Carbon sequestration through carbon farming to earn carbon credit

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Abstract

Carbon farming involves a single change in land management, such as zero tillage, agroforestry, methane-reducing feed supplements or stubble retention which maximizes capture of carbon and reduction of emissions. In carbon farming, the amounts of CO_2, CH_4, and N_2O will be reduced with increasing C sinks in soil because of increased soil aeration from organic carbon addition which reduces denitrification and increases sink capacity for CH_4. Soil organic carbon adds electron acceptors and increases redox-potential of soils to decrease N_2O source capacity of soil. Carbon farming induces microbial immobilization of available N_2 in soil, which also decreases the N_2O source capacity of soil. Carbon farming is successful when the gain of carbon resulting from enhanced land management and/or conservation practices exceeds the carbon losses. The benefits include green house gas reduction, carbon sequestration, increased biodiversity, buffering against drought and greater water use efficiency. Development of different programs will facilitate the buying and selling of carbon credits between landholders and Government agencies. Landholders receive carbon credits for storing carbon in the soil which are assembled and sold when planned to reduce emissions. These credits are often bought independently of an exchange, and can boost the financial status of the client, and help to demonstrate that the practices are helpful in mitigating the effects of the industrial society.

Introduction

Carbon farming describes a collection of eco-friendly techniques that have the ability to increase carbon sink into the soil *i.e., carbon sequestration*. Increasing the C sink in soil will help to reduce the amounts of CO_2, CH_4, and N_2O emission in environment. Carbon farming leads to reduction in greenhouse gas emissions is referred to as *abatement* activities. It holds carbon in vegetation and soils, and reduces greenhouse gas emissions. A carbon offset credit is a payment made by an emitter of carbon (a power plant, mine, oil refinery *etc.*) to the developer or owner of a carbon sequestration process (owner of a forest reserve, biochar project developer *etc.*). In carbon farming, there are some promising options that reduce greenhouse gas emissions; storage of carbon in soils and degraded rangelands through forests tree plantings and regrowth, carbon storage through incorporation of biochar which is carbon negative, substitution of biofuels for fossil fuels. Carbon farming provides land managers an opportunity to earn carbon credits through carbon storing or reducing greenhouse gas emissions on their own land. The emissions can be offset by selling the carbon credits to the Government nominated authority. Actually carbon farming is a voluntary carbon offsets scheme that provides economic rewards to landholders willing to reduce greenhouse gas emissions. Carbon farming reduces emissions by *sequestration*, where carbon is stored on the land, and *emissions avoidance*, which prevents the greenhouse gas emissions from entering the atmosphere. It involves implementing practices that improve the rate at which CO_2 is removed from the atmosphere and converted to plant material and/or soil organic matter.

Carbon farming

The phrase 'carbon farming' means using farming methods that reduce greenhouse gas emissions, and/or capture and hold carbon in vegetation and soils. Carbon farming can cover small changes in land management – like introducing no-till cropping, stubble retention, agroforestry, or methane-reducing feed supplements. At the other end of the scale, it can mean developing an integrated whole farm plan to reduce emissions and maximize carbon capture. It includes those activities that can earn Indian carbon credit units through the emissions reduction fund. Land management is the second largest contributor to carbon dioxide emissions on planet earth. Agriculture is the one sector that has the ability to transform from a net emitter of CO_2 to a net sequesterer of CO_2-there is no other human managed realm with this potential. Common agricultural practices, including driving a tractor, tilling the soil, over-grazing, using fossil fuel based fertilizers and pesticides result in significant carbon dioxide release. Alternatively, carbon can be stored long term (decades to centuries or more) beneficially in soils in a process called soil carbon sequestration. Carbon Farming involves implementing practices that are known to improve the rate at which CO_2 is removed from the atmosphere and converted to plant material and/or soil organic matter. Carbon farming is successful when carbon gains resulting from enhanced land management and/or conservation practices exceed carbon losses.

Carbon credit

International treaties have set quotas on the amount of GHG countries can produce, which in turn set quotas for businesses. Instruments like carbon credits and carbon offset were introduced in order to improve the scenario by encouraging firms to be more environment friendly in conducting their business. One carbon credit allows one tonne of carbon dioxide or a corresponding amount of other greenhouse gases to be discharged in the air. Businesses that are over their quotas must buy carbon credits for excess emissions, while those below can sell their remaining credits. This exchange of credits between businesses has encouraged carbon trading globally. These credits can be exchanged between businesses or bought and sold in international markets at prevailing market price at two exchanges, namely the Chicago Climate Exchange and the European Climate Exchange. The Multi-Commodity Exchange of India (MCX) may soon become the third exchange in the world to trade in carbon credits. The amount of global emissions can be controlled through the buying and selling of carbon credits in the carbon trading method. It is quite simple and convenient to purchase carbon credits from a number of firms, just like any other monetary instrument, as they are traded in an open market. Carbon trading is used when the company's emissions exceed its quota of carbon credits, forcing it to purchase credits from other companies which have spare carbon credits. As a result, the worldwide carbon emissions stay within permissible levels, and the companies come up with ecologically sustainable ways of conducting business. The system also motivates the organizations to be more eco friendly so that they can increase their earnings by selling carbon credits. As carbon credits are freely traded in the market, they make it very easy for businesses to follow the system. In the present scenario, the market of carbon credits has a direct impact on the firm's financial analysis. This has caused firms to actively seek ways to decrease their emissions and adopt cleaner ways of doing business. Thus, the whole system motivates companies and governments to promote environment friendly processes that reduce greenhouse gas emission. Carbon trading, also referred as emissions transacting, it is a joint effort designed to limit the amount of carbon that businesses, organizations and other entities produce over a specific period of time. The ones who are selling are companies that use clean technology and those buying are the world's polluters. In future, the menace of global warming can be effectively handled by this system.

Win-win carbon farming practices

The following practices, which relate to soils, livestock, trees, fertilizer and energy use, can be integrated into existing farming systems to increase soil organic carbon and enhance productivity.

Soils

Applying the practices below can help increase soil health by improving soil structure, reducing losses of carbon and nitrogen from the soil, and building soil organic matter. Improving nitrogen use efficiency and growing better pastures and crops can have direct financial benefits to farm businesses.

- Use conservation tillage and controlled traffic techniques in cropping operations.
- Avoid burning crop residues and retain prunings and stubble where practical.
- If cultivation is absolutely necessary, do not till excessively wet or dry soils.
- Avoid periods of bare fallow and ensure continuous plant cover where possible.
- Manage irrigation and soil drainage to reduce water logging.
- Rotate crops and include rotations of perennial pastures and legumes.
- Add composted material where practical.
- Manage soil structure to maximize plant uptake and minimize nitrogen loss (*e.g.* use gypsum on sodic soils).
- Manage livestock waste (dung and urine) to minimize nitrous oxide emissions.
- Manage soil nutrient levels by choosing nutrient targets, completing a nutrient budget to determine fertilizer requirements, match nutrients to the nitrogen input and hence maintain those targets.
- Don't overgraze pastures. Keep sufficient groundcover throughout the year.
- Manage livestock movement/ paddock rotations to reduce compaction/ soil structure decline in overgrazed paddocks.

Livestock

Methane is a major inefficiency in animal production systems. 6% – 10% of livestock gross energy intake is lost as methane: the equivalent of up to 55– 60 days grazing intake for ewes and steers, and 40 days for dairy cows. Nitrogen is another area of loss: between 70% and 95% of nitrogen consumed by ruminants is excreted. If used effectively, it can improve pasture or crop growth instead of being lost to the atmosphere. The following practices can reduce these losses:

- Optimize feed quality (digestibility).
- Use and minimize nutrient excretion.
- Manage flock or herd performance through increased reproductive efficiencies, selective culling and genetic optimization to enable faster finishing and other practices such as early joining and early weaning.
- Use a genetic improvement program to increase reproductive rates and shorten finishing times.
- Manage livestock waste (dung and urine) to minimize nitrous oxide emissions.

Trees

Trees store carbon in their wood and litter, where it remains until the trees rot or are destroyed (*e.g.* by fire). When carefully integrated into farms, trees can increase farm productivity through soil and water conservation and as shelter to animals. Local landcare network may be able to help with understanding what grants and resources are available in an area.

- Identify areas for shelterbelts, woodlots or wildlife areas - they could be less productive or degraded areas, such as erosion gullies.
- Establish new tree plantations, with species selection and site preparation geared towards the best survival and growth.
- Consider woodlots with tree species that can be used on-farm (*e.g.* for fodder, fence posts, poles or firewood), making sure you don’t use any weed species.
- Encourage regeneration of native trees and shrubs, for example by fencing out established native vegetation.
- Protect existing native trees and shrubs from loss or damage.
- Research options for creating and trading carbon credits through the Carbon Farming Initiative.

Fertilizer

Applying nitrogen fertilizers more efficiently reduces nitrous oxide emissions and nitrate runoff into waterways and has direct financial benefits. You can save money, boost production and reduce emissions of nitrous oxide by using best management practices for the rates, sources, timings and placement of fertilizers.

- Match nitrogen supply to crop or pasture demand by soil and plant testing to assess nitrogen supply and using decision support tools and seasonal forecasts.
- Avoid high application rates of nitrogen in any single application.
- Avoid applying nitrogen fertilizers (especially nitrate) to waterlogged soils.
- Avoid tillage under wet conditions.
- Incorporate fertilizer at the top of raised beds or ridges to avoid wet areas.
- Choose the best source of nitrogen. In the wet season urea and DAP will lose less nitrate and nitrous oxide than nitrate based fertilizers.
- Place fertilizer below the soil surface where possible.
- Use an inhibitor coated fertilizer where possible – in summer to reduce ammonia loss and in winter to reduce nitrous oxide and nitrate leaching losses.

Energy

No matter what happens with carbon trading policy and legislation, farmers will be affected by rising energy costs. Farmers who increase their energy efficiency and find alternative, low cost sources of fuel, heat and electricity may ultimately become more profitable. Relatively easy and low cost changes can have big influence on reducing energy consumption.

- Improve irrigation efficiency to reduce energy demand from operating pumps through monitoring soil moisture.
- Insulate buildings, storage and refrigeration devices, and heating and cooling pipes.
- Use light coloured, heat reflective paint on roofs and walls.
- Maximize the use of natural light and ventilation in farm buildings.
- Explore options for alternative sources of energy and fuel, such as bio-energy, renewable sources, green power.

Low carbon farming (LCF) strategy

It supports sustainable farming by encouraging farmers to adopt practices that reduce/ minimize/ remove the use of synthetic fertilizers while, at the same time, improving soil carbon content. This is done through reduced tillage, anaerobic composting, using organic fertilizers, mulching, intercropping, multi-cropping, and a horde of techniques specially designed for particular regions, populations and climatic zones.

- Planting fuel, fodder and fruit trees, and protecting those that are already there on the farms.
- Planting multiple crops on the same field support biodiversity.
- Proper crop mixes, based on science and demonstrated results, promotes resilience by bringing about a balance in the farm ecology and reducing the risk of crop failures due to pest attack. Multiple cropping also reduces the risk exposure for farmers against erratic and spatial rainfall.

Opportunities in carbon farming

Carbon farming initiative is a voluntary carbon offsets scheme that provides economic rewards to farmers and landholders who take steps to reduce greenhouse gas emissions. Farmers and landholders can choose whether or not to be involved. Carbon farming activities that reduce greenhouse gas emissions are referred to as abatement activities. They reduce emissions by storing carbon in soil or plants (sequestration projects) or reducing emissions of carbon and other harmful greenhouse gases (emission reduction or avoidance projects). Under carbon farming initiatives scheme, they may be able to earn carbon credits from activities such as:

- reducing livestock emissions
- increasing efficiency of fertilizer use
- enhancing carbon in agricultural soil
- Storing carbon through re-vegetation and re-forestation

Carbon credit implication

Its goal is to stop the increase of carbon dioxide emissions. The Kyoto Protocol presents nations with the challenge of reducing greenhouse gases and storing more carbon. A nation that finds it hard to meet its target of reducing GHG could pay another nation to reduce emissions by an appropriate quantity. The carbon credit system was ratified in conjunction with the Kyoto Protocol. For example, if an environmentalist group plants enough trees to reduce emissions by one ton, the group will be awarded a credit. If a steel producer has an emissions quota of 10 tons, but is expecting to produce 11 tons, it could purchase this carbon credit from the environmental group. The carbon credit system looks to reduce emissions by having countries honor their emission quotas and offer incentives for being below them. Simply put, one carbon credit is equivalent to one tonne of carbon dioxide or its equivalent greenhouse gas (GHG).

Indian initiatives for environmental management

Comparing the globally placed carbon trade, India seems nowhere near. However, policy statement for abatement of pollution, 1992 by the Govt. favours the use of MBIs for pollution control, wherever feasible. In the recent years, compulsion to comply with Euro II emission norms is a very confident step towards controlling air pollution. It has now become essential for companies to make environmental considerations as a part of their business decision making. The enactment of the Information Technology Act, 2000 has enabled the industry to kick-start the use of electronic mode as a valid legal medium for carrying out its business operations which were until now done compulsorily on paper. This includes initiatives like MCA e-filing, Income Tax e-filing, SEBI Reporting and other electronic communications via, emails and video conferencing. According to industry estimates, Indian companies are expected to generate at least $8.5 billion at the going rate of $10 per tonne of CER (certified emission reduction). Tata Sponge Iron Ltd got a CDM (clean development mechanism) certificate from the UN for its waste heat recovery project in Orissa. Reliance Energy already has energy efficiency and process development CDM projects. It’s the need of the hour to think very seriously on reducing environment loss by religiously following & implementing and innovating techniques & ways to contain the same. This is a high time to call a revolution for reducing carbon footprint in order to preserve what’s left of the ozone layer, which is a protective layer between sun’s harsh ultra violet rays and the living beings. Otherwise, the day is not far when the world will be full of hunger; sun burnt, blind people, scary sounds and many more incurable diseases.

What we professionals can do?

India is still not a signatory to the Kyoto Protocol, which in a way, is a road-block for effectively carrying out environmental management by the industries. Currently companies like Jindal Stainless, Essar Steel, Hyderabad Chemicals, Paschim Hydro Energy P. Ltd, The Andhra Pradesh Paper Mills Ltd, have been making use of market based instruments like Carbon Credits in their businesses.

- The various industry Chambers like FICCI, ASSOCHAM, CII should take-up the issue of introducing market based instruments like Carbon Credits through a legal framework with the Government. These trade organizations can also come up with some award program to the companies which religiously follow the norms. Such award program will work as a motivating factor in the industry to adopt the norms suo-moto.
- Introduction of corporate-run carbon funds
- Introduction of Government-run carbon programmes.
- We should stress upon and make the company management aware of the benefits of such market based instruments
- Awards like 'Best Green Idea' for employees coming up with suggestions; ideas, ways, etc. should be introduced.
- Ask the management of our respective organizations to take help of the MBIs wherever feasible.
- Computer-based entrance tests for educational courses.
- Organizations can also come up with policies for reducing wastes like for encouragement of use of metal water bottle in the organization in place of plastic water bottles which is sanitary, easy to clean and is capable of being used over and over.
- Organizations can also encourage use of reusable lunch bags / cups etc. in their cafeteria / lunch rooms which helps in avoiding use of plastic / paper, use of hand towels in toilets and lunch rooms instead of paper towels and electric dryers.

Mitigation of green house gasses

Agricultural lands occupy 37% of the earth's land surface. Agriculture accounts for 52 and 84% of global anthropogenic methane and nitrous oxide emissions. Agricultural soils may also act as a sink or source for CO_2, but the net flux is small. Many agricultural practices can potentially mitigate greenhouse gas (GHG) emissions, the most prominent of which are improved cropland and grazing land management and restoration of degraded lands and cultivated organic soils. Lower, but still significant mitigation potential is provided by water and rice management, set-aside, land use change and agroforestry, livestock management and manure management. The global technical mitigation potential from agriculture (excluding fossil fuel offsets from biomass) by 2030, considering all gases, is estimated to be approximately 5500–6000 Mt CO_2-eq. yr^{-1}, with economic potentials of approximately 1500–1600, 2500–2700 and 4000–4300 Mt CO_2-eq. yr^{-1} at carbon prices of up to 20, up to 50 and up to 100 US$ t CO_2-eq.$^{-1}$, respectively. In addition, GHG emissions could be reduced by substitution of fossil fuels for energy production by agricultural feedstocks (*e.g.* crop residues, dung and dedicated energy crops). The economic mitigation potential of biomass energy from agriculture is estimated to be 640, 2240 and 16 000Mt CO_2-eq. yr^{-1} at 0–20, 0–50 and 0–100 US$ t CO_2-eq.$^{-1}$, respectively. Agricultural activities have a broad and multi-faceted impact on all three of the main GHGs-carbon dioxide, methane, and nitrous oxide and policies designed to mitigate GHGs must consider impacts on all three GHGs. Globally, land use (including agriculture) accounts for about one-third of all GHG emissions due to human activities.

Can ‘carbon farming’ sustainably reduce greenhouse gas emissions?

From the perspective of global climate change, soils are a major compartment within the planetary carbon cycle, the second-largest pool after the oceans, holding more carbon than the atmosphere and all vegetation combined. Soils aren’t necessarily climate neutral, depending on how they’re managed: they can release additional carbon into the atmosphere through practices like overgrazing and excessive plowing, or soak up atmospheric carbon through practices like agroforestry and conservation agriculture. But when run properly, farms can be powerful tools in the fight against climate change. Estimates of the “technical potential” of agricultural soils to absorb carbon range from 3 to 8 gigatons (billion metric tons) of CO_2 equivalent a year for 20 to 30 years, enough to close the gap between what is achievable with emissions reductions and what is necessary to stabilize the climate. If boosting soil organic matter used to just look like a good way to farm, in other words, building soil carbon now looks like a key to planetary survival. Advocates of carbon farming agree that carbon markets are only one of several necessary routes to building carbon storage in soils, however-just as carbon sequestration in soils is just one of an array of essential strategies for addressing global climate change.

Conclusion

Indian Government initiatives may allow the land managers to earn carbon credits by reducing greenhouse gas emissions and storing carbon in vegetation and soil through carbon farming. Besides this, it may also allow landholders to generate offset credits from activities that reduce emissions or sequester carbon. The huge emitters will be able to utilize credits generated through the carbon farming to meet their emission reduction targets. The production of biochar from farm wastes and their application in soils may offer financial and environmental benefits. Once environmental cost of carbon based greenhouse gas emission have been suitably internalized, we can expect effective market forces and price mechanism. Considering the urgent need to take action on climate change, it is recommended to include carbon farming in the portfolio of mitigation strategies. Thus, carbon farming may serve as a promising mitigation strategy deserving higher attention as many other geoengineering options.

My References

1. Das, S.K., 2014. Chemicals responsible for systemic acquired resistance in plant a critical review. Journal of atoms and molecules 4 (3), 45-51.
2. Das, S.K., Avasthe, R.K., Gopi, R., 2014. Vermiwash: Use in organic agriculture for improved crop production. Popular kheti 2 (4), 45-46.
3. Roy, A., Das, S.K., Tripathi, A.K., Singh, N.U., 2015. Biodiversity in North East India and their Conservation. Progressive Agriculture 15 (2), 182-189.
4. Barman, H., Roy, A., Das, S.K., 2015. Evaluation of plant products and antagonistic microbes against grey blight (*Pestalotiopsis theae*), a devastating pathogen of tea. African journal of microbiology research 9 (18), 1263-1267.
5. Das, S.K., 2014. Scope and relevance of using pesticide mixtures in crop protection: A critical review. International journal of environmental science and toxicology 2(5), 119-123.
6. Das, S.K., Mukherjee, I., Kumar, A., 2015. Effect of soil type and organic manure on adsorption-desorption of flubendiamide. Environmental monitoring and assessment 187 (7), 403.

7. Das, S.K., 2013. Mode of action of pesticides and the novel trends. A critical review. International research journal of agricultural science and soil science 3(11) 393-403.
8. Das, S.K., 2014. Recent development and future of botanical pesticides in India. Popular kheti 2 (2), 93-99.
9. Mate, C.J., Mukherjee, I., Das, S.K., 2014. Mobility of spiromesifen in packed soil columns under laboratory conditions. Environmental monitoring and assessment 186 (11), 7195-7202.
10. Das, S.K., Avasthe, R.K., Singh, M., Sharma, K., 2015. Biobeds: on-farm biopurification for environmental protection. Current science 109 (9), 1521-1521.
11. Das, S.K., Avasthe, R.K., 2015. Carbon farming and credit for mitigating greenhouse gases. Current science 109 (7), 1223.
12. Mukherjee, I., Das, S.K., Kumar, A., 2012. A Fast Method for Determination of Flubendiamide in Vegetables by Liquid Chromatography. Pesticide research journal 24 (2), 159-162.
13. Das, S.K., Avasthe, R.K., Singh, R., Babu, S., 2014. Biochar as carbon negative in carbon credit under changing climate. Current science 107 (7), 1090-1091.
14. Das, S.K., Mukherjee, I., 2011. Effect of light and pH on persistence of flubendiamide. Bulletin of environmental contamination toxicology 87, 292-296.
15. Das, S.K., Mukherjee, I., 2012. Effect of moisture and organic manure on persistence of flubendiamide in soil. Bulletin of environmental contamination toxicology 88, 515-520.
16. Das, S.K., Mukherjee, I., 2012. Dissipation of flubendiamide in/on Okra [*Abelmoschus esculenta (*L.) Moench] Fruits. Bulletin of environmental contamination toxicology 88, 381-384.
17. Das, S.K., Mukherjee, I., 2012. Flubendiamide transport through packed soil columns. Bulletin of environmental contamination toxicology 88: 229-233.
18. Das, S.K., Mukherjee, I., 2014. Influence of microbial community on degradation of flubendiamide in two Indian soils. Environmental monitoring and assessment, 186, 3213-3219.
19. Das, S.K., 2014. Role of micronutrient in rice cultivation and management strategy in organic agriculture-A reappraisal. Agricultural sciences 5 (09), 765.
20. Das, S.K., 2014. Recent developments in clean up techniques of pesticide residue analysis for toxicology study: a critical review. Universal journal of agricultural research 2 (6), 198-202.

21. Das, S.K., Mukherjee, I., 2017. Metsulfuron-methyl herbicide on dehydrogenase and acid phosphatase enzyme activity on three different soils. International journal of bio-resource and stress management 8 (2), 236-241.
22. Das, S.K., Roy, A., Barman, H., 2016. Fungi toxic efficiency of some plant volatile essential oils against plant pathogenic fungi. African journal of microbiology research 10 (37), 1581-1585.
23. Mukherjee, I., Das, S.K., Kumar, A., 2016. Degradation of flubendiamide as affected by elevated CO2, temperature, and carbon mineralization rate in soil. Environmental science and pollution research 23 (19), 19931-19939.
24. Das, S.K., Mukherjee, I., Roy, A., 2016. Alachlor and Metribuzin Herbicide on N_2-fixing Bacteria in a Sandy Loam soil. International journal of bio-resource and stress management 7 (2), 334-338.
25. Barman, H., Roy, A., Das, S.K., Singh, N.U., Dangi, D.K., Tripathi, A.K., 2016. Antifungal properties of some selected plant extracts against leaf blight (*Alternaria alternata*) in tomato. Research on Crops 17 (1), 151-156.
26. Das, S.K., Avasthe, R.K., Singh, M., 2015. Buckwheat: the natural enhancer in rhizosphere phosphorus. Current science 109 (10), 1763.
27. Mate, C.J., Mukherjee, I., Das, S.K., 2015. Persistence of spiromesifen in soil: influence of moisture, light, pH and organic amendment. Environmental monitoring and assessment 187 (2), 7.
28. Das, S.K., Mondal, T., 2014. Mode of action of herbicides and recent trends in development: a reappraisal. International journal of agricultural and soil science 2, 27-32.
29. Mukherjee, I., Das, S.K., Kumar, A., 2018. Atmospheric CO_2 level and temperature affect degradation of pretilachlor and butachlor in Indian soil. Bulletin of environmental contamination and toxicology 100 (6), 856-861.
30. Das, S.K., 2017. Rice cultivation under changing climate with mitigation practices: A mini review. Universal journal of agricultural research 5 (6), 333-337
31. Das, S.K., 2015. Acid sulphate soil: management strategy for soil health and productivity. Popular kheti 3 (2), 2-7.
32. Barman, H., Das, S.K., Roy, A., 2018. Zinc in soil environment for plant health and management strategy. Universal journal of agricultural research 6, 149-54.

33. Das, S.K., Avasthe, R.K., Yadav, A., 2017. Secondary and micronutrients: deficiency symptoms and management in organic farming. Innovative farming 2 (4), 209-211.
34. Das, S.K., Ghosh, G.K., 2017. Soil hydro-physical Environment as Influenced by Different Biochar Amendments. International journal of bio-resource and stress management 8 (5), 668-673.
35. Das, S.K., Mukherjee, I., Roy, A., 2017. Flubendiamide as new generation insecticide in plant toxicology: A policy paper. Advance in clinical toxicology 2, 100-122.
36. Das, S.K., 2015. Integrated nematode management in chickpea Against Meloidogyne incognita-a view point. Universal journal of agricultural research 5 (5), 145-149.
37. Das, S.K., 2019. Soil carbon sequestration strategies under organic production system: A policy decision. Agrica 8 (1), 1-6.
38. Das, S.K., 2019. Qualitative evaluation of fodder trees and grasses in hill region. Journal of krishi vigyan 7 (2), 276-279.
39. Das, S.K., Avasthe, R.K., Ghosh, G.K., 2019. *Solanum betaceum*: An Underutilized but potential tree species with anticancer activity. Bio-science research bulletin 35 (1), 36-37.
40. Roy, A., Das, A., Das, S.K., Datta, M., Datta, J., Tripathi, A.K., Singh, N.U., 2018. Impact analysis of National Agricultural Innovation Project (NAIP): A paradigm shift in income and consumption in Tripura. Green farming 9 (3), 559-564.
41. Das, S.K., Avasthe, R.K., Singh, M., Roy, A., 2018. Managing soil fertility under organic production system through integrated approach. Green farming 9 (3), 449-454.
42. Das, S.K., Mukherjee, I., 2018. Propesticides and their implications. Insecticides: agriculture and toxicology, 107.
43. Das, S.K., 2018. Microbial toxins as lead molecules: an overview. Popular agriculture 2(3), 1-3.
44. Das, S.K., Avasthe, R.K., 2018. Plant nutrition management strategy: A policy for optimum yield. Acta scientific agriculture 2 (5) 65-70.
45. Singh, N.S., Mukherjee, I., Das, S.K., Varghese, E., 2018. Leaching of clothianidin in two different Indian soils: Effect of organic amendment. Bulletin of environmental contamination and toxicology 100 (4), 553-559.
46. Das, S.K., Avasthe, R.K., Singh, M., Yadav, A., 2018. Soil health improvement using biochar application in Sikkim: A success story. Innovative farming 3 (1), 48-50.

47. Barman, H., Das, S.K., Roy, A., 2018. Future of nano science in technology for prosperity: A policy paper. Nanoscience and technology 5 (1), 1-5.
48. Das, S.K., Avasthe, R.K., Singh, M., Dutta, S.K., Roy, A., 2018. Zinc in plant-soil system and management strategy. Agrica 7 (1), 1-6.
49. Das, S.K., Avasthe, R.K., 2018. Development of innovative low cost biochar production technology. Journal of krishi vigyan 7 (1) 223-225.
50. Das, S.K., Avasthe, R.K., Sharma, P., Sharma, K., 2017. Rainfall characteristics pattern and distribution analysis at Tadong East Sikkim. Indian journal of hill farming 30 (2), 326-330.
51. Roy, A., Singh, N.U., Tripathi, A.K., Yumnam, A., Sinha, P.K., Kumar, B., Das, S.K., 2017. Dynamics of pulse production in north-east region of India- A state-wise analysis. Economic affairs 62 (4), 655-662.
52. Das, S.K., Avasthe, R.K., 2017. Livelihood improvement of rural tribal farmers through soil health management, input support system and training-A success story. Innovative farming 2 (3), 171-173.
53. Das, S.K., Avasthe, R.K., Sharma, K., Singh, M., Sharma, P., 2017. Soil fertility assessment in different villages of east sikkim district. Indian journal of hill farming 30 (1), 14-16.
54. Das, S.K., Ghosh, G.K., Mukherjee, I., Avasthe, R.K., 2017. Nano-science for agrochemicals in plant protection. Popular kheti 5 (4), 173-175.
55. Das, S.K., Ghosh, G.K., Avasthe, R.K., 2017. Biochar amendments on physico-chemical and biological properties of soils. Agrica 6 (2), 79-87.
56. Sharma, M., Rana, M., Sharma, P., Das, S.K., 2016. Effect of different organic substrates and plant botanicals on growth and flowering of chincherinchee (*Ornithogalum thyrosides* Jacq). Indian journal of hill farming 29 (2), 72-74.
57. Gopi, R., Avasthe, R.K., Kalita, H., Kapoor, C., Yadav, A., Babu, S., Das, S.K., 2016. Traditional pest and disease management practices in Sikkim himalayan region. International journal of bio-resource and stress management 7 (3), 471-476.
58. Sharma, P., Sharma, K., Das, S.K., 2016. Ethno medicinal plants uses in health care by the himalayan tribal people in India. Popular kheti. 4 (3) 41-45.
59. Gopi, R., Kapoor, C., Kalita, H., Das, S.K., Avasthe, R.K., 2015. A new report of downy mildew on buckwheat (*Fagopyrum esculentum*) caused by *Perenospora* sp. in Sikkim. Journal of mycopathological research 53 (2), 95-297.

60. Roy, A., Dkhar, D.S., Tripathi, A.K., Singh, N.U., Kumar, D., Das, S.K., Debnath, A., 2014. Growth performance of agriculture and allied sectors in the north east India. Economic affairs 59 (Special), 783-795.
61. Das, S.K., 2017. Nanoparticles advanced characterization techniques: A view point. Journal atoms and molecules 7 (4): 1091-1098.
62. Das, S.K., Avasthe, R.K., Ghosh, G.K., Dutta, S.K., 2019. Pseudocereal buckwheat with potential anticancer activity. Bulletin of pure and applied sciences section B-botany 38 (2), 94-95.
63. Singh, M., Das, S.K., Avasthe, R.K., 2018. Effect of multipurpose trees on production and soil fertility on large cardamom based agro forestry system in Sikkim Himalaya. Indian journal of agroforestry 20 (2), 25-29.
64. Mukherjee, I., Das, S.K., Kumar, A., Shukla, L., 2020. Sludge amendment affects the persistence, carbon mineralization and enzyme activity of atrazine and bifenthrin. Bulletin of environmental contamination and toxicology 105 (2), 291-298.
65. Das, S.K., Ghosh, G.K., Avasthe, R.K., 2020. Ecotoxicological responses of weed biochar on seed germination and seedling growth in acidic soil. Environmental technology and innovation, 101074.
66. Das, S.K., Ghosh, G.K., Avasthe, R.K., 2020. Evaluating biomass-derived biochar on seed germination and early seedling growth of maize and black gram. Biomass conversion and biorefinery 1-14.
67. Das, S.K., Ghosh, G.K., Avasthe, R.K., 2020. Valorizing biomass to engineered biochar and its impact on soil, plant, water, and microbial dynamics: a review. Biomass conversion and biorefinery 1-17.
68. Das, S.K., 2020. Influence of phosphorus and organic matter on microbial transformation of arsenic. Environmental technology and innovation, 100930.
69. Das, S.K., Avasthe, R.K., 2020. Packages of Organic Nutrient Management as Soil Policy for Upgrading Cropping System to Restore Soil Productivity, Organic Agriculture, Shaon Kumar Das, IntechOpen, DOI: 10.5772/intechopen.91928. Available from: https://www.intechopen.com/books/organic-agriculture/packages-of-organic-nutrient-management-as-soil-policy-for-upgrading-cropping-system-to-restore-soil

70. Das, S.K., Ghosh, G.K., 2020. Soil health management through low cost biochar technology. Biochar applications in agriculture and environment management, 193-206.
71. Gopi, R., Avasthe, R.K., Kalita, H., Yadav, A., Das, S.K., Rai, D., 2020. Eco-friendly management of tomato late blight using botanicals, bio-control agents, compost tea and copper fungicides. Indian journal of agricultural sciences 90 (1), 35-39.
72. Das, S.K., Avasthe, R.K., 2018. Soil organic nutrients management through integrated approach: A policy for environment & ecology. Environmental analysis and ecology studies 4 (1), 1-8.
73. Das, S.K., Ghosh, G,K., Avasthe, R.K., 2020. Applications of biomass derived biochar in modern science and technology. Environmental Technology and Innovation. 21: 101306. https://doi.org/10.1016/j.eti.2020.101306
74. Das, S.K., Ghosh, G,K., Avasthe, R.K., Sinha, K., 2021. Compositional heterogeneity of different biochar: Effect of pyrolysis temperature and feedstocks. Journal of Environmental Management. 278 (2): 111501. https://doi.org/10.1016/j.jenvman.2020.111501
75. Das, S.K., Ghosh, G,K., Avasthe, R.K., Sinha, K., 2020. Morpho-mineralogical exploration of crop, weed and tree derived biochar. Journal of Hazardous Materials. 124370. https://doi.org/10.1016/j.jhazmat.2020.124370
76. Das, S.K., Ghosh, G,K., Avasthe, R.K., 2020. Biochar application for environmental management and toxic pollutant remediation. Biomass Conversion and Biorefinery. https://doi.org/10.1007/s13399-020-01078-1
77. Das, S.K., Ghosh, G,K., Avasthe, R.K., 2020. Application of biochar in agriculture and environment, and its safety issues. Biomass Conversion and Biorefinery. https://doi.org/10.1007/s13399-020-01013-4
78. Das, S.K., Avasthe, R.K., Kalita, H., Yadav, A. and Gopi, R. 2020. Organic Soil Nutrient Practices in Sikkim and Impact at Field Level for Tribal Farmers': A Success Story. Biotica Research Today. 2, 2 (Feb. 2020), 24-26.
79. Singh, M., Gupta, B., Das, S.K., 2018. Soil organic carbon density under different agroforestry systems along an elevation gradient in north-western Himalaya. Range Management and Agroforestry. 39(1)" 8-13.
80. Singh, M., Gupta, B., Babu, S., Avasthe, R.K., Das, S.K., 2017. Fodder, fuelwood consumption pattern and energy dynamics along elevation gradient in Giri Catchment,

Himachal Pradesh, India. Indian Journal of Agricultural Sciences 87 (2): 261–5, February 2017/Article

81. Das, S.K., Avasthe, R.K., Singh, M., 2016. Carbon-negative biochar from weed biomass for agricultural research in India. Current Science. 110 (11), 2045-2046
82. Das, S.K., 2016. Screening of Bioactive Compounds for Development of New Pesticides: A Mini Review. Universal Journal of Agricultural Research 4 (1), 15-20.
83. Singh, M., Gupta, B., Das, S.K. 2015. Assessment of Economic Viability of Different Agroforestry Systems in Giri Catchment, Himachal Pradesh. Economic Affairs. 60(3): 557-561.
84. Barman, H., Roy, A., Das, S.K., 2015. Evaluation of plant products and antagonistic microbes against leaf blight (*Alternaria alternata*), A devastating pathogen of Tomato. Trends in Biosciences. 8(13): 3374-3377.
85. Mukherjee, I., Das, S.K., Kumar, A. 2014. P-41. Adsorption of flubendiamide in two Indian soils varying in physicochemical properties. 4th International Conference of Young Scientists: Chemistry Today–2014: August 18-22, 2014.-Yerevan: YCA, 2014–234 pages.
86. Avasthe, R.K., Das, S.K., Reza, S.K., 2014. Integrated Nutrient Management through Organic Sources. Handbook on organic crop production in Sikkim. (Eds. RK Avasthe, Yashoda Pradhan and Khorlo Bhutia). Published by Sikkim Organic Mission, Govt. of Sikkim and ICAR Research Complex, Sikkim Centre, Tadong, Gangtok, Sikkim. Pp 317-328.
87. Das, S.K., 2013. Integrated nutrient management using only through organic sources. Popular Kheti. 1(4): 126.
88. Das, S.K. Avasthe, R.K., Roy, A., Singh, N.U., Soil sample analysis methods: A ready reckoner for soil testing. http://www.kiran.nic.in/pdf/publications/2020/Soil%20Sample%20Analysis%20Methods%20Shaon%20Kumar%20Das.pdf
89. Das, S.K., 2019. Carbon Sequestration and Climate Change. https://foodandscientificreports.com/assets/uploads/issues/1583721457carbon_sequestration.pdf
90. Avasthe, R.K., Babu, S., Singh, R., Das, S.K., Impact of organic food production on soil quality.https://www.researchgate.net/profile/Shaon_Das4/publication/326827479_Impact_of

_Organic_Food_Production_on_Soil_Quality/links/5b65855e0f7e9bd7ae93a50b/Impact-of-Organic-Food-Production-on-Soil-Quality.pdf

91. Das, S.K., Avasthe, R.K., Roy, A., Yadav, A., Singh, M., Managing soil acidity through liming and organic nutrients for optimizing crop production in Sikkim. http://kiran.nic.in/pdf/publications/Sikkim/Managing_soil_acidity_through_liming-and_organic_nutrients-Sikkim.pdf
92. Das, S.K., Roy, A., Ghosh, G.K., Boron Nutrition in Soil System and Management Strategy.http://www.kiran.nic.in/pdf/publications/2017/Boron_Nutrition_in_Soil_System_and_Management_Strategy.pdf
93. Das, S.K., Avasthe, R.K., Roy, A., Farming for North East with technology options for sustainable feeding the populace. http://kiran.nic.in/pdf/publications/2017/Farming_for_NorthEastwith_technology_optionsforsustainable_feeding_populace.pdf
94. Das, S.K., Avasthe, R.K., Gopi, R., Roy, A., Singh, M., Nanotechnology in pesticide formulation: A new era in plant protection. http://www.kiran.nic.in/pdf/publications/Sikkim/Nanotechnology.pdf
95. Das, S.K., Persistence and mobility behavior of flubendiamide in soil. IARI, Division of Agricultural Chemicals. https://krishikosh.egranth.ac.in/handle/1/81262