Development of Regenerative Tea Cultivation Modelsthrough Dual Approach of Soil and Plant Health Management towards Crop Sustainability, Soil Quality Development, Pesticide Reduction and Climate Change Mitigation – A Case Study from Lakhipara Tea Estate, Dooars, West Bengal, India: PART-II

Abstract

The first part of this research article that documents the impact of the studied models for Regenerative tea production towards crop sustainability, pesticide load reduction and revenue generation.

Introduction

Climate change impact on theIndian tea industry is reflected in the increasing drought like conditions, changing rainfall patterns and increased incidences of pest infestation. Projections predict that tea-producing areas will shrink under future climate scenarios, potentially hammering tea growers and the national economies. A sustainable tea management program with adoption of Inhana Rational Farming (IRF) Technology was initiated towards development of plant health and restoration of soil quality, for Crop Sustainability and enabling reduction in pesticide. Three year's study at Lakhipara Tea Estate, Dooars, West Bengal showed an increase in crop productivity with significant reduction of chemical pesticides under the different resource based regenerative farming models. The impact was found to be more pronounced when the three year's resultsobtained in respect of crop productivity and pesticide usage was compared with rest of the garden area. In this part (Part-II) of the research article the impact of the studied regenerative farming models in terms of nutrient use efficiency, soil quality development, soil carbon sequestration, energy use efficiency, carbon footprint and GHG mitigation potentials, social cost saving and finally changes in field management cost and income potential; have been discussed.

3.4 Nutrient Use Efficiency under different Regenerative Farming Models

Improving the efficiency of nitrogen (N) uptake and utilization in plants could potentially increase crop yields while reducing N fertilization and, subsequently, environmental pollution.

The study shows an increase in the nitrogen use efficiency of the plants in all the experimental plots under the sustainable management program (Table 1). Highest N- use efficiency (57.13 %) was observed under Expt-1, where 100 % urea-N was removed and soil management was done through Novcom compost @ 9 ton/ ha. Crop sustenance under this experiment indicates that it is possible to replace 2 units of Chemical-N with 1 unit Organic –N through focus on plant health management. Importance of plant health management towards higher N uptake and utilization was further established under Expt-5, where about 15 % urea-N application was reduced but no compost was applied. Not only the high crop load was maintained despite 15% reduction in nitrogen application, rather higher crop yield over the target (Avg. 2479 kg/ha over 2391 kg/ha target, during 2014-16) could be achieved, which substantiates the impact of 'Plant Health Management' towards the nutrient use efficiency of the plants .

Table 1: Nutrient Use efficiency in the Experimental Project Plots under different Regenerative Farming Models at Lakhipara T. E.

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Expt.	PLOT	AREA (ha)	Avg. Yield	Nutrient Use efficiency under different Regenerative Farming Models			
				NUE-N	NUE-P	NUE-K	NUE-NPK
Expt-1	BB-1A	1.83	1982	24.05 (56.95)	36.79 (-31.57)	55.18 (212.65)	11.49 (61.43)
Expt-2	BB-1BC	11.26	1982	20.90 (36.44)	35.47 (-34.02)	24.96 (41.41)	8.60 (20.85)
Expt-3	BB-2	16.89	1949	16.91 (25.23)	34.15 (-29.24)	26.02 (50.18)	7.88 (20.22)
Expt-4	BB-3C	5.75	2121	21.33 (48.75)	42.87 (-10.96)	31.23 (35.98)	9.78 (31.13)
	BB-3D	5.00	2321	17.92 (19.80)	46.90 (-20.87)	21.50 (37.02)	8.09 (19.26)
Expt-5	BB-3AB	11.26	2101	18.03 (19.61)	62.39 (15.84)	32.62 (63.49)	9.79 (32.19)
	BB-3EXT	10.83	2867	22.45 (28.32)	74.04 (5.68)	23.78 (29.67)	9.99 (25.83)
Total		**62.82**	**2187**	**19.19** **(26.91)**	**45.02** **(-17.47)**	**25.97** **(42.08)**	**8.86** **(23.35)**

3.5 Comparative Nitrogen use efficiency (NUE_N) ingeneral garden *vs.* project area

Comparative study of average nitrogen use efficiency in project area (NUE_N: 19.39) vis a vis general garden (NUE_N : 15.04) during 2014-16 showed a significant 28.9 % increase in project area irrespective of compost application or not (Fig 1). The findings strongly suggest the primary role of plant health management towards increasing the ability of plant to assimilate and remobilize the N taken up from the soil, producing amino acids to be used as N carriers or signaling and regulatory pathway components and ultimately to produce crop [1]. Thus the study indicated that incorporation of regenerative farming principles into practice helps to improve plant health which inturn activates the plant physiological functioning resulting in better uptake and assimilation of nutrients.

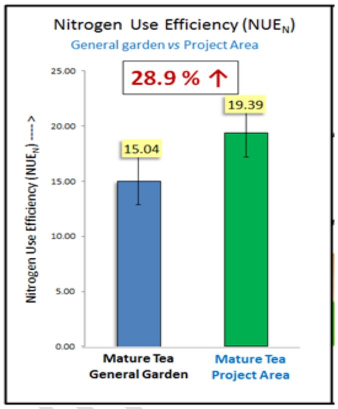


Fig. 1 : Comparative study of nitrogen use efficiency in mature tea of general garden *vis-a-vis* the project area.

3.6 Soil Quality Development - Conventional chemical vis-a-vis integrated soil management under regenerative farming.

Soil physical properties *viz.* textural class& bulk densitywere analyzed for all the soil samples (Table 2). The results indicated that soil texture of all the experimental plots were sandy clay loam to sandy loam with sand, silt and clay varying from 48.94 to 68.30, 13.15 to 28.70 and 18.53 to 22.62 percent respectively. The bulk density of the soils varied from 1.04 to 1.14 g cm^{-3}. The soils of all the experimental plots were within the range of strongly to very strongly acidic (4.5 – 5.5) in reaction except BB3C under Expt-3 & BB3AB under Expt-5 which are in the extremely acidic zone ($pH < 4.4$). Post integration of Novcom compost (in different dosage) with chemical fertilizers for a period of three years, a slight increase in soil pH was noticed which was not statistically significant, but the phenomenon is of immense importance considering that yearly corrective management for soil acidity is common in the case of conventional gardens. Similarly, increase of soil organic carbon in soil was also noticed in the experimental plots and the highest increase in organic carbon was found under Expt-1 (1.86) where compost was applied at 9 ton / ha followed by Expt-2 (1.70), where compost was applied 4 ton / ha. Status of available- NPKS in the soils of the experimental plots varied from 259 to 414 $kgha^{-1}$, 18 and 93 $kgha^{-1}$, 163 and 192 $kgha^{-1}$ and 22 and 39 $kgha^{-1}$ respectively and overall 8 % increase in available nutrient status was documented post 3 years experimentation which indicated the favourable influence of compost towards higher nutrient availability in acid tea soils.

3.7 Analysis of soil biological parameters under Sustainable Tea Initiative: Microbial activity is probably the most important factor that controls nutrient re-cycling in soil. Microorganisms participate in disintegration and decomposition processes leading to the release of trapped nutrients as well as synthesize and release hormones that are essential for plant growth [2]. Microorganisms in fact are the driving force of nutrient supply in soils and are the primary recipients of increased photo-assimilates from plants growing in elevated atmospheric CO_2. Microbial biomass and soil respiration can be referred as sensitive indicators of ecosystem development and disturbance. Anderson [3] pointed out that the qMBC (MBC/OC ratio) and metabolic quotient (qCO_2) could be used as more sensitive indicators of soil microbial response to land use, soil management, and environmental variables (Table 3). Results indicated a highest increase of soil microbial biomass carbon under Expt -1 (BBIA plot) that received organic soil management with quality compost. This was followed by Expt-3 (BB-2 plot) and Expt – 2 (BB-1BC plot). Nominal increase in soil microbial biomass was also noticed in the plots (Expt-5), where no compost was applied, which indicated that reduction of pesticide/herbicide load also helped towards soil micro flora rejuvenation. High values of qCO_2 usually indicate stressing condition in disturbed systems [4] and, in the project area, overall qCO_2 value decreased by 35 % which indicated that under regenerative farming practice, microbial community getfavourable environment leading to requirement of lower energy for maintenance, which could be detected at the microbial community level by the lower CO_2–C evolution rate per cell mass and unit time [5]. On the other hand, FDA hydrolysis which indicated overall enzymatic activity by the soil microbes was increased by >44 % in the project area. At the same time, post three years of experimentation an overall 47 % decrease of QR value was noticed in the plots receiving complete organic or integrated soil management. The findings indicated that, application of good quality compost either singly or integration with fertilizer, coupled with reduction in use of pesticide/herbicide, not only reduced the microclimatic stress factors in soil but also created a favourable micro-environment that facilitated soil microbial rejuvenation.

3.8 Variation in Soil Quality Indicesunder Sustainable Tea Initiative: The Soil Fertility Index (FI) which was developed to assess the overall status of major nutrients in soil was comparatively higher in the case of compost applied plots with an overall increment of 7.6 percent. Where as soil microbial activity potential (MAP) which indicated the overall soil microbial activity under a specific management practice was increased significantly. Enhancement of MAP value in the project area post three years of experimentation indicated the favourable impact of organic/ integrated soil management and reduction in pesticide/herbicide usage towards improvement of soil biological quality. Finally the soil quality index (SQI) which is an important tool for assessing the soil health status increased by 5.8 % post 3 years experimentation indicating the favourable impact of the sustainable tea initiative towards soil quality development. The study conclusively pointed out the relevance of on- farm produced, good quality compost having self- generated microflora population along with reduction of

Table 2: Change in soil physical, physic-chemical and nutritional properties in the different Regenerative Farming Models at Lakhipara Tea Estate, Dooars, West Bengal

Expt.	Plot	Particle Size Distribution (%)			Texture	Bulk Density	pH_w (1: 2.5)	Org. C %	Av-N	AvP_2O_5	AvK_2O	$AvSO_4$
		Soil physical, physic-chemical and nutritional properties										
		Sand	Clay	Silt					(Kgha^{-1})			
Expt-1	BB-1A	46.74	22.1	31.16	Loam	1.11	4.56 (4.57)	2.03 (1.86)	455 (364)	49 (29)	165 (163)	36 (32)
Expt-2	BB-1BC	65.18	18.1	16.72	Sandy Loam	1.09	4.62 (5.28)	1.95 (1.70)	433 (375)	43 (28)	204 (190)	36 (24)
Expt-3	BB-2	48.68	22.62	28.7	Sandy clay loam	1.13	4.93 (4.61)	1.62 (1.57)	388 (366)	39 (24)	203 (192)	50 (37)
Expt-4	BB-3C	49.94	22.1	27.96	Sandy clay loam	1.04	5.79 (4.29)	1.49 (1.44)	363 (367)	39 (43)	183 (176)	35 (26)
	BB-3D	52.45	19.92	27.63	Sandy loam	1.06	5.20 (5.01)	1.30 (1.01)	295 (282)	36 (33)	183 (190)	44 (22)
Expt-5	BB-3AB	51.39	22.1	26.51	Sandy clay loam	1.14	4.28 (4.27)	1.40 (1.45)	408 (414)	41 (32)	199 (195)	48 (39)
	BB-3EXT	67.31	18.53	14.16	Sandy Loam	1.08	4.92 (5.45)	0.53 (0.57)	266 (259)	32 (28)	208 (169)	41 (38)
Overall	-	**55.69**	**20.73**	**23.57**	Sandy clay loam	**1.10**	**4.99** **(4.83)**	**1.43** **(1.34)**	**366** **(345)**	**39** **(34)**	**197** **(184)**	**42** **(32)**

Table 3: Change in soil microbial properties and soil quality indices in the different Regenerative Farming Models at Lakhipara Tea Estate, Dooars, West Bengal

Expt.	Plot	Soil Microbiological Properties								Soil Quality Indices			
		MBC	**SR**	**SIR**	**FDA**	**qMBC**	**qCO_2**	**qFDA**	**QR**	**PI**	**FI**	**MAP**	**SQI**
Expt-1	BB-1A	496.7 (158.4)	1.05 (0.68)	12.40 (3.95)	195.5 (92.6)	2.45 (0.85)	2.11 (4.29)	0.96 (0.50)	0.08 (0.17)	24.00	25.00 (23.00)	19.00 (8.00)	0.79 (0.51)
Expt-2	BB-1BC	394.8 (191.7)	1.02 (1.16)	9.85 (4.78)	180.7 (101.1)	2.02 (1.13)	2.63 (6.06)	0.93 (0.60)	0.11 (0.24)	22.00	23.00 (20.57)	19.00 (10.00)	0.71 (0.48)
Expt-3	BB-2	437.3 (188.7)	1.33 (1.12)	10.91 (4.70)	161.3 (103.8)	2.71 (1.25)	3.05 (6.09)	1.01 (0.67)	0.12 (0.24)	23.00	24.00 (22.00)	17.00 (10.00)	0.71 (0.52)
Expt-4	BB-3C	318.5 (237.3)	0.98 (1.04)	7.94 (5.92)	136.3 (85.9)	2.14 (1.65)	3.06 (4.38)	0.92 (0.60)	0.12 (0.18)	23.00	21.00 (20.00)	17.00 (10.83)	0.65 (0.51)
	BB-3D	348.5 (239.8)	0.51 (0.68)	8.70 (5.98)	146.9 (88.4)	2.68 (2.37)	1.47 (2.84)	1.13 (0.87)	0.06 (0.11)	22.00	22.00 (23.00)	17.00 (11.67)	0.65 (0.56)
Expt-5	BB-3AB	248.2 (209.4)	1.71 (1.66)	6.19 (5.22)	92.3 (100.4)	1.77 (1.46)	6.91 (8.34)	0.66 (0.70)	0.28 (0.33)	23.00	20.00 (20.00)	13.00 (10.83)	0.55 (0.51)
	BB-3EXT	218.5 (180.4)	1.31 (1.20)	5.45 (4.50)	103.8 (90.3)	4.17 (3.23)	5.96 (6.89)	1.97 (1.63)	0.24 (0.28)	22.00	15.43 (14.57)	17.00 (15.00)	0.54 (0.49)
Overall	-	381.8 (199.1)	**1.23** **(1.18)**	**8.53** **(4.96)**	**140.1** **(97.2)**	**2.61** **(1.72)**	**4.02** **(6.16)**	**1.13** **(0.82)**	**0.23** **(0.25)**	**23.00**	**23.00** **(21.00)**	**17.00** **(10.00)**	**0.69** **(0.51)**

Note : *MBC- Microbial Biomass Carbon (µg CO_2-C/g dry soil), SR- Soil Respiration, SIR – Soil Induced Respiration, FDA- Fluorescein Di-acetate Hydrolysis (µg/g dry soil), qMBC- Microbial Quotient (%), qCO_2 – Microbial Metabolic Quotient, qFDA : Specific hydrolytic activity (%),QR- Soil Microbial Respiration quotient;*PI – Physical Index; FI – Fertility Index, MAP : Microbial Activity Potential, SQI : Soil Quality Index pesticide/herbicides use towards the time bound rejuvenation of soil health (Fig 2). Thus the study showed that soil health management should emphasize on the quality of the soil inputs in terms of diversity and population of the self-generated lifeforms in order to restore the soil nutrient dynamics without any time lag;

Pic 1 : Cow urine collection

Pic 2 : Organic concoction preparation

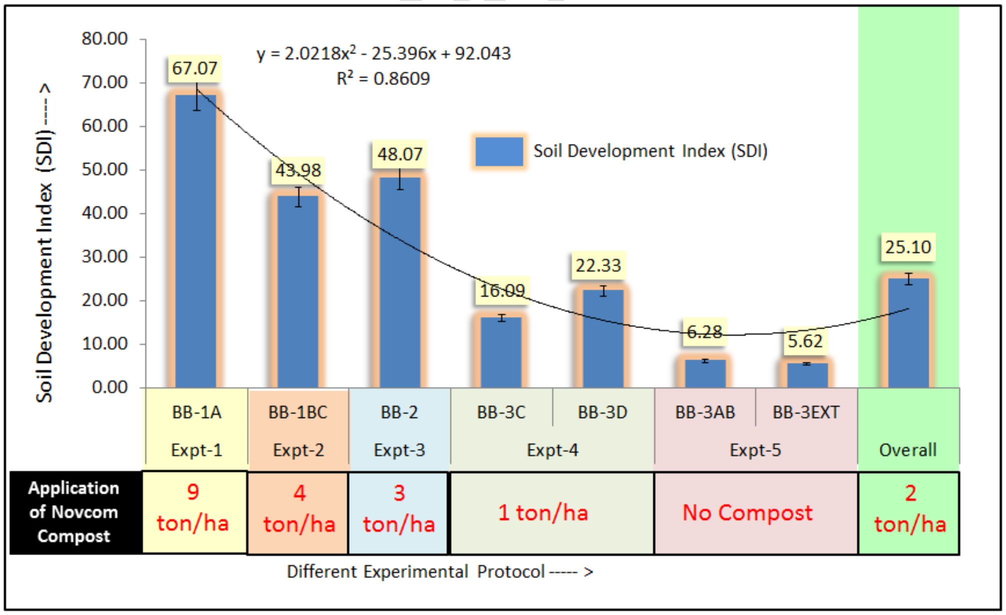


Fig 2 : Comparative study of Soil Development Index (SDI) with Novcom compost application in the project area.

3.9 Comparative study of carbon sequestration under Sustainable Tea Initiative

The recent attention to global warming have motivated the scientific community to search for efficient soil management and cropping systems to convert CO_2 from the air into SOC [6]. Agricultural practices can render a soil either a sink or a source of atmospheric carbon dioxide (CO_2), with direct influence on the greenhouse effect [7,8]. So, study of soil organic carbon sequestration rate will indicate the ecological sustainability of any cultivation practice. To study the impact of sustainable tea initiative on the soil carbon sequestration, the soil organic carbon stock up to the major root zone (0 to 30 cm) were evaluated for the different treatment plots, and the study revealed that about 6.72 % in the soil organic carbon stock (7370 kg/ha in 2014) in the project area by 2017, the value figuring at 7865 kg/ha (Fig 3). Soil Org. C sequestration rate (SOSR) varied from 87 to 457 kg/ha/year under different dose of compost application with average of 165 kg/ha/year in the project area (Fig 4).

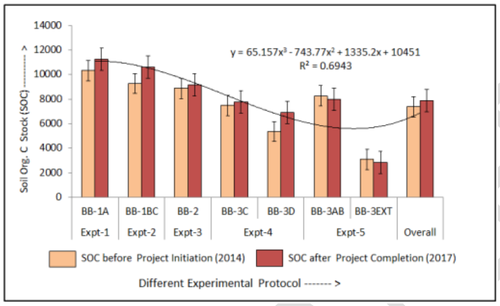


Fig 3 : Soil Organic Carbon Stock in different Experimental Protocol.

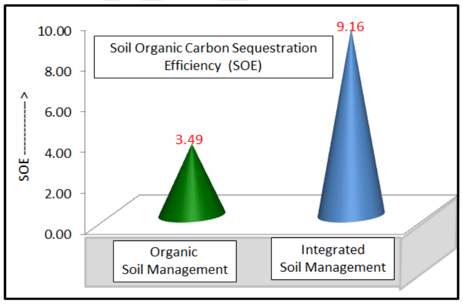


Fig 4 : Comparative change of soil organic carbon sequestration efficiency (SOE) .

However soil organic carbon sequestration efficiency (SOE) was highest under integrated soil management, indicating the importance of soil microbial activity towards improving the rate of soil organic carbon sequestration. Compost provide a continuous mass and an energy flow that release organic compounds to stimulate the soil biota biodiversity and the soil organic matter (SOM) changes [9, 10, 11].

3.10 Comparative study of Energy Usage under Sustainable Initiatives at Lakhipara Tea Estate, Dooars:

Energy usage is one of the indices of sustainable agricultural practice and thus perfectly fit to evaluate impact of any regenerative farming initiatives. Nature friendly regenerative farming initiatives should have more usage of renewable energy sources and has lower energy usage as compared to industrial agricultural practice. Field energy usage varied in the different experimental plots depending on usage of mainly N-fertilizers and agro-chemical usage. As expected in Exp-1 where 100 % chemical NPK was replaced by organic soil management, total field energy usage is about 12 % lower than the average field energy usage in the project area, and about 24 % lower than the highest energy usage plots. However, comparative study of the field energy use efficiency during the pre-experimentation (year 2013) and the average energy use efficiency under the sustainable tea initiative (2014-16) revealed an overall increase in efficiency (approx. 14 %) under the latter. Increase in energy use efficiency was highest in Expt.-4 (24.36 % increase) followed by Expt.-5 (18.74 % increase) which was the combined effect of chemical fertilizer reduction (Fig 5).

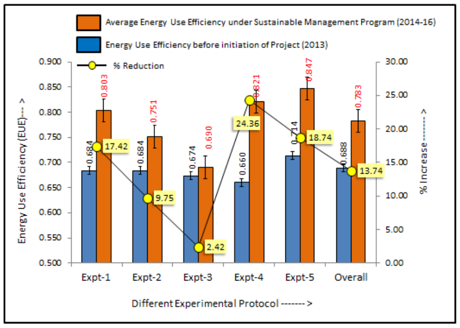


Fig 5 : Energy use efficiency under different experimental protocol in the Project area

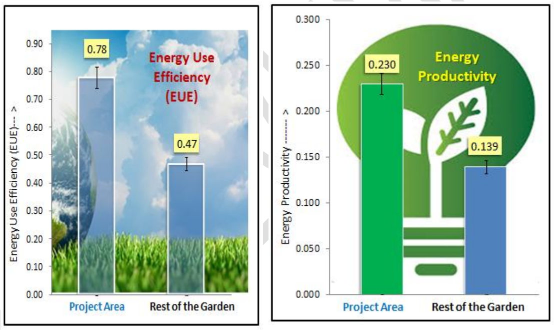
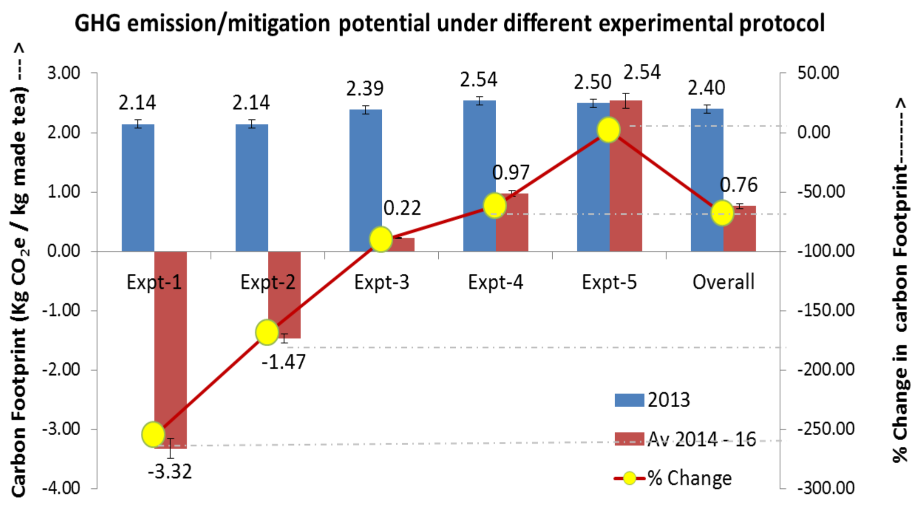


Fig 6A &6B : Comparative energy use efficiency and energy productivity in the Project area *vis- a-vis*rest garden area, Lakhipara T.E.

3.11 Comparative Energy Use Indices under Inhana Sustainable Tea initiative *vis-a-vis* Rest Garden Area: Energy use efficiency in the project area (EUE: 0.78) was 66 % higher as compared to that recorded for the total garden (EUE: 0.47) (Fig 6A). Significantly higher energy use efficiency in the project area was due to the comparatively lower use of synthetic fertilizers as well as agro- chemicals for pest/disease management. Similarly energy productivity in project area was 65 % higher in the project area which indicated that adoption of regenerative farming practice can etch out the road map for sustainable crop production through efficient energy use (Fig 6B). Efficient energy use can be achieved through reduction/ part replacement of the chemical fertilizers, as well as better nutrient use efficiency; as enabled by the application of good quality compost and the focus on plant health management'. The composite approach at the same time also helped to cut down the synthetic pesticide load on the crop as reflected in the comparatively higher energy productivity in the project area as compared to the total garden.

3.12 GHG mitigation potentials under regenerative farming initiatives

Climate change is the most critical environmental challenge facing humanity today with severe implications for natural ecosystems, agriculture and health. Agricultural sector, which is the second highest contributor of GHG in turn faces major a major setback, with global warming predicted to significantly affect agricultural production [12, 13]. Regenerative agricultural initiatives can play a decisive role in climate change mitigation and adaptation. In the present study, acomparative study of GHG emission under conventional practice and under Sustainable Tea Initiative (average of 2014-16) was done using ACFA version 1.0. The study indicated an overall 68 % reduction in carbon emission in the project area, with significantly differing GHG mitigation under the different regenerative agriculture models. GHG mitigation potential was highest in Expt.- 1 (255 % GHG reduction; 5.46 kg CO_2-eq / kg made tea) followed by Expt.- 2 (169 % GHG reduction; 3.61 kg CO_2-eq / kg made tea), Expt.- 3 (90 % GHG reduction; 2.16 kg CO_2-eq / kg made tea) and Expt.- 4 (62 % GHG reduction; 1.57 kg CO_2-eq / kg made tea) (Fig 7). This phenomenal achievement was primarily contributed by IRF Technology which enabled reduction of Urea-N without compromising crop yield and resource recycling (through utilization of Novcom compost), towards efficient soil carbon sequestration.



Application of Novcom Compost	9 ton /ha	4 ton /ha	3 ton /ha	1 ton /ha	No Compost	**2 ton /ha**

Fig. 7: GHG mission/mitigation under conventional practice (in 2013) *vis-a-vis* Sustainable Tea Initiative (average of 2014-16) at Lakhipara T.E.

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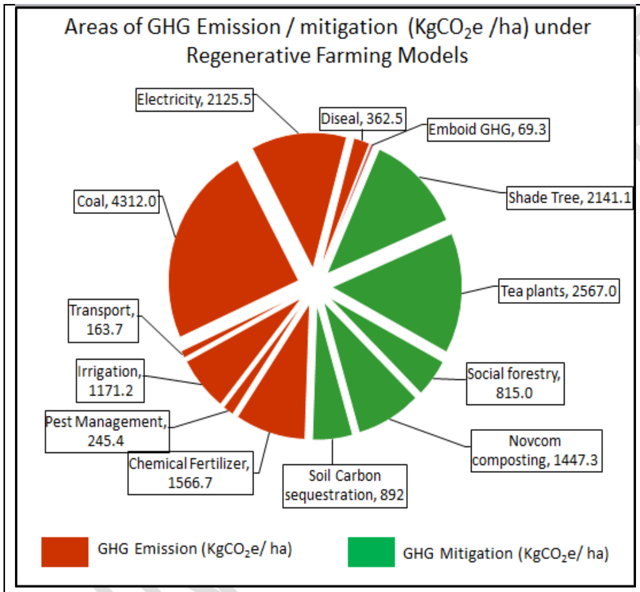
In the case of Expt.-1 and Expt.-2, GHG emission value (average of 2014-16) was negative (-3.32 & -1.47 kg CO_2-eq / kg made tea) which indicated that not only GHG emission (due to field agricultural activities) was completely reduced, CO_2 sequestration was also brought about under the sustainable tea initiative. These results implied that under this program up to field level practice, 3.32 and 1.47 kg CO_2 was sequestered for every 1 kg made tea production under Expt.-1 and Expt.-2 respectively.

It was interesting to observe the reduction of GHG emission potential under Expt.-5, where no compost/ organic inputs were applied for soil management. The finding indicated that even under conventional farming, there is scope of reducing the GHG emission potential through adoption of 'Plant Health Management' (Fig 8).



Source of GHG Emission	**% of total Emission**
Chemical Fertilizer	15.90
Pest Management	2.49
Irrigation	11.89
Transport	1.66
Coal	43.76
Electricity	21.57
Diseal	3.68
Emboid energy	0.70
Source of GHG Mitigation	**% of total Mitigation**
Shade Tree	27.23
Tea plants	32.65
Social forestry	10.37
Novcom composting	18.41
Soil carbon sequestration	11.35

Fig. 8: Overall GHG emission / mitigation under different operations in the project area at Lakhipara T.E.

Plant Health management under IRF Technology helps to enhance uptake and utilization of nutrients from soil, hence reduction of fertilizer-N without compromising crop yield can be possible. Thus sustainable tea initiatives with specific focus on soil and plant health management not only helped to reduce the N-fertilizer and the requirement of plant-protection chemicals, but also influenced the crop productivity in a positive manner which cumulatively enabled the reduction of GHG emission potential even under 100 % conventional practice and thus overqualified as a regenerative farming model with satisfying its prime objectivities.

Another interesting findingwas that an initial investment of Rs. 3937/- could potentially reduce 1 MT of CO_2e per ha. But when assessed for an entire year there was an actual saving of Rs. 395/- on field input management cost perMT of CO_2e mitigation; due to reduction in the use of of chemical fertilizers and pesticides. Moreover, there was an increase in the income potential of the garden by Rs. 3688/- per MT of CO_2e mitigation; due to an increase in crop productivity. The cost economics reflected that carbon footprint of made teacan indeed serve as an indicator of both ecological and economical sustainability.

3.13 Social cost saving

The social cost of carbon (SCC) is an estimate of the cost, in dollars, of the damage done by each additional ton of carbon emissions. In principle, it includes the value of all climate change impacts, including (but not limited to) changes in net agricultural productivity, human health effects, property damage from increased flood risk natural disasters, disruption of energy systems, risk of conflict, environmental migration, and the value of ecosystem services. It also is an estimate of the benefit of any action taken to reduce one ton of carbon emissions.

The ability of cost-benefit analyses to account for positive and negative impacts of reducing greenhouse gas emissions is an important part of policymaking [14], but most importantly it can help to adjudge the synergies of an agricultural model with regenerative agriculture practice. Estimation of the SCC in the project area in terms of the total GHG mitigation of about 237 MT CO_2e, could essentially contribute a benefit of approximately $49,512 or Rs 40.6 lakh/year.

Pic 3 : Winter work activity as per guideline of sustainability program

3.14 Comparative study of field management cost and income potential

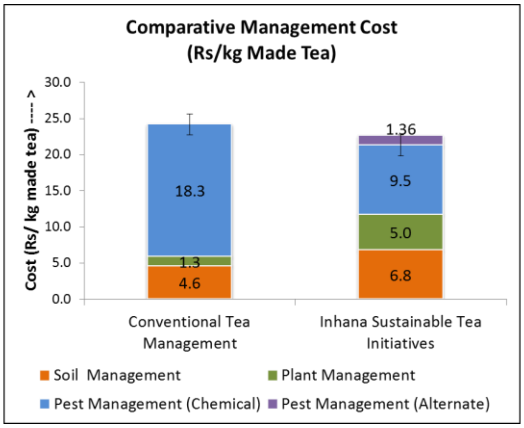


Fig. 9 : Comparative study of field management cost underconventional practice *vis-a-vis* Sustainable Tea Initiative at Lakhipara T.E.

Comparative study of crop management cost was done in respect of inputs and their application, under the different crop management systems. The overall crop management cost under the IRF Sustainable Tea Initiative (Fig 9) was found to reduce by 6.4% as compared to conventional tea management (Rs 22.6 over 24.2 per kg made tea). Reduction of cost under the former despite adoption of the activities for soil health management, contradicted the general myth or perception that adoption of any additional program more specifically soil inputs enhances the overall management cost. Also, there was approximately 37.4 percent reduction of unsustainable inputs i.e., chemical fertilizers and pesticides under this program, which helped to reduce the negative impact on soil and plant health.

The study also indicated that an investment of Rs 6.20/ kg made tea in the sustainability account, finally led to a reduction of the overall cultivation cost by about Rs. 1.5 /kg made tea. This was contributed by about 50 % reduction of chemical pesticide cost with crop sustainability; which would actually ensure long term sustainability of the garden due to reduced dependence on the toxic agrochemicals. Also due to higher crop yield in the project area, the garden got an additional income of Rs. 14000/- (approximately) per ha considering the average selling price of Lakhipara tea during 2014-16; not considering any higher price realization for sustainable - low residue teas. This was a significant achievement considering that the rest of the area lost an income of more than Rs 21,000/- per ha due to crop loss during the same period,as a result of higher pest infestation and higher abiotic stress. Thus the project clearly indicated that adoption of sustainable initiative based on a comprehensive - scientific technology could enhance the income potential of a garden without incurring anyadditional cost.

Ideally the investment on sustainable management of soil and plant health should be more than 60 % of the total management cost. Hence, unsustainability in the present cultivation program is depicted in the pest control cost which commanded a lion share of the total management cost (76.0%) versus a mere 24.0% investment for sustainable management of soil and plant health. Under the sustainable tea initiative, there was not only a reduction in the total cultivation cost, the ratio of chemical pest control cost with respect to that incurred for sustainable management of soil and plant health repositioned at 42: 58, which indicated an enhancement of sustainability cofactor and system stability.

4. CONCLUSION

Adoption of regenerative agriculture principles for ‘Sustainable Tea Management’ at Lakhipara Tea Estate served the dual objectives of pesticide reduction and crop yield improvement. The three years study **(encompassing different pruning cycles with respective soil restoration program)** indicated that adoption of IRF Technology and Novcom Composting Technology of IORF for soil and plant health management enabled rejuvenation of soil microflora population and diversity and improved plant health that helped in restoration of the soil-plant-ecology interactions. These were reflected in the higher nutrient use efficiency, reduction in pest pressure, and higher bush resilience. Improved bush resilience is the prerequisite criteria for better management of the biotic and abiotic stress factors for consistent crop performance, lesser pesticide requirement and efficient energy use, leading to reduction of the overall carbon footprint and most importantly an improved cost effectivity ratio. The study highlighted the need for induction of a comprehensive - scientific technology to achieve the desired objectives within a defined period of time. The findings can serve as a benchmark towards development of an effective roadmap for safe and sustainable, carbon saving tea production.

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