STRATEGY PAPER

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Strategy for Upscaling Carbon Farming in India

NATIONAL ACADEMY OF AGRICULTURAL SCIENCES, NEW DELHI

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CONVENER : Prof. Biswapati Mandal, BCKV, Kalyani

REVIEWERS : Dr. B. Venkateswarlu, Former VC, VNMKV, Parbhani
Dr. Ch. Srinivasa Rao, Director, ICAR-IARI, New Delhi

EDITORS : Dr. V.K. Baranwal
Dr. R.K. Jain

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NASC, Dev Prakash Shastry Marg, New Delhi - 110 012, India
Tel: (011) 25846051-52; Fax: (011) 25846054
Email: naas-mail@naas.org.in; Website: www.naas.org.in

Preface

Land degradation and climate change are two major challenges in Indian agriculture. Carbon farming is considered to be the panacea for these problems. Considering the importance of C-farming, recently Govt. of India has notified for a Carbon Credit Trading Scheme (2023), and subsequently the framework for a voluntary carbon market (2024) for its adoption and upscaling among the farmers of the country. However, farmers are neither well-equipped of its techniques nor the intricacies of its implementation.

Success of C-farming depends on many factors. Of these, C-capturing or C-emitting capacity of soils, optimal systems/practices for different agro-ecologies, robust protocol for monitoring, reporting and verification, and marketing system, cost-effectiveness, and other socio-economic factors are important. A critical analysis of these factors is essential for implementing the C-farming program.

This strategy paper is the outcome of a strategy workshop on C-farming held on May 4, 2024, and it captures an in-depth analysis of the issues deliberated by experts including the scientists from different institutes, policy makers, and service providers from across the country. On behalf of the Academy, I appreciate the efforts of Prof. Biswapati Mandal for taking the lead and convening the workshop and bringing out its recommendations in the form of this strategy paper. My sincere appreciations are due to the Reviewers, Dr. B. Venkateswarlu and Dr. Ch. Srinivasa Rao; Editors, Dr. V.K. Baranwal and Dr. R.K. Jain also the Secretary, Dr. W.S. Lakra for their dedicated efforts in bringing out this strategy paper. I believe the document will serve the intended purpose.

January 2025 — **(Himanshu Pathak)**
New Delhi — *President, NAAS*

Strategy for Upscaling Carbon Farming in India

Indian agriculture is presently confronted with two major challenges; one is land degradation, and the other is climate change. Both have serious impacts on the agricultural production of the country. Carbon (C) farming can offer some relief to both the challenges. It also complements the other Government efforts of reducing greenhouse gas (GHG) emissions and achieving climate neutrality by 2070. Besides incentivizing farmers directly to cope with climatic hazards, it has many other indirect benefits too (Fig 1). Considering our commitment to land degradation neutrality by 2030, and Govt. of India's intent that it would rehabilitate only 26 mha out of 120 mha of degraded land by 2030, introduction of C-farming scheme could be a good weapon for farmers to fight against climate change impacts and conserving their land resources.

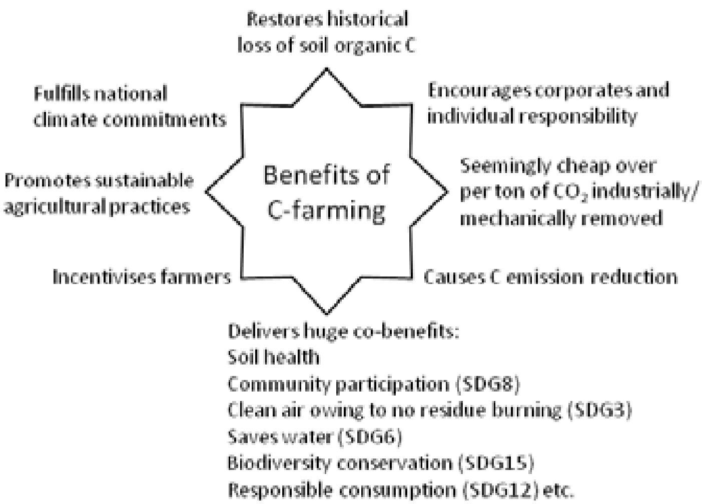

Fig. 1. Possible benefits of C-farming

Carbon farming is a method of crop husbandry aimed at either sequestering atmospheric C into the soil and in crop roots, stems and leaves or curbing emission of C (GHG) from soil. Its aim is to increase the rate at which C is sequestered into soil and plant material with the goal of creating a net capture of C from the atmosphere. This sequestration (removal) of historic C emissions is essential, as emission reduction (avoidance) alone is unlikely to stabilize our environment. These two processes i.e. removal and avoidance, with different characteristics, together determine the C yield or C credits (one credit ≡ 1.0 Mg CO_2e) of C-farming, as depicted below (Fig 2).

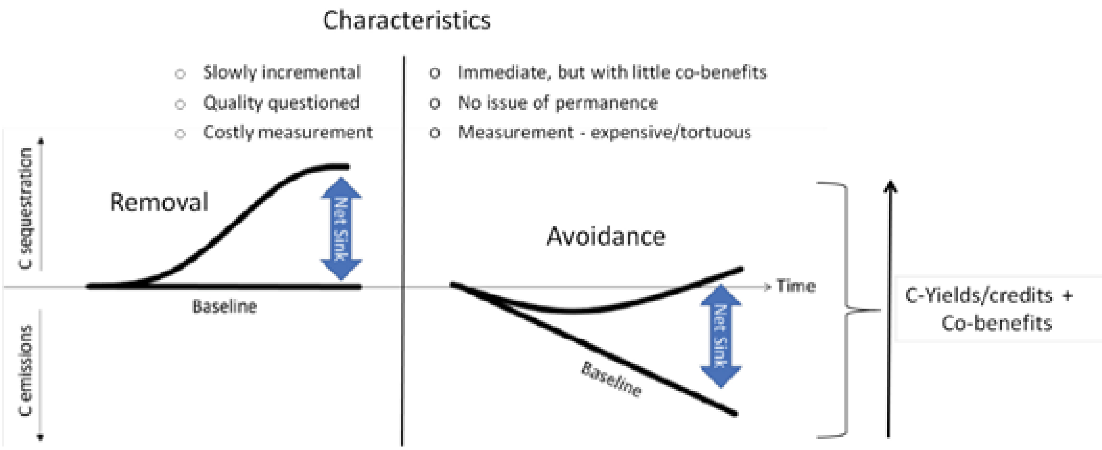

Fig. 2. Carbon farming entailing removal and avoidance processes with characteristics

Though C-farming is seen as a good tool to fight climate change, maintain soil health and earn economic benefits by farmers, there are many challenges in its upscaling and wider adoption. The major challenges include its effectiveness, size and permanency of the C-credits generated and the methods of its measurement. To circumvent these, in general, most experts give more weightage to avoidance than removal processes of C-farming. However, considering the importance of C-farming, recently Government of India (GoI) has notified for a Carbon Credit Trading Scheme (2023), and also the framework for a voluntary carbon market (2024) for upscaling its adoption in agriculture. A strategy workshop on C-farming was, therefore, organized, in continuation of the earlier related topics (NAAS policy paper 69, 100 and 117), under the auspices of the National Academy of Agricultural Sciences to have a reproducible, science-based and farmer friendly C-farming program for the country.

1. A SUITABLE NICHE FOR C-FARMING

To harvest a good C yield from soils, the soils must have good C capturing or C emitting (to curb) capacity. Results of long-term experiments (LTEs) across different agro-ecological zones (AEZs) of the country showed that there were no significant gains in soil C even with good addition of C through organics for decades (Pathak *et al*., 2011). This is also confirmed by the non-compliance to ‘4 per mille’ (an initiative launched at COP21 in Paris with an aspiration to increase global soil organic matter stocks by 4 per 1000 per year as a compensation for the global emissions of GHG (by anthropogenic sources) target in soils subjected to balanced nutrition with organics under LTEs in different zones of the country (Fig 3).

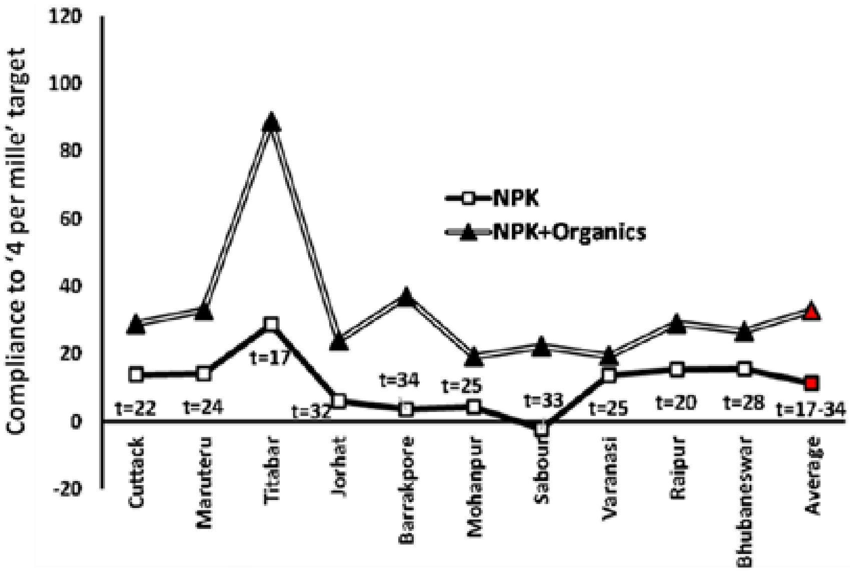

Fig. 3. Showing non-compliance (100) to '4 per mille' target of increasing Soil Organic Carbon (SOC) with balanced nutrition and organics addition

This low C yield in Indian soils is attributed to a high soil respiration, high land surface temperature and light-texture/low clay content. This makes it difficult to earn handsome C credits by adopting C-farming practices in the reported zones of the country. Therefore, identifying sites with a good appetite for C is the key to the success of the C-farming scheme to be introduced by the GoI. Critical analysis by overlaying of maps capturing land surface temperature, soil clay content, and C-yield of LTEs with C enhancing practices recommended in different AEZs will help in identifying ideal locations for upscaling C-farming with suitable practices. Similarly, for hotspots having high CH_4 and N_2O emissions, avoidance is a priority over Soil Organic Carbon (SOC) sequestration for good gains out of C-farming. There is a need of a robust nation-wide database of CH_4 and N_2O emissions for delineating potential project areas and identifying site-specific management practices in order to make C-farming projects successful.

2. THE OPTIMAL SYSTEMS/PRACTICES FOR DIFFERENT AGRO-ECOLOGIES

Like the AEZs, the selection of crops, cropping systems and management practices are also important for a successful C-farming program. Normally, there is a depletion of C in soils with intensive cultivation. At First, this depletion needs to be compensated to cause a net enrichment and earn C credits. The critical C inputs (CCI) needed to offset the depletion and cause a zero change in soil C varies with the intensity of ploughing, soil types and AEZs (Mandal et al., 2007). On an average, the amount of CCI is almost equivalent to the value of soil respiration of the zone concerned. Database is generated for this amount of CCI by different researchers using LTEs for different AEZs (Fig 4). Crops, cropping systems and management practices that could add more than this amount of CCI can only yield (C) credits, and be used for C-farming. While promoting C-farming in different AEZs in the country, attention must be given that the recommended practices can supply at least more than this critical amount. Again, the amount of C inputs added in soil by a particular system/practice can be computed with reasonable accuracy by using factors available in literature knowing the yield obtained for different crops and cropping systems (portions of the hidden-half, stubbles, and other left-over parts) and C concentration of the added organics. Based on these values, the suitability of the existing systems/practices followed at different AEZs and the needs for tailoring them could be assessed. Such assessment may help to recommend zone-specific 2-4 optimized practices for promotion of C-farming. This principle of selection of practices for different agro-ecologies can be further improved by knowledge of crop root architecture as their intertwining with soil mineral enhance-C stabilization. Further, the unique root geometry of crops is responsible for allocating C to a deeper depth with higher durability. This may help in countering the much criticism made for the non-permanence nature of C credits earned through the removal mechanism. Use of these science-led fundamental principles will be useful in making C-farming a successful enterprise. Additionally, to fine-tune the selection, research may be funded to identify which set of systems/practices are optimal for different zones through a well-coordinated network of experiments across India, on priority.

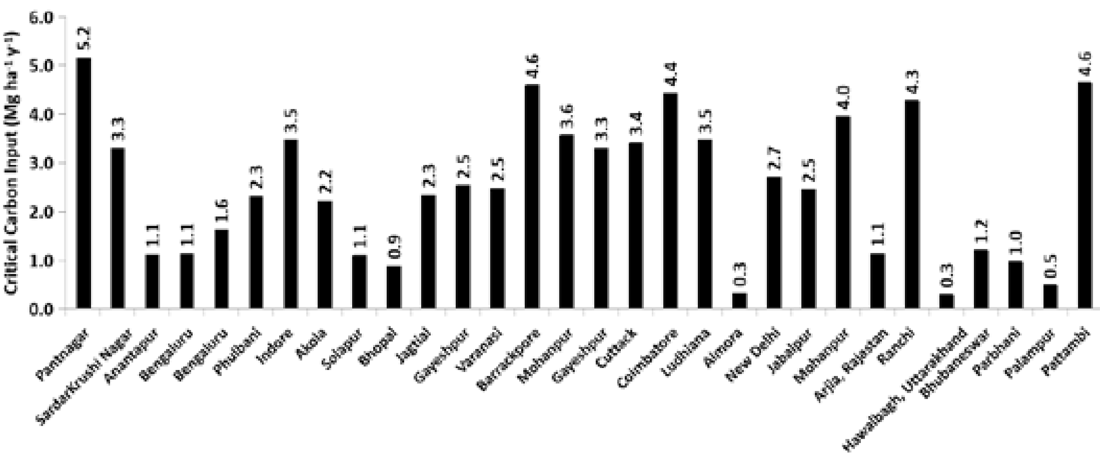

Fig. 4. Values of critical C-inputs needed to be added in soils of different locations in India to cause a zero change in soil organic carbon upon cultivation

3. MEASURING C-YIELD OF C-FARMING

The primary bottleneck for introducing and upscaling C-farming in India is lack of cost-effective and robust protocol for monitoring, reporting and verification. The existing protocols vary across key dimensions like scientific rigor, additionality, and permanence. Collection of representative samples for soil organic C measurement over an area is a challenging task due to its inherent spatial variation. The problem seems to be aggravated in India because 86% of its farmers are small and marginal; they follow diverse management practices and add varied quantities of C inputs. Moreover, SOC changes very slowly over time even with receiving the best C-farming management practices. All these necessitate high-density sampling and analysis involving prohibitively high cost that offsets the benefits of C-credits accrued out of C-farming. Problems also exist with other available so-called new, advanced protocols based on proximal sensing (MIR/NIR spectroscopy) and satellite remote sensing, and use of models. Considering the complexities, a group of scientists advocated fusion of a limited sampling cum modeling approach and use of proximal sensing (MIR/NIR spectroscopy) and remote sensing for a cost-effective computation of soil C credit. However, the major problem is that there is no system of rationalization of C-data available in the country, even for making a stratified/homogenized baseline; although use of machine learning tools with soil health mission databases is an attractive possibility. To start with, a more pragmatic approach would be to develop default factors for the selected best management practices in different AEZs of the country utilizing the data-set of LTEs/ permanent manurial trials/state universities trials etc. Involving appropriate experts, ICAR/SAUs may be requested to compute and develop the said factors across the country.

4. LAND DEGRADATION AND C-FARMING

Land degradation accompanied with a significant loss of C is extensive in India. Depending upon the processes, intensity and area affected by degradation due to soil erosion, annual C loss varies, on average, from 0.33 million tonnes (mt) in Sikkim to 20.33 mt in Madhya Pradesh. However, it is not confirmed if the low loss in Sikkim was associated with it becoming a 100% organic State since 2016 or not. Due to financial constraints, it is not feasible to go for rehabilitation and stop C loss from the entire affected areas. In such situations, critical area treatment in watershed-basis is an option, finding out the hot-spots based upon the difference between the prevailing erosion rates and the permissible erosion limits reported. Carbon-centric site-specific sustainable soil management technologies for accelerating the process of natural ecological succession have been enlisted for district-wise priority areas for different states (http://www.cswcrtiweb.org/index1.html? Statewise_Reports/Reports_states.htm). It could not only bring down the soil erosion and C loss of the catchment but also cause a net enrichment of C in it. An estimation of C yield of a few promising rehabilitation measures under different landscape types is enlisted below (Table 1).

5. CARBON FARMING WITH PERENNIAL HORTICULTURAL SYSTEMS IN WASTE LANDS

Like forestry, perennial horticultural systems are also a good avenue for C-farming. This system includes crops like fruits, nuts, and spices that have a longer productive lifespan compared to arable crops, and as such it suffers from less criticism for non-permanency nature of C-credits in agriculture. It currently covers approximately 7.5 mha with sequestering rate of about 10-20 t C $ha^{-1}yr^{-1}$ compared to about 50 t C $ha^{-1}yr^{-1}$ by forests. In India, several niche areas could be targeted for exploiting carbon sequestration through these perennial systems. These include agroforestry systems, degraded lands, orchard intensification-enhancing existing orchards with improved

Table 1. Carbon sequestration potential through restoration of eroded lands in India (Mandal *et al*., 2020)

Erosion types	Area (mha)	C-sequestration potential (t C ha^{-1} yr^{-1})	Total potential (mt C yr^{-1})	Technological options
Water erosion in arable lands	73.27	0.08- 0.12	5.86- 8.79	Cover crops, Strip crops, Green manures, Vegetative strips, Inter cropping with legume, Plant residue mulch
Ravine lands	3.97	0.14	0.56	Grass planting (*Imperata*, *Saccharum* spp.)
		0.29	1.15	Bamboos in Agroforestry
Shifting cultivation	4.91	0.74	3.63	Agroforestry piper betel
		0.50	2.46	Alder (*Alnus* spp.) and black piper (*Piper* spp.)
		0.41	2.01	Hedgerow cultivation *Gliricidia* + *Sachharum* spp. (Grass Filter Strip)
		0.39	1.91	*Indigofera* + (GFS) *Saccharum* spp.
Water erosion in open forest	9.30	0.50	4.65	Forest regeneration, Erosion control reduced forest degradation
Pasture and grazing lands	10.26	0.53	5.44	Controlled grazing, Rotational grazing, Woody plant and Fire management
		0.80	8.21	Improved species, Fertilization, Grassland management
Riverine lands Torrents	2.73	0.15	0.41	Water harvesting, Water conservation and regeneration of natural vegetation

management practices, home gardens and urban green spaces, arid and semi-arid regions, forest buffer zones, plantation crops - expanding and intensifying plantations of crops like tea, coffee, coconut, and rubber with improved agroforestry systems, mountain and hill regions etc. However, for immediate exploitation about 5.3 mha are available in Chambal ravines (0.72 mha), Bundelkhand region (1.26 mha), western Rajasthan, Kutch region, lateritic exposures in Konkan and Odisha coasts, avenues of recent national (0.15 mha) and state (0.20 mha) highways, and deforested lands across the country. Assuming exploitation of this by about 20%, it accounts for about 1.10 mha. If one takes annual C-yield at the rate of 20 t ha^{-1}, it yields ~22 mt of harvestable C per year from this sector (Ganeshamurthy et al., 2019). With the help of already existing 'National Horticultural Mission', attempt may be made to realise the avenues indicated involving the concerned State Government to help achieving a net-zero and nutritional security for the country.

6. OTHER ZONE/AREA-SPECIFIC TECHNOLOGIES FOR C-FARMING

(i) Some zone-specific technologies available in India are enumerated in Table 2. The ICAR-Indian Institute of Farming System Research has developed integrated farming system models across different agro-climatic regions. They have identified rice-wheat in Madhya Pradesh, Haryana, Punjab, Uttar Pradesh, Bihar; sugarcane-ratoon-wheat in western Uttar Pradesh; and soybean-wheat in central India as C-positive farming systems and recommended to use them in C-farming with good C-yield.

(ii) In the coastal ecosystem, arable agriculture suffers from many constraints. Integrated mangrove-aquaculture (IMA) systems can be introduced and upscaled as a nature-based C capturing option in soils of this region. Around 10% of India's brackish-water aquaculture area of 1.2 mha (Mission Brackish Water/Saline Aquaculture-2022) can be targeted under such IMA system. Further, cultivation of fast-growing trees with arable crops under agri-silvicultural systems, and cultivation of Salvadora, quinoa and Dill have the potential to capture C particularly in highly degraded saline/sodic (>40 dS/m) barren lands. In the Gujarat coastline, bio-shields comprising mangrove, energy and fruit trees along with fodder cultivation are considered as C-positive.

(iii) In the fragile hill ecosystem, location specific agroforestry approaches (say, sisso + pineapple in low altitudes, alder + cardamom in high altitudes) are the best option for C-farming. Besides, perennial forage crops (hybrid napier, congo signal, native grass mixtures), alley cropping with hedge row crops (*Gliricidia spp.* in low altitudes of Tripura, *Crotolaria spp.*/*Tephrosia spp.* in mid altitudes of Meghalaya),

Table 2. Ecosystem specific technology options for SOC improvement in India (NAAS, 2021)

Agro-ecosystem	Technologies				
IGP	**Residue recycling, Biochar**	**CA**	**Agri-horticulture**	**Minimized soil-based brick industry**	**Reclamation of salt-affected soils**
Rainfed	Cover crops	Local organics, manure, GM/GM combined with CR	Agroforestry	Tank silt and farm ponds	Rainfed horticulture and intercrops
Eastern	Land reclamation, aerial seeding	IFS/INM	SSNM	Crop diversification	Organic farming
NEH	Aerial seeding	Contouring, terracing	*Jhum* land rehabilitation	Riverbank stabilization	Relay cropping
Arid	Sand dune stabilization	Agroforestry	IFS	Water management and farm ponds	Agri-horticulture, perennial fruit crops
Himalayan	Land covers	Agroforestry/ afforestation	Contouring	Perennial fruit crops	Agri-horticulture
Central	Sustainable intensification	Legumes	Organic farming	Water erosion reduction technologies	Intercrops
Island	Organic manures	Composting local organics	IFS/INM	Sea-bank stabilization	Contouring

IGP: Indo-Gangetic Plains; NEH North Eastern Hill regions; IFS: Integrated Farming System; SSNM: Site-Specific Nutrient Management; CA: Conservation Agriculture; GM: Green Manures; CR: Crop Residues

cover crops (local cowpea in Tripura, rice bean in mid and high altitudes) etc. are some other potential options for sustainable C-farming.

(iv) Similarly, challenging areas such as sandy soil with low water and nutrient holding capacity, high land surface temperature, poor plant biomass production capacity accompanied with high loss of top fertile soil through wind erosion processes (e.g. loss of 45.9 kg C ha^{-1} and 4.4 kg N ha^{-1} during summer months at Jaisalmer) (Santra et al., 2021) make the arid zones a less suitable sites for C-farming. Under these conditions, even with best C-farming practices, C-yield/credits may not be substantial and remunerative also. However, indigenously prepared partially humified compost using native vegetations such as *Crotolaria burhia* (Saniya), *Aerva javenica* (Bui), *Leptodenia pyrotechnica* (Khimp), *Teprosia purpurea* (Dhamasha) etc. may act as a good amendment for stabilizing the soils and improving its moisture holding capacity for increased biomass formation. Adopting tailored site-specific integrated farming system incorporating horticultural components with ber (*Ziziphus sp*), pomegranate (*Punica granatum*), lasora (*Cordia myxa*), karonda (*Carissa carandus*), anola (*Emblica officinalis*) etc and also agroforestry components with khejri (*Prosopis cineraria*), rohida (*Tecomela undulata*), ker (*Caparis decidua*), jal (*Salvadora oleoides*) etc. may be useful for harvesting C, but weighing critically the competitive use of precious water resource of the zone. These conclusions are supported by the observed low SOC stock [e.g. 2.89-5.26 Mg ha^{-1} in 0-15 cm soil layer in hyper arid condition of Jaisalmer and 11.95 Mg ha^{-1} in 0-30 cm soil layer in fallow land in Jodhpur (Santra et al., 2021)] in arable lands compared with a much higher amount [e.g. 19.52 Mg ha^{-1} in 0-30 cm soil layer under *Prosopis cineraria* (khejri), 16.29 Mg ha^{-1} under *Ziziphus sp* (ber), and 16.81 Mg ha^{-1} under *Punica granatum* (pomegranate) etc.] in lands under different fruit plantations and agroforestry. All these indicated a good potentiality of agroforestry systems for C-farming in the arid zone.

(v) In India, about 0.30 mha of land comes under mining. However, these lands become available for other purposes also once the mines are closed. Post-mining land has great potential for C-farming, especially with presence of certain tree species like *Dalbergia sissoo*, *Cassia siamea*, *Albizia lebbeck*, *Acacia auriculiformis*, *Leucaena leucocephala* etc. These trees have deep root systems that scavenge nutrients from subsoil, making the sites ideal for C-farming. Besides, mining sites often have large volumes of waste rocks, some of which contain high levels of potassium and magnesium. These rocks can be pulverized and used as amendment in agricultural soils. Weathering of these rocks can aid in capturing C as inorganic carbonates, while they also add nutrients to soils. Revegetation practices and lessons learned from restoring post-mining land can be effectively applied to wastelands and marginal agricultural lands also. With simple and transparent land tenure/leasing systems in hand for mining lands, actions may be taken to rehabilitate those with C-farming.

(vi) Rainfed dryland agroecosystem constitutes a good part of Indian agriculture. The system suffers from progressive degradation due to low SOC. Utmost attempts may, therefore, be made to tap its potential for C-farming using suitable management practices. In fact, results of long-term experiments with suitable management practices showed a good potential for C sequestration in soils across the region. Upscaling those practices would not only help to curb the degradation enriching SOC, but also help farmers to earn some extra yield and income. Some easy to adopt such soil management practices with good C-yield for different soil types are presented below (Table 3).

Table 3. Carbon sequestration rate in surface soil (0-0.2 m) under different rainfed agroecosystems and soil types (Mg $ha^{-1}yr^{-1}$) using data from long-term experiments (Srinivasarao *et al.*, 2014)

Production systems (soil type/order)	Suggested practices	Carbon sequestration, Mg $ha^{-1}yr^{-1}$		Potential CER from suggested practices	
		Farmer practice	Suggested practice	Mg $ha^{-1}yr^{-1}$	Value, US $
Groundnut based (in Alfisols)	50% RDF + 4 Mg groundnut shell/ha	0.08	0.45	0.370	7.40
Groundnut–finger millet (in Alfisols)	FYM 10 Mg + 100% RDF (NPK)	−0.138	0.241	0.379	7.58
Finger millet–finger millet (in Alfisols)	FYM 10 Mg + 100% RDF (NPK)	0.046	0.378	0.332	6.64
Sorghum based (in Vertisols)	25 kg N (FYM) + 25 kg N (urea)	0.101	0.288	0.187	3.74
Soybean based (in Vertisols)	6 Mg FYM/ha + 20 kg N +13 kg P	−0.219	0.338	0.557	11.14
Rice based (in Inceptisols)	100% organic (FYM)	−0.014	0.128	0.142	2.84
Pearl millet based (in Aridisols)	50% N (chemical fertilizer) + 50% N (FYM)	−0.252	−0.110	0.142	2.84

Certified emission reduction (CER) @ US$ 20/Mg; RDF: Recommended dose of fertilizer; FYM: Farm yard manure

7. PAYMENT FOR C-FARMING

There are many complex issues for payment, not just the complexities of quantification of the amount of C yield, as indicated above. There is no or rudimentary institutional structure of C-market for C-farming payment, and dispute redressal system. An initiative from Government is a must to establish such a structure. In fact, simplifying access of farmers to such an organized carbon market is the key for making C-farming program a success. Coming to the actual complex issues of payment show that farmers' sincerity and wisdom and the accompanied health of soil of their fields matters. Farmers with wisdom keep their field-soils in good health following good land-care practices with regular application of organics, balanced fertilizers etc.; while the others with casual attitude and lack of kinship maintain it in no good, but deteriorated conditions. Soil C saturation deficit for the former group will be much less than that of soils of the latter group making the latter earning more C-credits through C-farming (Fig 5). The State principle of 'fairness', 'polluters should pay', and 'natural justice' thus violated.

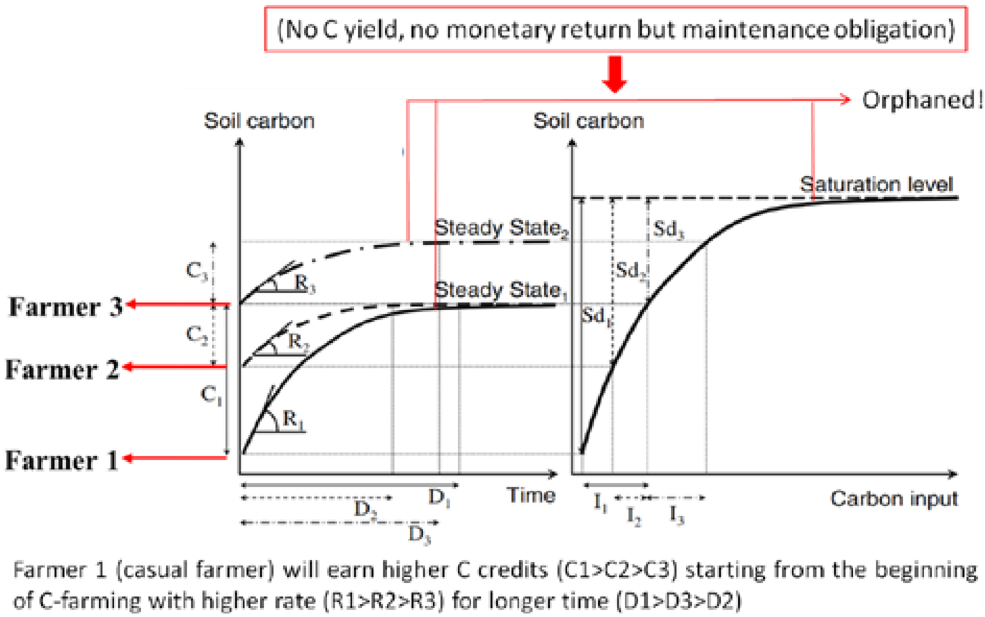

Fig. 5. Showing the intricacies of payment for C-farming with a 'casual farmer (non-adopter of good land-care practices, Farmer 1)' getting more benefits than a 'good farmer (adopter of good land-care practices, Farmer 2 & 3)' violating the principles of 'fairness', 'polluters should pay', and 'natural justice'

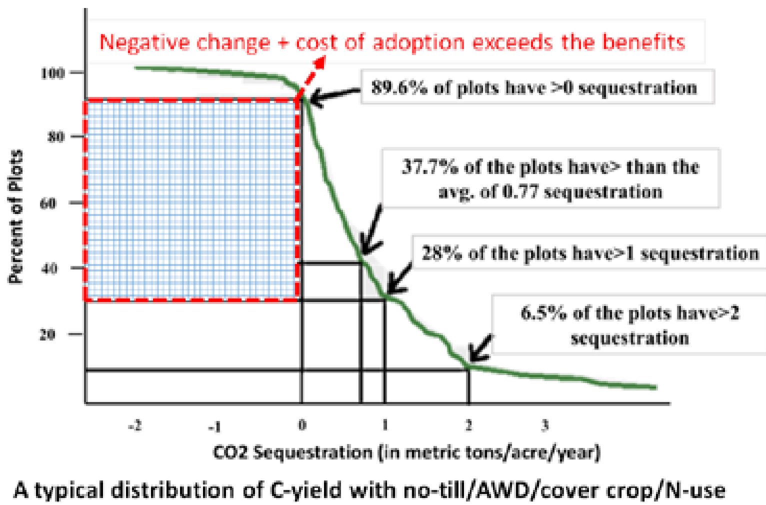

Fig. 6. Showing the possibility of earning C-credits in field conditions *vis-a-vis* the cost of adopting the recommended practices. A good percent of plot-owners may end up with little C-credits hardly exceeding the cost of implementing the C-farming practices. Under such conditions action-based (practice-wise) payment may be a way forward for upscaling C-farming, considering its many co-benefits, as narrated in the text and Fig 1.

Consider another situation wherein farmers of a village adopting C-farming practices say no-till, alternate wetting and drying (AWD), cover crops etc. obtained typical distribution of C-yield in their plots (Fig 6). The graph shows that ~10% farmers earned negative/zero yield, 62% obtained <0.77 unit, 72% obtained <1.0 unit, and alternately only 28% received >1.0 unit. Only those obtained >1.0 unit of C-yield could earn just the sufficient amount for meeting the extra costs needed for adopting the recommended practice. Under this typical scenario of C-farming, the principle of pay for work, and equal pay for equal work is hardly maintained. To overcome these complexities, across suitable zones as demarcated by robust science mentioned above, payment may be made per ha on action-based, practice-wise. Such a mode of payment is simple, involved lower monitoring cost, easy to cover a larger area, but with less effectiveness. Payment on the basis of result-based C-yield, per output could be done only with stringent monitoring and measurement for which cost effective protocols are lacking in India. To make it attractive with inherent low C-yield potentiality of Indian soils, co-benefits of C-farming may also be priced, since sometimes indirect co-benefits outweighed the direct benefits in tropical, subtropical countries like ours. In the initial stage, it is therefore suggested to go for practice-wise, upfront payment to meet the cost of its adoption, with priced co-benefits for easy uptake by all the stakeholders involved.

8. ECONOMIC POTENTIAL OF C-FARMING

Carbon-farming farmers are now considered as the shepherds of our climate. But how good is the economics of C-farming for its practitioners? As indicated earlier, neither the C appetite of Indian soil is substantial, nor its yield, even with good practices. Compilation of Indian literature (including reports of LTEs) showed, on average, a low C yield found in soils under different C-farming practices (Kiran Kumara, 2023). Even with the best market price, monetary gains to farmers out of these credits are also not substantial. Obviously, this scenario may not be attractive to them. Especially, if the investments for adopting new practices, transaction costs (in the form of measurement, monitoring etc.), third party verification and certification etc. are high. Cumulatively, these costs may be so high that it results in either no or very limited net monetary benefits for farmers. In addition, sometimes it takes a considerable time to receive the monetary benefits for adopting C-farming practices. All these features associated with C-farming are not supportive for its upscaling among the farmers.

To win over these challenges, at first, the pricing-policy of C-credits should be well-grounded, like the minimum support price of crops. Secondly, the indicated huge co-benefits (Fig 1) accrued out of the practices may be priced, and also the mode of payment for adoption of the practices may be changed to an upfront one with initial incentives to encourage farmers' participation.

9. CARBON FARMING AND OTHER SOCIETAL ISSUES

Indian farmers are mostly traditional, and conservative with risk-averse mindsets, for many reasons. If risk-sharing mechanisms of C-farming are not straightened and shared, but tilted towards farmers, it will be difficult to attract them in the program. This is more so if they experienced sudden climatic hazards that wiped out the entire C-yield accrued in the contract period. As shown in Fig 5, there is no place for adhocism in adoption of C-farming practices. To be effective, it needs to be a long-term venture, at least quasi-permanent; in turn, it is ordained to lose flexibility in future land use during the long (say 10 to 100 years) commitment period. Now, the question is how many farmers (of the predominant small and marginal size) in the country, with such a small gain in C-credits, will commit and remain bound to it for so many years?

Another important recent development in Indian agriculture is an abrupt increase in the proportion of operational holdings shifted from self to leased system of cultivation. How easy will it be to continue to the commitment made by the landowner for the adopted practices with a possible frequent change in lessees of his land, and also with the uncompromising kinship? Questions also arise as to the worth of making large scale shift in land management vs the amount of credits accrued. Should they undo their experiences gained from their own practices for generations together for aspiring good ecosystem properties that changes slowly and takes long to stabilize? Further, considering the prevailing ups and downs of the voluntary carbon market (VCM), is it good to tie our hapless farmers to a volatile market and legalities that could make farming more economically unstable?

To developers, for ease of doing business, big farmers with contiguous land are preferred for C-farming, because of some unique advantages; and as such the technology is possibly not scale-neutral. There is strong prediction for a huge increase in demands for C-credits in the coming days with the increase in price of the credits. Now, if it becomes attractive, it may lead to consolidation of holdings at the cost of small, marginal to mid-sized farmers with land in the vicinity of big farmers. Ultimately, it may give control of our food system to corporates, and endanger the socialistic nature of our democracy! To allay all these apprehensions, and combat climate emergency and land degradation, there is a great scope for formulation of a robust, transparent, science-informed, and farmer-centric C-farming policy, as explained in the previous paragraphs, for upscaling the technology among the farmers of the country.

10. EMPOWERING FARMERS FOR C-FARMING

The concept of C-farming is of recent origin. Farmers are acquainted with neither the technology nor the business of it i.e. carbon market. There are concerns that asymmetric information, lack of transparency and inadequate regulation could lead to unfair pricing practices for carbon credits, resulting in further low earnings for farmers. Additionally, the lack of knowledge and awareness about the technology among them may also lead to their exploitation. The grey areas of credit calculation need to be acquainted with, particularly the baseline fixation and also the sharing of the revenues generated among the executors -farmers, developers, implementing agencies etc.

Given the fast-growing VCM in the country, there is an urgent need for policy measures to ensure transparency, regulation, and widespread awareness about VCM. The efficient and transparent functioning of VCM and for that matter the whole program of C-farming can only be ensured with institutional back up (Fig 7). In this connection, launching of a 'National Demonstration on C-farming'-like project in the country may be contemplated, not only for hands on training and educating the farmers, but also to get them experienced with the all-round benefits of C-farming under the supervision of different ICAR institutes, KVKs, SAUs or the State Directorate of Agriculture. This empowerment can further be strengthened by making an animated film on C-farming and its distribution to farmers via websites, social media and also through the KVK-led Farmers' Schools, farmer producer organizations, NABARD-sponsored Farmers' Clubs etc. Agro-ecological zone-wise development of a tailor-made advisory or a decision tool for farmers will also be handy and effective. Improving carbon content in soil is the panacea for so many offshoots of present-day agriculture; utmost efforts may be given by all the stakeholders to make C-farming practice a success for posterity.

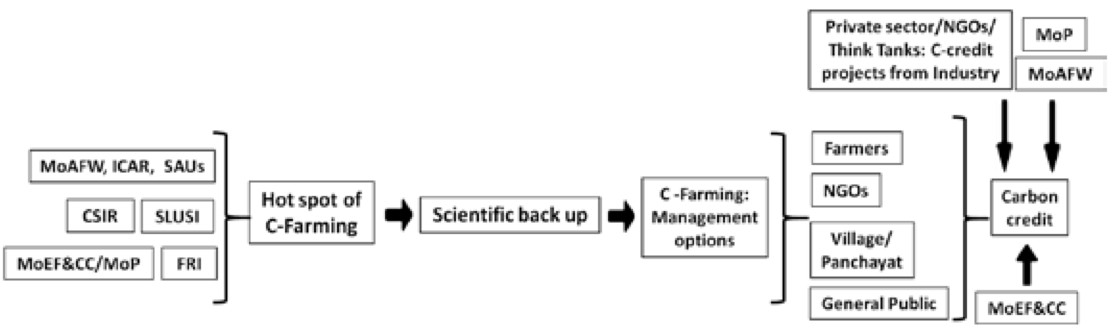

Fig. 7. Showing C-credit framework

CSIR: Council of Scientific and Industrial Research; FRI: Forest Research Institute; ICAR: Indian Council of Agricultural Research; MoAFW: Ministry of Agriculture and Farmers Welfare; MoEF&CC: Ministry of Environment, Forest and Climate Change: MoP: Ministry of Power; NGOs: Non-Governmental Organizations; SLUSI: Soil and Land Use Survey of India

11. RECOMMENDATIONS

(i) Identify and demarcate regions/soils with good appetite for C or hotspots with high CH_4 and N_2O emissions using database of long-term experiments with the help of ICAR's institutes and State Agricultural Universities.

(ii) Screen out the best practices for C-farming based on carbon yield (removal and avoidance), co-benefits, and scalability. Utilize research institutes/SAUs, agro-ecological zoning, and stakeholder consultations to finalize region-specific 'master' practices.

(iii) Develop 'default factors' for the selected 'master' practices for different AEZs utilizing available expertise of the country for calculating C-yield during initial period of introduction of C-farming scheme.

(iv) Develop cost-effective soil carbon measurement techniques and project Monitoring, Reporting, and Verification systems by combining limited sampling, modelling and remote sensing. Establish a centralized database for standardizing baseline measurements and sourcing soil data.

(v) Explore innovative C-farming models for arid, coastal and hill regions, and eroded and post-mining lands. For example, agroforestry with prosopis in arid, integrated mangrove-aquaculture in coastal, and agro-silvicultural systems in degraded regions.

(vi) Launch a 'National Demonstration on Carbon Farming' scheme under the supervision of SAUs and ICAR Institutes at different regions for empowering farmers and its upscaling. Utilize digital platforms and localized materials to spread awareness about carbon markets and sustainable practices.

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