets of low carbon society is only through implementation of practices on a community basis rather than in isolated patches. For this, governments have to implement policies for promoting low carbon and organic practices in the agricultural sector. These policies and technological options are to be pro-poor and should have socio-economic benefits too. Significant barriers in implementation of these policies are to be overcome by national policies to meet the needs of different farmers and agricultural systems [36]. The Indonesian government has introduced "Go Organic 2010" for promoting organic agriculture and to become a significant organic exporter of the world [39]. Research findings in Indonesia that proved to bear significant GHG mitigation effects from agriculture included zero tillage (saves water, diesel and reduces crop-residue burning); leaf color charts (for judicious application of N fertilizers & thereby reduced pest & disease attack); the system of rice intensification (SRI) (higher yields, low irrigation water); and aerobic composting (eliminates CH_4 & N_2O emissions) etc. [39]. In India, important policy options for promoting GHG mitigation include a) innovative payment mechanisms and support systems for novel institutions of agricultural mitigation; b) development of appropriate extension system such as linkages to new markets (carbon markets), access to new regulatory structures, government priorities and policies; c) robust way of encouraging low carbon farming technologies through effective dissemination of information and capacity building (workshops, seminars etc.); d) identification of progressive farmers and motivating them to adopt new low carbon farming technologies; e) high resource allocation to research on climate-smart agriculture (CSA); f) resource allocation to infrastructural and institutional innovations in water and nutrient management; g) development of physical and institutional infrastructure in rural areas to enhance resilience in agriculture in the face of uncertainties of climate change etc. [38]. Brazil reported a large reduction in Amazon deforestation, which is its major source of carbon emissions and announced its official goal to reduce GHG emissions by 36-39 percent by 2020 [44]. Brazil had launched a low carbon agriculture program during 2010 to provide incentive to farmers as encouragement to adopt technological processes for minimizing the ill-effects of on-farm GHG emissions. This program provides a credit of USD 1.3 billion to sustainable and low carbon farm practices that resulted in positive balance in CO_2 emissions and carbon sequestration [18].

Certain key policy considerations are also to be borne in mind for low carbon technology transfer to developing countries. They include a) technology transfer to be viewed as part of a broader process of sustained, low carbon technological capacity development in recipient countries; b) technology transfer involves both vertical (from R&D to commercialization) and horizontal transfer (one geographical region to other); c) less integrated technology transfer arrangements like involving knowledge exchange and diffusion through recipient country economies; d) recipient countries to aim to develop capacity of low carbon technology through procuring technological know-how and knowledge necessary for innovation; e) access to Intellectual Property Rights (IPRs) that may be necessary for facilitating technology transfer; and f) there is a central role for both national and international policy interventions in achieving technology transfer [37].

Low Carbon Patterns/Practices in Agriculture

The emission and transport of these GHGs in crop fields are dependent on several factors. For example, in rice, the production, consumption and transport of CH_4, N_2O and CO_2 are influenced by factors such as soil type, water regime, fertilizer application rate, cultivation system and rice variety [58]. Adjusting/altering these factors suiting to minimization of these GHG emissions, though important, it is also essential to monitor for simultaneous reductions since, some of these gases can have tradeoff relationships. For example, water regime change in rice through mid season drainage and moist intermittent irrigation conditions can bring down CH_4 emissions, while enhancing N_2O emissions. Hence, it is important to devise/adopt technologies that offer win-win solutions i.e., contribute to simultaneous reductions of both CH_4 and N_2O emissions [59]. Some climate-smart agriculture techniques are contributing to increased agricultural productivity, improved adaptation or resilience of crops to biological stresses along with mitigation of GHGs, a "triple win" situation. Studies from Kenya and Uganda have reported triple win potential of soil nutrient management strategies through inorganic fertilizers, mulching, and manure (21, 34, 52). Agriculture practices that contribute to low GHG emissions when facilitated with right innovations, investments and policy incentives can help mitigate the ill-effects of climate change besides contributing to food security [18]. Though the agricultural practices that favor GHG mitigation are available and adoptable, they are not always profitable. In particular, the transaction costs of switching from high carbon to low carbon farming are very high. This is true especially with smallholder farmers with limited resources in developing countries [18, 47]. It is because of this reason; offering incentives for fostering change of practices towards low carbon agriculture assumes significance [18].

Some of the examples of low carbon management practices that could offer GHGs mitigation include 1) use of improved crop varieties with high carbon sink capacity, high yield potential, have resilience against climate change and resistance to pests and diseases. 2) judicious use of fertilizers and manures 3) increased carbon sequestration through use of cover crops, incorporation of crop residues 4) crop rotation particularly with legumes 5) reduction of carbon losses through zero tillage or reduced tillage 6) restoration of degraded lands 7) afforestation 8) agroforestry 9) organic and low input agriculture etc. Successful implementation of crop management practices with high GHG mitigation potential have been reported from various countries (7, 18, 40)

Carbon Market & Benefits to Farmers

Farmers apart from being impacted by climate change, also play vital role towards climate change mitigation. Mitigation of GHGs in agriculture is well established and documented [42, 43]. However, exclusion of agriculture in both formal and informal carbon markets is largely attributed to the prevailing uncertainty in agricultural mitigation of GHGs. Kenyans are the first to earn carbon credits from sustainable farming [56]. These are the first credits issued worldwide under the sustainable and management (SALM) carbon accounting methodology through Kenya Agricultural Carbon Project (KACP). These credits are based on "Verified Carbon Standard" (VCS) for sequestering carbon in soil. Overall, these credits represent a reduction of 24,788 metric tones of CO_2, equivalent to emissions from 5,164 vehicles in a year.

In the United States, various systems of carbon trading are at different stages of evolvement [35]. These trades can be either by private negotiations or by formal exchange mechanisms like "Cash Market", "Futures Market", and "Auction". Trading in Cash Market is similar to commodity cash market and Chicago Climate Exchange claims to be claims to be North America's only and the world's first global market place, which is launched in 2003 (Source: Chicago Climate Exchange). The Chicago Climate Futures Exchange (a subsidiary of Chicago Climate Exchange) offers standardized and cleared future contracts on emission allowances (Source: Chicago Climate Futures Exchange). In Auction type, the World Green Exchange (launched by World Energy Exchange) brings together buyers and sellers of carbon credits by holding auctions (Source: World Green Exchange).

In countries like India, World Bank's Bio Carbon Fund has signed an agreement to buy 0.276 million tones of CO_2 equivalent to emission reduction between 2008 and 2017. With this, small and marginal farmers would be able to earn additional income by selling carbon credits to World Bank [13]. Farmers will have to sell the carbon credits by planting trees on their degraded lands. As part of this agreement, 2,800 farmers will have to establish plantations in 3,500 hectares of dry and waste lands.

There are several constraints that are preventing farmers from taking full advantage of growing carbon markets. Some of these obstacles include; uncertainty in the flow of benefit potential, high transaction costs, disputes over the ownership of emission reductions, poor governance, lack of knowledge regarding carbon markets etc. So, certain standards and specifications needs to be established a) for facilitating efficient transaction of carbon credits b) for measurable and verifiable claim of carbon credits ownership c) for precise quantification/ monitoring of carbon being sequestered through various mitigation practices.

It is also very important to have clear communication system that equips farmers with all the necessary information regarding carbon markets, opportunities for mitigation, incentives they may receive from mitigation, how to minimize financial risks especially if they have to make a trade-off between their agricultural income and expected cash returns from mitigation, conflict resolution systems that assist farmers with disputes related to carbon credits ownership etc.

Conclusions

Agriculture is one of the largest sources of anthropogenic GHG emissions. GHGs mitigation is a daunting task ahead globally. In this context, low carbon farming and its practices assume significance. Carbon offset payments offer scope for empowering farmers and also contribute to low carbon society. Agricultural practices that result in reduced GHGs while not compromising food security needs to devised and adopted. Proper certification of low carbon technologies is an important step in this direction and hence precise standards are to be used. These standards are to be used for certifying in all areas of low carbon farming such as nutrient management, soil and grassland management and livestock management etc. Apart from mitigation of GHGs and global warming; low carbon farming or climate smart agriculture could also empower farmers and provide tangible benefits in the form of carbon offset payments, enhanced soil fertility, carbon sequestration, overall improvement of soil health, practices that enhance water use efficiency, better crop varieties, minimization of losses related to soil erosion & high inputs etc.

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