*Review Article*

Carbon Neutrality in Agriculture for Sustainable Strategies for Climate resilience

.

ABSTRACT

|  |
| --- |
| The majority of non-CO2 emissions of agriculture includes methane (54%), nitrous oxide (28%) and carbon dioxide (18%) which collectively account for 12% of the world's yearly greenhouse gas (GHG) emissions (7.1 Gt CO2 equivalent). Agriculture serves a major role in climate change. Agricultural practices addressing emissions of Greenhouse Gas emissions. Conventional farming use in synthetic fertilizers. Deforestation and soil degradation are examples of inappropriate land use practices that lower the amount of organic matter in soil. The inappropriate carbon footprint of agriculture is a result of these activities as well as the wasteful use of inputs like water. carbon-neutral methods that reduce greenhouse gas emissions from the production of crops and livestock and agricultural rice, enteric fermentation, manure.  These include switching to alternative rice farming techniques, using technologies for managing nitrogen fertilizers, decarbonizing on-farm energy use, and developing feeding and breeding strategies that lower enteric methane. When taken as a whole, these actions can cut agricultural GHG emissions by as much as 45%. However, to achieve net-zero agriculture, carbon dioxide removal technology offsets will be needed to balance residual emissions of 3.8 Gt CO2 equivalent year. Bioenergy with improved carbon collection and storage. Greenhouse Gas emissions profoundly influenced by its effects. We provide an overview of inventions and technology aimed at lowering greenhouse gas emissions from agriculture. |

***Keywords: [ Carbon neutrality, Carbon sequestration. Climate change. Greenhouse gas emissions , Conservation agriculture }***

1. INTRODUCTION

Indian agriculture is transformed due the Green revolutions and White revolutions local market to the global market which benefits to all consumers in world (Bawa and Seidler 2023). The agriculture productivity of rice and wheat may be increase with a 208% and 109% increase for wheat and rice respectively (Pingali 2012).

The exploitation of nitrogen fertilizer significantly improved agricultural productivity. Current agricultural practices contribute significantly to greenhouse gas emission. GHG emissions Contributes agriculture activity in direct and indirect activities accounts 30% total global anthropogenic activity GHG emissions (Skinner *et a*l. 2019).Nitrous oxide (N2O) and methane contributes to 60 % and 50% (P. Kumar *et al*. 2020). Soil organic carbon play crucial role in reduce the emissions of GHGs and mitigate climate change . Soil organic carbon important factor to maintain soil health and improve the physical , chemical and biological properties .

The main contribution of global agricultural GHG emissions is CH4 from livestock enteric fermentation and rice cultivation whereas N2O is mostly attributed to the application of N-fertilizer. Also the biomass burning of savannah, forest and crop residues contributes to both CH4 and N2O emissions (Burney *et al*. 2010).The excessive use of nitrogen (N) fertilizer led to a significant increase in agricultural productivity, the current agricultural activities emit large amounts of GHG.Concerns over climate change has increased globally as a result of the rise in atmospheric GHG levels.Environmental disasters including widespread flooding, protracted droughts, and destructive wildfires have been brought on by the significant changes in the global climate brought about by the increase in GHG emissions through the past many years.Humans rely significantly on agriculture for their survival, especially in an agrarian nation like India, where over half of the populations works in the field, while 58% Many rural households rely on it to survive(Eliazer Nelson *et al.* 2019; Chand 2022). The intergovernmental panel on Climate Change (IPCC) as reported by the global mean surface temperature has rise 0.6 oC since 1861and further increase of 1.1 to 6.4 oC is expected by 2100(IPCC 2007). The global carbon cycle soil play crucial role in Carbon budget because they contain more carbon than atmosphere and plant (Wang *et al.* 2010).Terrestrial carbon is 75% in earth in top one meter of soil depth. Integrated nutrient management of soil have potential to sequester more carbon. Efficient use of pesticides, irrigation , fertilizers and farm machinery. Soil and crop management is play a significant role for sustainable agriculture development Lal (2008)

**2 Role of Global carbon cycle and carbon pool**

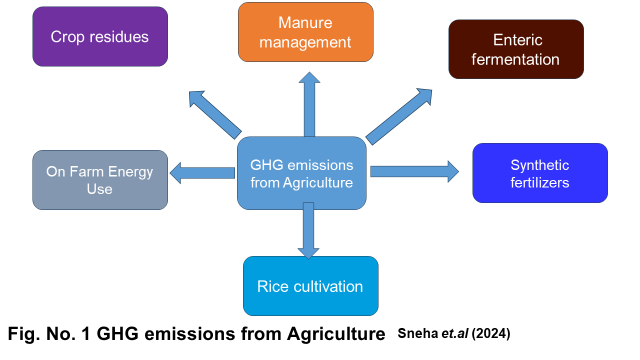
Carbon cycle knowledge it essential for the mitigating climate change strategies. The day by day increase the atmosphere CO2  due to the anthropogenic activities. The interaction carbon pools is biochemical and climate process. The carbon is stored following pools. *Viz.* oceanic pools (3800 Pg), geological pools(5000Pg), pedological pool (2500 Pg), atmospheric pool(760 Pg) and biotic pool (560 Pg) (Lal 2011).

**3.Soil carbon Storage facts**

Carbon is play crucial role in the earth. It is the building block for life on the earth and movements through the atmosphere, oceans, plants and soils. Pool of Carbon is major store house large amount of carbon. It is the movement of carbon between these carbon pools is called a flux.

**4.Concept of Carbon Neutrality**

Carbon Neutral farming is aims to balance the carbon emissions produced by farming activities with equivalent carbon removals or sequestration, resulting in net – zero carbon footprint (Sneha *et al* 2024).



**Carbon emission in agriculture**

GHG emissions are significantly influenced by agriculture because of a variety of agricultural activities. GHGs in agriculture are caused by methane emissions from rice crops, enteric fermentation, livestock manure management emissions, burning agricultural residue, changes in land use, emissions from fossil fuels, and nutrient management that lacks scientific knowledge. The emissions from enteric, manure and pasture are 4.2 Gt CO2-eq year-1, whereas the unbalanced inorganic fertilizers are 3.6 Gt CO2-eq year-1 and the changes in land use are 3.3 Gt CO2-eq year-1(Poore, J)

**Share in Emissions of GHG in India**

In 2020 India GHG emissions energy sector reached 75.66% and agriculture 13.75%, Industries 8.08%, waste 2.56%. Electricity play major role in the emissions of GHG it contributes half of on farm energy are the electricity (0.46 Gt CO2 -eq per year) and remaining half are use the fuel in farm operation combustions (0.53 Gt CO2 -eq per year) FAOSTAT (2023) and Flammini A *et.al*(2022). .The energy is required non - renewable source of coal emission of GHG, second emission of agriculture is due to injudicious use of fertilizers, rice production Enteric fermentation and Manure management. Use of the renewable source of such as solar energy, wind power, ocean energy are regarded most important and efficient use to achieve C neutrality Wang F. *et.al* (2021). C neutrality help to reduce the emissions of GHG in the atmosphere and climate change. Conservation agriculture practices sequestration of atmospheric carbon to the soil. Global anthropogenic (GHG) emissions of food production systems contribute 16.5 GtCO2 e year−1 from a total 54 GtCO2 e year Crippa, M. *et al*.(2021) and FAO (2022). Synthetic nitrogen fertilizer contribute 8.3% of farm gate emissions in FAO (2019).

**Impact of agrochemicals on carbon emissions**

Agriculture use of agrochemical is increasing after the green revolution. Various agrochemical use like fertilizers, pesticides, fungicides, herbicides (fig. 1). The transportation and packaging of agrochemical required energy and GHG emissions ( Bhat *et.al.* 1994). Fertilizer is the one of the crucial factor impact on Carbon footprint Iriarte, A ( 2010) and Gasol, C.M *et.al* (2012)

**Crop residue burning**

India generates large quantity crop residue 500-550 million tonnes after harvest. Each year , approximately 90-140 million tonnes of these residues are burned on farms , primary to clear fields for the next planting season.this [ractice significantly contributes to carbon dioxide emissions from agriculture S.K et.al(2011).

**Carbon dioxide emissions**

In agriculture CO2 released due to the soil microorganism respirations or crop residue burning (Bairwa *et al*., 2020; Janzen 2004).

**Mitigating GHGs Emission from Indian Agriculture**

Agriculture can significantly reduce greenhouse gas emissions by implementing low -carbon technologies sand sustainable practices. The following three approaches for mitigating GHGs

**Avoiding emissions:**

Use crop residues from agricultural lands as fuel directly or after they are converted to fuels like diesel or ethanol. Upon combustion, these bioenergy feedstocks will also release carbon dioxide (CO2), but this carbon will now come from recent atmospheric processes (photosynthesis) rather than fossil fuels. These bioenergy sources' net contribution to the atmosphere is equal to the emissions of fossil fuels that are eliminated, less any emissions that occur during processing, transportation, or manufacturing. By using agricultural management techniques that prevent the cultivation of new lands that are currently covered by forest, grassland, or other non-agricultural vegetation, greenhouse gas emissions, particularly CO2, can also be prevented.

**Enhancement of removals:**

Agriculture soil store significant carbon reserves, primarily in soil organic matter. However, these systems have lost a substantial amount of carbon over time, through some can be restored through better management practices . Approach that enhances photosynthesis carbon input contributes to carbon sequestration.

**Reduction in emissions**:

The efficient management of carbon and nitrogen flows in the agriculture is reduce the flux of CO2 , CH4 and N2 O. Optimum use of nitrogen fertilizers is reduce the emissions of N2 O it helps to increase the nitrogen use efficiency. The nitrogen fertilizers can available in both cation and anion form , the anion form of fertilizer leaching loss is more than the cation form because the anion exchange capacity of soil is less . emission of nitrogen fertilizer also depend on climatic factors ,humid climate leaching losses high.

Reducing greenhouse gas emissions from agriculture can be accomplished by storing carbon in the soil and nitrous oxide emissions through improve land use management. Incorporating more perennial plants or those with deep root systems into crop rotations enhances carbon storage in the soil.

**Mitigation of methane emission from rice fields**

Rice cultivation emissions of methane from rice crop due to anaerobic conditions. The global emissions of methane in rice from 31 to 280 Tg y-1 . India rice farming contributes methane emissions 97 Mt CO2 -eq FAO (2017). Reduce methane emissions from rice cultivation various strategies use. These are improving organic matter management by aerobic degradation of composting. Potential to reduce the methane emission use system of rice intensification (SRI) and Direct -seeding of rice . The DSR and SRI use alternate irrigations that do not require continuous soil submergence, it help reduce the methane emission.

**Mitigation of nitrous oxide emission**

Nitrous oxide emissions is reduce nitrogen use efficiency Patak .H. (1999). Leaching of nitrate is the main source of emissions of nitrous oxide. Site specific nutrient management and use of nitrification inhibitors helps to reduce the emission of nitrous oxide.

**Table 1. Tillage operations and average C emission**

|  |  |  |
| --- | --- | --- |
| **Tillage operation** | **Equivalent carbon emission (kg CE/ ha)** | |
| **Range** | **Mean SD** |
| Mouldboard ploughing | 13.4- 20.1 | 15.2±4.1 |
| Chisel ploughing | 4.5-11.1 | 17.9±2.3 |
| Heavy tandem disking | 4.6-11.2 | 8.3±2.5 |
| Standard tandem disking | 4.0- 7.1 | 5.8±1.7 |
| Sub-soiler | 8.5- 14.1 | 11.3±2.8 |
| Field cultivation | 3.02-8.6 | 4.0±1.8 |
| Rotary hoeing | 1.2- 2.9 | 2.0±0.9 |

**Source: Lal 2004 b**

Tillage is defined as the mechanical manipulation of soil with tools and implement result in good tilth. Tillage field operations which required fossil fuel consumption it emission CO2 .Tillage is the various operation *viz.* primary tillage and secondary, Primary tillage include preparations of land in ploughing and secondary harrowing, seedbed preaparation. The Mouldboard ploughing CO2 emissions highest followed by subsoiler Table 1. Ploughing is requirement varies with depth of ploughing ,operation, type of soil, (Schrock *et.al*.1985, Bowers 1989, Rautare 2003)

**Table No. 2. Different Conservation methods for carbon sequestration**

|  |  |
| --- | --- |
| **Conservation method** | **Characteristics** |
| Plant selection | Species cultivar variety,  Growth habits  Rotation sequence  Biomass energy crops |
| Tillage | Types and frequency |
| Fertilizer | Rate, timing, placement  Organic amendments |
| Integrated management | Pest control  Crop/ livestock systems |

Source: Franzluebbers (2008)

Conservations Agriculture

Conservation agriculture is the optimal utilization of resource and efficient use of technologies to save and conserve the natural resources to conserving environment. Principle of conservation agriculture can be stated three main processes as described by FAO.

1. Minimal soil disturbance : disturbed area must be less than 15 cm wide or 25% of cropped area. No periodic tillage that disturbs a greater area then aforementioned limits.

Soil cover: Ground cover must be more than 30%.

3. Crop Rotation : Rotations should involves at least three different crops.

Forms of conservation agriculture

Major forms of conservation agriculture includes

* Minimum , reduced or no tillage
* Crop rotation
* Strip cropping
* Green manuring
* Erosion control
* Stubble mulching
* Integrated nutrient management
* Integrated pest management
* Irrigation management
* Cover cropping

Conservation agriculture crucial management practice in agriculture because with play importance role in maintain the carbon into the soil. SOC is the essential to regulates the physical , chemical and biological properties of soil. CA help to reduce the loss of organic carbon . various management approaches to sequester carbon to atmosphere to biosphere are suggested by Frazlubbers (2008) maximum utilizations table 2.

Land preparation various operation carried out that primary C emission is mobile tillage operation are tillage sowing, intercultural, harvesting , and transportation and stationary operations pumping, grain drying, secondary source of the C emissions are packaging, storing fertilizers and pesticides. Tertiary source of C emission farm building. More fuel use used in the transportations this requires significantly energy which increase the GHGs emissions ( Vlek *et.al*. 2003, Chauhan *et.al*. 2005, Maraseni *et.al*. 2010 a,b, Maraseni and Cockfield 2011 )

**Table.No. 3 Averge net carbon flux with changes in tillage practices**

|  |  |  |
| --- | --- | --- |
|  | **Conventional tillage**  **(kg C/ha/year)** | **No tillage**  **(kg C/ha/year)** |
| C emission from soil | 0 | -337 |
| C emission from farm machinery | +69 | +23 |
| C emission from Agril. Inputs | +99 | +114 |
| Net C flux | +168 | -200 |
| Relative C flux | 0 | -368 |

Source: (West and marland 2002)

Cultivation of climate resilient crops

Use the climate resilient and low carbon footprint crop such as millets and tuber, The wheat and rice are the low carbon footprint of 3218 kg CO2 equivalent ha-1  , as against 3968 kg and 3401 kg for wheat and rice respectively Tiwari H (2022). Cassava plant have potential to C sequestration and mitigation of GHG by Jonh *et.al.* (2014). Crop has the ability to sustain the and yield give without application of manure and fertilizer in long term fertilizer experiment 20 years such crops attributes the climate resilent and C sequestrations.

**Table 4. Adaptation options for climate change in Indian agriculture and their co benefits for mitigation.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Option** | **Description** | **Adaptation Benefits** | **Mitigation Co-benefits** |
| Climate resilient crop varieties | Crop varieties tolerant to drought, flood and heat; of shorter duration with high yield | •Increased and stable production  •Saving of water and energy  •Increased income | •Reduce GHG due to shorter duration  •Reduced in CO2 with less energy-use for irrigation |
| Water-saving technologies | Drip and sprinkler, Laser-aided land leveling, Fertigation | •Saving of water  •Increased nutrient use efficiency  •Increased production income | •Reduced CO2 due to less water-use  •Reduced N2O with increased N-efficiency •Reduced CH4 with no submergence in rice cultivation |
| Changing planting date | Adjusting planting dates to avoid heat stress during flowering and maturity | •Reduced yield loss  •Less water-use and energy-use | Reduced CO2 with less energy-use for irrigation |
| Integrated farming system | Inclusion of crop, livestock and fishery to improve livelihood | •Increased farm income  •Livelihood security | Reduced GHGs because efficient use of agriculture inputs |
| Crop diversification | Growing suitable crops to adjust the adverse climate | •Less water and energy use  Increased stable production | Reduced CO2 with less energy-use for irrigation |
| Integrated  pest management | Combining physical, chemical and biological methods of pest management | Increased yield with reduced loss due to pest infestations | Reduced CO2 with less energy-use for pesticide manufacturing |
| Organic farming | Use of organic sources of nutrients Avoiding use of chemical pesticides | Less energy requirement  Improved soil health | Reduced CO2 with less energy-use for pesticide and fertilizer manufacturing  C sequestration |
| Conservation agriculture | Zero tillage Crop rotation Residue cover of soil | Less energy and water requirement  Improved soil health | Reduced GHGs because of conservation and efficient use of agri inputs  C sequestration |
| Precision farming | Precise and site-specific management of agri inputs | Increased input use efficiency  Increased yield | Reduced GHGs because of efficient use of agri inputs |
| Use of efficient microbes | Use of microbes for enhancing soil fertility and crop productivity | Improved soil health Increased yields | Reduced CH4 and N2O  C sequestration |
| Waste land management | Developing wastelands for forestry, agro forestry, grassland and crop production with improved water and nutrient management | Increased production  Livelihood security  Improved soil health increased income | Carbon sequestration |
| Improved weather-based agro-advisory | Forecasting of weather, particularly extreme events for crop management planning | •Reduced risk  • Increased and stable production | \_\_\_\_\_\_\_ |
| Intercropping/mixed cropping | Growing more than one crop to increase productivity and avoid crop failure | Increased nutrient use efficiency  Increased farm income | Reduced N2O and CO2 per unit production |
| Use of non conventional energy | Use of solar and wind energy to substitute fossil fuel-based conventional energy sources | Reduced dependence on imports  Increased farm income | Reduced CO2 with lesser use of fossil fuel |
| Use of biofuel | Use of biofuel from non edible crops and crop residues in conjunction with fossil fuel | Reduced dependence on fossil fuel  Increased farm income | Reduced CO2 with lesser use of fossil fuel  C sequestration with growing of perennial non-edible crops |

Source: Pathak *et al.* (2014)

**Conservation tillage and carbon sequestration**

The reduction of on farm emission zero tillage is important zas compare to the conventional method . Vanden Bygaart *et al.* (2003) found that reduced tillage increases the amount of carbon sequestered by an average of 320-150 kg C/ha in 35 studies of western Canada and that the removal of fallow enhanced soil carbon storage by 150-60 kg C/ha based on 19 Studies. West and Marland (2002) reported that carbon 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 CO2 emission from agricultural machinery. Thus, there was 67.70% and 65.41% reduction in CO2 emission as compared to conventional tillage for corn and soybean cultivation respectively.

Conclusion

Agriculture significantly impacts the environment and practicing conservation agriculture and other resource conservation technologies can play a significant role in SOC sequestration by increasing soil carbon sinks, reducing GHG emissions, and sustaining agricultural productivity at higher level. Rate and amount of SOC sequestration differ with soil types, depths; land use and landcover and varies from one region to another. Sequestration of carbon in soil can improve soil health and improvement in soil health will help in improving input use efficiency in agriculture. Thus sequestering carbon in soil and biota can mitigate climate change

**References**

*Aulakh MS, Wassmann R, Rennenberg H.. Methane transport capacity of twenty-two rice cultivars from five major Asian rice-growing countries. Agric Ecosyst Environ 2002;91:59–71.*

Bawa KS, Seidler R (2023) Sustainable pathways toward reimagining India’s agricultural systems. Commun Earth Environ 4(1):262.

Bowers C G. 1989. Tillage draft and energy measurements for twelve southeastern soil series. *Trans ASAE* **32:** 1 492–502.

Bairwa, R., Mamta, D. L. D., & Bagoria, N. (2020). In-situ trash management induced sustainability of soil health to produce the qualitative products. *Journal Homepage URL*, 5(2), 249–254

Poore, J., and Nemecek, T. (2018). Reducing food’s environmental impacts through producers and consumers. *Science* **360**, 987–992

Crippa, M. et al. Food systems are responsible for a third of global anthropogenic GHG emissions. *Nat. Food* ***2****, 198–209. https:// doi.org/10.1038/s43016-021-00225-9 (2021).*

FAO. (2022) FAOSTAT Emission Shares dataset. http://fenix.fao.org/faostat/internal/en/#data/EM, Downloaded on 11-03-2022. FAO

FAO [Food and Agriculture Organization]. FAOSTAT-Agricultural Emissions; 2017.

FAO.(2019) Emissions from agriculture and forest land. Global, regional and country trends 1990–2019. FAOSTAT *Analytical Brief 25.*

FAOSTAT 2023 Climate change: Agrifood systems emissions

Lal R. 2004b. Carbon emission from farm operations. *Environment International* **30**: 981–90.

Wang .F.*et.al* (2021) Technologies and perspectives for achieving carbon neutrality. Innovation (Camb). 2021 Oct 30;2(4):100180.

Bhat M.G, English B C, Turhollow A F, Nyangito H O. 1994. Energy in synthetic fertilizers and pesticides: Revisted. Oak Ridge National Labroratory, Oak Ridge, Tennessee.

Franzluebbers A J. 2008. Soil organic carbon sequestration with conservation agriculture in the southeastern USA : potential and limitations. *http//www.fao.org/ ag/ca/carbon Offset Consultations/ Carbonme, accessed on 22.02..2012.:1-11.*

Iriarte, A.; Rieradevall, J.; Gabarrell, X(2010). Life cycle assessment of sunflower and rapeseed as energy crops under Chilean conditions. J. Clean. Prod. **18,** 336–345

Flammini A, Pan X, Tubiello F N, Qiu S Y, Rocha Souza L, Quadrelli R, Bracco S, Benoit P and Sims R 2022 Emissions of greenhouse gases from energy use in agriculture, forestry and fisheries: 1970–2019 *Earth Syst. Sci*. Data **14** 811–21

Gasol, C.M.; Salvia, J.; Serra, J.; Antón, A.; Sevigne, E.; Rieradevall, J.; Gabarrell, X (2012). A life cycle assessment of biodiesel production from winter rape grown in Southern Europe. Biomass Bioenergy **40**, 71–81.

Janzen, H. H. (2004). Carbon cycling in earth systems—A soil science perspective*. Agriculture, Ecosystems & Environment*, 104(3), 399–417.

John KS, Beegum, SUS, Ravi V2014.. Management of waste lands by exploiting the carbon sequestration potential and climate resilience of Cassava. J Root Crops. 2014;40:28-32.

Rautray S K. 2003. Mechanization of rice-wheat cropping systemfor increasing the productivity. *Annual Report* – *Rice-WheatConsortium, CIAE, Bhopal*.

Schrock M D, Kramer J K and Clark S J. 1985. Fuel requirementsfor field operations in Kansas. *Transactions of the AmericanSociety of Agricultural Engineers* **28**: 669–874.

Sharma SK, Choudhary A, Sarkar P, Biswas S, Singh A, Dadhich PK. (2011) Greenhouse gas inventory estimates for *India Curr Sci*. 2011;101:405-415.

Pathak H, Bhatia A and Jain N (2014) Greenhouse Gas Emission from Indian Agriculture: Trends, Mitigation and Policy Needs. *Indian Agricultural Research Institute*, New Delhi - 110012, p39.

Pathak,H.,(1999) Emissions of nitrous oxide from soils. Curr. Sci.,  
 **77**, 359–369

Vlek P, Rodriguez- khul G and Sommer R. L.2003. Energy use and CO2 production in tropical agriculture and means and strategies for reduction and mitigsation. *Environment Development and sustauinability* **6**: 213-33.

Chauhan N S, Mohapatra P K, and Pandey P K, 2005 . Improving energy productivity in paddy production through benchmarking an application of data envelopment analysis. Energy Conversion and Management **47** : 1063-85.

Maraseni T N, Cockfield G and Maroulis J. 2010a. An assessment of greenhouse emissions: Implications for the Australian cotton industry. *Journal of Agriculture Science* **148**: 501-10

Maraseni T N, Cockfield G and Maroulis J. 2010b An assessment of greenhouse emissions from the Australian vegetables industry. *Journal of Environmental Science and Health* part B **45**: 578-88.

Maraseni T N and Cockfield G. 2011. Does the adoption of zero tillage reduce greenhouse gas emissions an assessment for the grains industry in Australia. *Agricultural Systems* **104** :451-8.

Tiwari H, Naresh RK, Kumar L, Kattaria SK, Tewari S, Saini A, et al 2022. Millets for food and nutritional security for small and marginal farmers of north west india in the context of climate change: A review. *Int J Plant Soil Sci*. 2022;34(23):1694-1705.

Sneha S.R., Rajasree G. and Shalini Pillai.P.(2024). International Journal of Environment and Climate Change,vol.14, pp.458-472.

Skinner C, Gattinger A, Krauss M, Krause H-M, Mayer J, Van Der Heijden MGA, Mäder P (2019) The impact of long-term organic farming on soil-derived greenhouse gas emissions. *Sci Rep* 9(1):1702

West T O and Marland G. 2002. A synthesis of carbon sequestration,carbon emissions, and net carbon flux in agriculture: comparingtillage practices in the United States. *Journal of Agriculture,Ecosystems and Environment* **91**: 217–32.

West TO, Marland G. A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States. Agric Ecosyst Environ. 2002;91(1-3):217–232.

Vanden Bygaart A J, Gregorich E G and Angers D A. 2003. Influence of agricultural management on soil organic carbon: a compendium and assessment of Canadian studies*Canadian Journal of Soil Science* volume 83