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Development of Regenerative Tea Cultivation Models through 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-I)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Climate change is a reality and its impact on the tea plantations is apparent in the rise of pest intensity, higher agrochemical use, inconsistent crop yields, declining grand growth period, increased abiotic stress and various other challenges; that threaten long-term sustainability of the Indian tea sector.

The urgency to adopt sustainable practices is increasing by the day but to gain time bound results a comprehensive focus encompassing soil and plant health development will be crucial.

To deal with climate challenge head-on, the Indian tea industry is making changes at various levels of operations. The sustainable tea initiative at Lakhipara tea estate, was one such attempt by the Goodricke Group Limited in their Dooars tea growing region of West Bengal. The program was initiated in 2014 with an aim to reduce pesticide use, improve soil quality, and produce quality teas while sustaining crop yields, improving renewable energy use and lowering the carbon footprint. Adoption of Inhana Rational Farming (IRF) Technology and taking the essence from 'Trophobiosis Theory' of French Scientist F. Chaboussou, the program focused on management of soil and plant health.

Three years evaluation of crop yields in respect of the budgeted crop, revealed on an average an excess of 78 kg/ha/year in the project area. In rest of the garden area a contrasting crop loss of 118 kg was recorded per ha during the same period. The higher crop performance positively correlated with the higher nutrient use efficiency which was 17.7 percent higher in the project area (NUE_{NPK} : 8.86) as compared to the general garden area (NUE_{NPK} : 7.53), which reflected the impact of plant health management towards enhanced nutrient uptake, assimilation and utilization. Assessment of pesticide usage, revealed up to 77% decrease in usage in the project area during 2014-16, as compared to the pre- project year. Comparison with pesticide usage of the Dooars tea growing region during this same period, indicated a 62% lower Crop Pesticide Pollution Index (CPPI) in the project area. The finding indicated a 52 to 77% reduction in the accumulated toxicity potential of the applied pesticides in the project area; thereby accrediting safer tea development under this program, when adjudged in terms of pesticide residue.

Assessment of soil quality revealed an overall eight percent increment in Soil Fertility Index (FI) value, with significant improvement in soil microbial activity potential (MAP) values i.e., by almost four times. The finding pointed towards the favourable impact of soil health management primarily through Novcom composting towards enhancement of soil microbial interactions. Post three years of experimentation the overall Soil Quality Iindex (SQI) value increased by 6% in the project area. The finding corroborated a concurrent 6.72% increase in the soil organic carbon stock during the same period.

Reduction in use of non- renewable inputs viz. chemical fertilizers and pesticides in the project area was indicated by approximately 40 percent enhancement in energy use efficiency and energy productivity post the assessment period. Carbon assessment in terms of kg CO_2 equivalents/ kg made tea (using ACFA version 1.0) indicated approx. 65 to 70 % lower footprint in the project area, primarily due to 20 to 30 % reduction in chemical fertilizers and 60 to 70 % reduction in the use of synthetic pesticides.

The results indicated that while integrated soil management is the pre-requisite criteria towards rejuvenation of soil health and for restoration of the habitat for predators, it does not play a direct role in reducing the pest pressure and simultaneously the requirement of pesticides. Physiologically activated plants/ bushes on the other hand; due to their higher nutrient assimilation capacity and efficient protein synthesis are always lesser susceptible to pest attack. Hence, focus on activation of plant physiology can reduce the plant- pest interaction leading to a natural reduction in the requirement for pesticides vis-à-vis the pesticide usage.

Keywords: Novcom composting technology; Inhana Rational Farming (IRF) Technology; healthy plants; pesticide load; carbon sequestration; energy use efficiency; GHG mitigation; ACFA (Version 1.0); social cost; regenerative sustainability.

1. INTRODUCTION

As our climate continues to heat up and the impacts of that warming grow more frequent and severe, farmers and farm communities around the world will be increasingly challenged [1]. In fact, the chemical farming based industrial model that dominates our nation's agriculture—a model that neglects soils, reduces diversity, and relies too heavily on fertilizers and pesticides—makes our farms susceptible to climate impacts. The combination of advancing climate change and an already-vulnerable industrial system is a “perfect storm” that threatens farmers’ livelihoods and our sustainability. As a consequence, India has the world's highest social cost of carbon [2]. A report by the London-based global think tank Overseas Development Institute found that India may lose anywhere around 3–10% of its Gross domestic product (GDP) annually by 2100 and its poverty rate may rise by 3.5% in 2040 due to climate change [3, 4].

However, the tea industry is not immune to the adverse impact of changes in temperature and precipitation patterns. The impacts of climate change on the tea include irreversible yield losses, impacts on regional economies, and the threatening of millions of livelihoods of humans in many nations [5, 6]. Tea as a C_3 plant is less efficient in production and partitioning of photosynthates and this lesser efficiency is further compromised with removal of vegetative propagation of the apical growth in the form of plucking and also sink-limited as well because shoots are harvested before their maximum biomass is reached in order to maintain quality characters of made tea. A study by Duncan et al [7] has found that an additional one degree above an average temperature of 28°C reduces tea yields by around 4%. This is because high temperatures and intense sunlight cause damage to the tea leaf and dry out the soil. It also decreases the overall taste and quality of the product making it difficult for tea planters to sell [8]. Moreover, tea accounts for 35%–50% of secondary metabolites on a dry weight basis; these metabolites are also vulnerable to climatic variables altering phytochemical and organoleptic (texture, color, taste visual appeal, aroma) properties, which has divergent impacts on tea quality, market prices, consumer demand, and the psychological implications of tea consumers across nations [9].

The Indian tea industry has been facing tough challenges in terms of productivity downfall, depleting soil health and rising pest virulence; issues that are further aggravated by the climate change impact. The fall in production coupled with increasing cost of agrochemicals and labour has led to a sharp increase in the cost of production. This has not only shaken the sustenance of the tea industry, but also compromises the yearly development program, which is imperative for the future sustainability of any tea estate. The Dooars region of West Bengal in India is a major tea producing region contributing around 25% of the national tea yield [10]. However, climate change impact *viz.* heavy rainfall, shortening of the rainy season, and increasing temperatures have taken a toll on tea bush performance. Moreover, as increasing temperatures and prevalence of pests and plant diseases are associated [8], more than 100 percent increase of pest/disease incidences as compared to the past decade has increased the challenges in terms of agrochemical cost and pesticide residues.

In this background, adopting regenerative farming principles in tea cultivation; offers a resourced based practical solution for long term sustainability and climate change mitigation. Sustainable practices and the term Regenerative systems share the same science and philosophies, but vary in terms of how they impact on ecosystem. ‘Sustainable’ is an umbrella term for any practice that aims to preserve an existing agro-ecosystem to support the goal of making a farm more future-fit and resilient. Regenerative agriculture on the other hand aims to increase biodiversity, enrich soils, preserve carbon and enhance ecosystem services to sustain crop productivity. However, the ecological framework to support sustainable agriculture may no longer be in place in some cases, for which, *regenerative* agriculture could be a more accurate pathway towards meeting a grower’s goal.

In the present study, different regenerative agriculture models were formulated with incorporation of Inhana Rational Farming (IRF) Technology; and inducted in Lakhipara Tea estate, one of the Goodricke group’s quality tea gardens in the Dooars tea growing region (West Bengal, India); to evaluate the impact in tea ecosystem.

2. MATERIALS AND METHODS

The study was part of the sustainable initiative by Goodricke Group Ltd, a leading tea producer of India, who started the ‘Sustainable Tea Management Program’ in technical association with (IORF) in its group tea estates, to produce ‘Safe and Sustainable (*Low Pesticide Footprint*) Teas’ from 2014 onwards. The experiment was conducted towards developing a sustainable cultivation module in tea which would perfectly align with the principles of regenerative agriculture.

2.1 Study Area

The present study was carried out in Lakhipara Tea Estate of Dooars, West Bengal, India. Located in the misty foothills of the Bhutan hills in the district of Jalpaiguri, it lies at the latitude of 26.82°N and longitude of 89.02°E at an elevation of 174 m (ASL). The climatic character is sub-tropical and humid. The average temperature range (Maximum to Minimum) varies between 33°C to 6°C between summer and winter. As a result of drizzling, the climate has maximum relative humidity, which is 86 percent on an average throughout the year. An appreciable difference between day and night temperatures is also noticed throughout the year. The average rainfall is about 3160 mm per year and it is most frequent between the months of April to October. However, about 90 percent of the rainfall occurs between the months of May to September. The soil characteristics of the region consists of high percentage of alluvial deposits on nearly level (0-2 %) slope. The porous nature of the soil restricts surface irrigation because of its poor water retaining capacity, poor infiltration and lesser aeration [11].

2.2 Concept of Healthy Plants

A healthy plant is one that can grow and produce despite environmental stress, pests, and competition. Concept of healthy plants can be defined as plants' optimum potential to utilize two unique properties of self-nourishment and self-protection which nature has designed for them. That means plants will make their own food and protect themselves from external biotic and abiotic stress. However, in industrial agriculture the factor that affects our food relates to both the plant's immune system and an unanticipated vicious cycle that is linked to both nitrogen fertilizers and the rescue chemicals.

The French researcher, Francis Chaboussou, demonstrated that fungicides, pesticides and herbicides negatively affect the plant metabolism, Thereby increasing their susceptibility to pests [12]. Nitrogen mismanagement can have a similar impact. Chaboussou's Theory of Trophobiosis simply states that the nutritional state of the crop will affect its susceptibility to pests and disease [13]. His study indicated that protein metabolism is amongst the most sensitive of all plant processes and it can be compromised with repeated use of fungicides and pesticides. Compromised protein metabolism causes the consequent buildup of amino acids and reducing sugars in the plant cell sap. And the insects and fungi prefer to feed on plants that are over supplied with short chain amino acids and simple sugars. This is because amino acids are the protein building blocks and the reducing sugars offer the energy source for this protein synthesis. Chaboussou also stated that nitrogen mismanagement is also a major player in creating conditions to foster pest and disease pressure. Heavy applications of soluble nitrogen fertilizers increase the cellular concentration of nitrate, ammonia and amino acids faster than can be used for the synthesis of protein which increase the risk of pest pressure after application of nitrogen [14].

2.3 Inhana Rational Farming (IRF) Technology

Inhana Rational Farming (IRF) Technology works towards the rejuvenation of the Plant and Soil Health in terms of restoring Plants' inherent characteristics of (i) Self-Nutrition and (ii) Self–Protection and reinstatement of the Soil Micro-life and its functionalities [15] (Fig. 1.). Plant health management under IRF Technology is based on the same principle as the Trophobiosis Theory. The objective is to create a crop production management system where the plants can meet their nutritional requirement in an efficient manner and protect themselves from the biotic and abiotic stress so as to reduce the dependency on the two hands of un-sustainability i.e. the fertilizers and the pesticides, even under the climate change impacts.

The Technology is based on the Principle of 'Energy Management' which advocates that the soil and plant system are not deficient of elements; they are just de-activated under chemical bombardment. Hence, there is scope for Re-activation of elements; provided a process of energy infusion is adopted. IRF Technology through its 'Inhana Energy Solutions' strives towards providing the required specific energies to the soil and plant system that can restore their inherent functionalities [16].

2.4 Development of Regenerative Tea Cultivation Models- a journey of more than two decades

The base lining for these models started almost one and half decades back when sustainable organic cultivation and carbon neutrality in tea was demonstrated through the adoption of

Inhana Rational Farming (IRF) Technology [17]. The dual approach of soil and plant health management, which was adopted for the purpose was scientifically documented and re-validated under FAO-CFC-TBI project (2009 -11) which had a clear mandate on developing sustainable pathways for organic tea cultivation [18]. But considering that organic is limited by its resource dependency specially for organic soil management, strict regulation on field management and certification criteria, the need arose to bring forth a moderate pathway that can provide ecosystem benefits and help growers to slowly shed the conventional chemical inputs, but not burden them with strict regulations. This was the background for induction of sustainable tea program at Lakhipara tea estate. However, as the study progressed it demonstrated the climate impacts in terms of carbon capture in soil and energy transition from Non- renewable to renewable; which indicated its synergies to a Regenerative Agriculture Model.

Picture 1. Landscape view of Lakhipara Tea Estate, Dooars, West Bengal

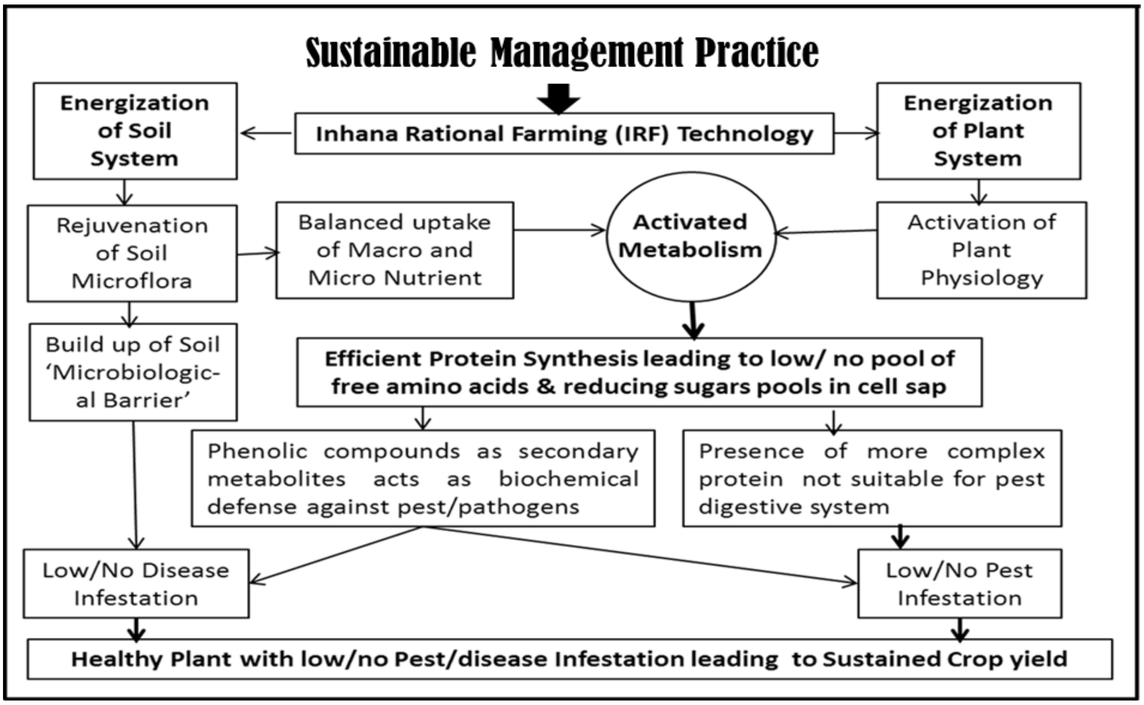

Fig. 1. Sustainable management through Inhana Rational Farming (IRF) Technology, in the backdrop of Trophobiosis Theory [14]

2.5 Management Done under the Program

Crop management plan was designed post SWOT study of the project area (*which included soil analysis, history of crop performance and pest/disease infestation pattern*) and integrated with the existent garden practice. Month wise activity was developed, and demonstration was set up for on- farm production of Novcom compost (*from garden weeds and cow dung*) and organic concoctions. Inhana Plant Health Management (IPHM) schedule, that utilizes various Potentized and Energized Botanical Solutions as well as on- farm developed Plant Tonic and Plant Elixir towards activation of plant physiological functions viz. photosynthesis, metabolism, nutrient assimilation etc. and better host- defense mechanism against pest/ disease. This leads to reduction of free amino acid and reducing sugars in the plant cell sap and enables better secretion of bio-chemicals; that on one hand reduces pest susceptibility and improves disease resistance and alternately improves tea quality due to enrichment of the antioxidant potentials. Pest management plan excluded the prophylactic application of chemical pesticides and focused on bush sanitation, improvement of drainage, increased aeration and reduction of overshaded conditions.

2.6 Experimental Design

The focus on designing the experimental setup in Lakhipara micro-plots was to generate the database to study the impact of management undertaken with adoption of Inhana Rational Farming (IRF) Technology towards crop performance and pesticide use reduction under chemical nutrient reduction in varying dosage and integrated application of Novcom compost (Tables 1, 2 & 3). Five different experiments were set up (based on different dose of organic soil resource) for the purpose and the assessment was done w.r.t five different components i.e., crop yield, nutrient use efficiency, reduction in pesticide load, variation in soil quality & finally the environmental sustainability quotients like carbon sequestration, energy use efficiency & GHG mitigation potential.

2.7 Analysis of soil and compost quality

2.7.1 Analysis of compost samples

30 Novcom compost heaps were selected randomly from over 100 Novcom compost heaps in 3 years and total 60 compost samples were drawn out from the selected heaps for their quality assessment and quality assessment was done as per standard methodology [19, 20, 21].

2.7.2 Analysis of soil samples

Soil samples were collected from major rootzone (0 – 30 cm) before initiation of the program (January, 2014) and 3 years after completion of tea season (January 2017). From each project plots 5 samples were collected in zig-zag manner and make one composite sample for analysis.

IRF Package of Practice for Regenerative Farming

SOIL HEALTH MANAGEMENT
- Application of on-farm Novcom compost @ 1 – 9 ton as per protocol
- Reduction of N fertilizer 15 – 100 % & applied in combination with Novcom compost
- Application of Rock Phosphate & Elemental Sulphate with Novcom compost
- Application of CDS in soil post Novcom compost application
- Minimize herbicide application

PLANT HEALTH MANAGEMENT
- 8 – 10 rounds Inhana solutions for Plant Health Management
- Selective nutrient foliar with CDS/P5 (Plant Elixir) concoctions
- Pre & Post Pruning management
- Organic prophylactic disease management
- Specific hail management program
- Bush health recovery program post red spider / helopeltis/looper infestation

INTEGRATED PEST MANAGEMENT
- Alternate pest control options during lean months (November to March)
- Use of 2 -3 rounds neem/karanj concoction for bush sanitation & pest cycle breakup
- Use of lime sulphur / micronized sulphur & other concoctions
- Intensified observation, & spot application
- Restricted use of Hard Chemicals (as per rating of toxicity load)

Chart 1. IRF Management practice for regenerative farming in tea

Table 1. Experimental Plots at Lakhipara Tea Estate

Treatment Plots	Sec No	Project Area	
		Area	**Regenerative Farming Module**
Exp. -1	BB 1 A	1.83 ha	Replacement of 100 % Chemical Nutrients with 9 ton on-farm Novcom Compost along with Inhana Plant Health Management
Exp. -2	BB 1 BC	11.26 ha	Replacement of 50 % Chemical- N through Integrated Soil Management with 4 ton on-farm Novcom Compost & Inhana Plant Health Management
Exp. -3	BB 2 AB	16.89 ha	Replacement of 35 % Chemical- N through Integrated Soil Management with 3 ton on-farm Novcom Compost & Inhana Plant Health Management
Exp. -4	BB 3 C BB3D	5.75 ha 5.0 ha	Replacement of 25 % Chemical- N through Integrated Soil Management with 1 ton on-farm Novcom Compost & Inhana Plant Health Management
Exp. -5	BB 3 AB BB 3 Ext	11.26 ha 10.83 ha	Replacement of 15 % Chemical- N through Inhana Plant Health Management

Table 2. Management done under conventional farming and regenerative farming with adoption of IRF Technology

Expt	Plots	Year 2013 (Conventional Management)			Year 2014 -16 (Inhana Sustainable Tea Initiative)				
		Foliar Application (Chemical Fertilizer)	Chemical Pesticide Application (Effective Rounds)	Total rounds of spray	Inhana Solutions for Plant Management	Foliar Application (Chemical Fertilizers in combination of CDS or P5)	Chemical Pesticide Application (Effective rounds)	Neem & Karanj oil concoction	Total rounds of spray
Expt-1	BB-1A	7	19.52	26.52	10	7	14.80	4.0	35.80
Expt-2	BB-1BC	7	19.52	26.52	10	7	14.80	4.0	35.80
Exp-3	BB-2	7	28.25	35.25	9	7	14.77	3.5	34.27
Exp-4	BB-3C	7	20.51	27.51	9	6	14.35	4.0	33.35
	BB-3D	7	22.81	29.81	9	6	15.50	4.0	34.50
Exp-5	BB-3AB	7	24.25	31.25	10	9	10.41	4.0	33.41
	BB-3EXT	7	28.95	35.95	10	9	9.27	3.04	31.31
Overall		**7**	**24.69**	**31.69**	**9.6**	**7.5**	**13.07**	**3.70**	**33.86**

Table 3. Nutrient Management in the Project Plots at Lakhipara Tea Estates

Expt	**Plots**	**Area**	**NPK Recommended for Ground Application through Chemical Fertilizer**	**Manuring under Sustainable Tea Initiative**			**N+P+K Foliar Application (kg/ha)**	**Total nutrient given (kg/ha)**	**Total Nitrogen given (kg/ha)**
				Chemical Fertilizer (NPK)	**Novcom Compost (NPK)**	**Rock Phosphate (P)**			
Expt-1	BB-1A	1.83	260 (118+33+108)	0	9ton (71.2+34.2+31.5)	16	20	172.6	82.8
Expt-2	BB-1BC	11.26	260 (118+33+108)	134 kg (52+21+61)	4ton (31.6+15.2+14)	16	20	230.5	95.2
Exp-3	BB-2	16.89	260 (127+35+103)	170 kg (80+30+60)	3ton (23.7+15.2+14.0)	12	20	247.3	115.3
Exp-4	BB-3C	5.45	230 (118+35+77)	170 kg (80+30+60)	1ton (7.9+3.8+3.5)	12	20	216.9	99.5
	BB-3D	5.00	318 (142+35+142)	240 kg (110+30+100)	1ton (7.9+3.8+3.5)	12	20	286.9	129.5
Exp-5	BB-3AB	11.26	262 (127+35+100)	195 kg (105+30+60)	0	0	20	214.7	116.6
	BB-3EXT	10.83	322 (143+35+143)	267 kg (116+35+116)	0	0	20	286.7	127.6
Overall		62.52	273 (127+34.6+111)	185 (86+28.4+79)	1.96 ton	8.61	20.00	243.4	112.8

Picture 2. Preparation of Novcom compost and application in project sections at Lakhipara Tea Estate

Picture 3. Application of Inhana Plant Health Management solutions & Organic concoctions at Lakhipara Tea Estate

The soil samples were divided into two parts, one part was kept in the refrigerator at 4^0C for doing microbial analysis; the other part was air dried, ground in a wooden mortar and pestle and passed through 2 mm sieve. The sieved samples were stored separately in clean plastic containers. Soil physicochemical, fertility and microbial properties were analyzed as per standard methodology [20, 22, 23, 24]. Comparative values of selective soil quality parameters were used as per the formula of Bera et al [25] to calculate soil quality index under different treatments.

2.7.3 Analysis of pesticide load and toxicity on crop and soil

For this the pesticide use in each plot was documented as per day wise operation. Then the data base was processed to evaluate the pesticide load on crop (PL_C) and on soil (PL_S), followed by computation of the crop pesticide pollution index (CPPI) and soil pesticide pollution index (SPPI) as per methodology developed by Bera et al [26].

2.8 Evaluation of Soil Carbon Sequestration

Soil organic carbon stock (kg ha^{-1}) was calculated as per methodology of Veldkamp [27]. At the same time, soil organic carbon sequestration rate (SOSR, kg/ha/yr) from all project plots were evaluated as per standard formula [28]. Soil organic carbon sequestration efficiency of organic amendment (SEO) was also calculated as per methodology of Hua *et al* [29].

2.9 Evaluation of Energy Usage

Energy equivalents of inputs and output was sourced from different published work [30, 31, 32]. Based on the energy equivalents of inputs and output, energy use efficiency and energy productivity were calculated for conventional practice and Sustainable management program [33, 34].

2.10 Evaluation of Carbon Footprint (Farm Gate Level)

Carbon foot print of made tea produced under different experimental plots were measured through Agriculture Carbon Footprint Assessor (ACFA ver 1.0), which is a carbon computing standard for evaluating carbon footprint in Agriculture specially sustainable agriculture considering variability under Indian Agro ecosystem. Inhana Organic Research Foundation (IORF), Kolkata has developed ACFA ver 1.0 in collaboration with ICAR - Agricultural Technology Application Research Institute (ATARI), Kolkata and active support from scientists from several research institutes, universities and carbon auditing organization viz Visva Bharati University, Bidhan Chandra Krishi Viswavidyalaya (BCKV), University of Calcutta, Indian Statistical Institute (ISI), Nadia Krishi Vigyan Kendra, BCKV, ICAR and i-NoCarbon, UK. [35].

2.11 Evaluation of Social Cost (Farm Gate Level)

The social cost of greenhouse gases (SC-GHG) reflects the economic cost of the damage to society caused by each additional ton of carbon dioxide, methane, or nitrous oxide emissions [36]. SC-GHGs provide a range of dollar estimates that can be used to incorporate the social benefits of reducing emissions into cost-benefit analyses [37]. This tool lets users calculate the present value of economic damages from a given amount of greenhouse gas emissions using the Interagency Working Group's 2021 interim estimates [38] and New York's 2020 estimates [39].

2.12 Economic Analysis

The economics of various treatments was also worked out following the standard techniques [40].

2.13 Statistical Analysis

Statistical analysis was done using statistical software SPSS 11.5.

3. RESULT AND DISCUSSION

3.1 Analysis of Compost Quality

Preliminarily, maturity of compost was seen on the basis of subjective indicators such as color, smell, and feel [41]. Dark brown colour, earthy smell, moist and finely divided end product lacking ammonia off-odours indicated adequate maturity of the compost to promote plant growth. pH of the compost samples varied from 6.51 – 7.59 indicating matured and good quality compost [42]. Electrical conductivity value was found in between 1.39 and 2.32 dSm^{-1}, indicating high nutrient status while being safely below (< 4.0 dSm^{-1}) the stipulated range for saline toxicity as per USCC [43]. Organic carbon content in compost samples ranged between 25.5 to 31.21 percent with mean a value of 28.4, which surpasses even the standard value (>19.4 percent) [44]. Total NPK of the compost samples (Table 4) indicate that compost samples were rich in nutritional status where as C/N ratio of the compost samples was estimated to be around 14.4 rendering all the compost samples to be matured and suitable for soil application. At the same time higher mineralization index indicate faster availability for plant growth.

Microbial status of any compost is the premium touchstone for judging compost quality as because microbes are the driving force behind soil rejuvenation and play a crucial role towards crop sustenance by maintaining the soil–plant–nutrient dynamics. Microbial population in Novcom compost was significantly higher (at least 10^3 to 10^4 times higher colony forming units per gm moist compost) than the population obtained in case of other compost samples, as also found by other workers [45, 46. 47] while working with Novcom compost. This unique feature might be attributed to the fact that the entire microbial populace was self- generated unlike those inoculated in case of other composting processes.

The phytotoxicity bioassay test, as represented by germination index provided a mean for measuring the combined toxicity of whatever contaminants may be present [48] indicated the absence of phytotoxic effect in all the compost samples as per the standard value of 0.8 to 1.0 [21]. At the same time germination index value of >1.0 as obtained in case of most of the Novcom compost samples (mean value 1.09) indicated not only the absence of phytotoxicity [49] but moreover, it confirmed that Novcom compost enhanced rather than impaired germination and root growth [47]. Compost Quality Index (CQI) is an overall evaluation method [50] for easy understanding and perception regarding the qualitative aspects of any compost indicted that the compost samples were mostly good to very good class [50].

3.2 Comparative Crop Performance under Different Regenerative Farming Modules

Lakhipara tea estate is one of the high yielding quality garden in the Dooars tea growing zone with average productivity (mature tea) of 2600 kg/ha. However, the project area was one of the weakest zone within the garden, riddled with several problems viz. average age of more than 42 years, high pest infestation, low productivity as compared to the rest garden area and comparatively high vacancy (5 to 8 %). Moreover, most of the project area came under the ‘B’ & “C’ category based on plant height, shade status and drainage problem. Evaluation of crop performance under the different experimental protocol at Lakhipara micro project area indicate significant outcomes which can be better understood only when analyzed with the associate factors like nutrient application, crop budget, rest garden performance during same period.

In Exp-1, where 100 % chemical fertilizer was replaced by Novcom compost (100 % of recommended nutrient dose was replaced by 62% NPK from compost @ 9 ton/ ha), crop performance was at par with the average crop budget of 2014-16. In case of Exp-2, where 50 % chemical- N was replaced through integration of on-farm produced Novcom compost @ 4 ton/ ha; crop performance followed a similar trend as observed under Exp-1. These two experiments showed crop sustenance under reduction of urea N and replacement of 50% of the reduced N through microbial rich stable organic sources (on-farm Novcom compost). The study indicated that when focus is imparted towards plant health development, crop can be sustained even when 2 units of urea-N is replaced by 1 unit organic-N. The achievement seems a tough challenge when factors like poor soil health, plant age, and most importantly moderate hail damage in consecutive years (1st week of April in both 2014 & 2015) in the project area were taken into consideration.

In the case of Exp-3, 35 % Chemical- N was replaced through integration of on- farm produced Novcom compost @ 3 ton/ha & application of Inhana plant health management. Here, the average crop productivity (1949 kg/ha) was noted to be 4.4 % higher than the crop budget (1867 kg/ha) which implied about 82 kg excess made tea production per ha per year. And the achievement is significant considering moderate hail damage during the consecutive years.

The highest improvement in crop i.e., 7.4 % higher production (2214 kg/ha) than the target yield (2062 kg/ha) during 2014-16, was documented under Exp-4 where 25 % Chemical-N was replaced through integration of Novcom compost @ 1 ton/ ha. This implies an excess made tea production of 152 kg per ha per year (Fig. 2). The achievement is particularly significant considering all the other non-supportive factors as mentioned above; and conclusively demonstrates the importance of on-farm produced compost towards higher nutrient use efficacy and the role of plant health management in securing better crop performance.

In Exp-5, there was about 15 % reduction in Chemical- N application. There was no integration of compost in soil, but Inhana plant health management was applied on the bushes. Evaluation of crop performance revealed about 3.5% higher crop productivity (2475 kg/ha) on an average over the crop budget (2391 kg/ha) implying about 85 kg excess made tea production per ha per year. Over achievement of the budgeted crop even under 15% reduction of chemical- N, moderate hail damage and considering that the crop budget remains unachieved even under full dose of the recommended fertilizer and despite very low hail damage during the same period (2014-16); unarguably validates the impact of Inhana plant health management towards crop sustenance irrespective of the biotic and abiotic stress factors.

Table 4. Analysis of Novcom compost Quality Parameters as per National and International Standards

Parameters	Ideal range	Range value	Mean Value ± Std. E
Moisture percent (%)	35.0 - 55.0	55.30 – 66.40	59.8± 0.76
pH_{water} (1 : 5)	7.2 - 8.5	6.51 – 7.59	7.03± 0.07
EC (dSm^{-1})	< 4.0	1.39 - 2.32	1.79± 0.08
Organic carbon (%)	16.0 - 38.0	25.5 – 31.21	28.4± 0.48
Total nitrogen (%)	1.0 - 2.0	1.76 – 2.23	1.97± 0.06
Total phosphorus (%)	> 0.5	0.64 – 0.87	0.75± 0.02
Total potassium (%)	> 0.5	0.79 - 1.18	0.87± 0.02
C/N ratio	10.0-20.0	13.5 – 14.9	14.4± 0.27
CMI[1]	0.79 – 4.38	1.34 – 2.15	1.72± 0.07
Total bacterial count	> 10 x 10^{12}	24 – 110 x 10^{16}	$47 x 10^{16}$ ±$4.2 x 10^{16}$
Total fungal count	> 10 x 10^{12}	12 – 47 x 10^{16}	$26 x 10^{16}$ ±$1.77 x 10^{16}$
Total actinomycetes count	> 10 x 10^{12}	8 -29 x 10^{16}	$17 x 10^{16}$ ±$1.17 x 10^{16}$
CO_2 evolution rate (mgCO_2 – C/g OM/ day)	< 5.0 – stable	1.45 – 3.56	2.89± 0.12
Phytotoxicity Bioassay	>0.8	0.97 – 1.26	1.09± 0.03
Compost Quality Index (CQI)	>4.0	3.74 – 6.36	4.74± 0.09

Note : [1]CMI: Compost Mineralization Index

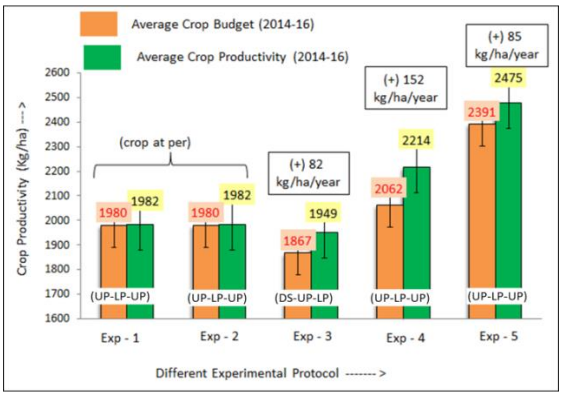

Fig. 2. Comparative study of crop performance under different Regenerative Farming Models

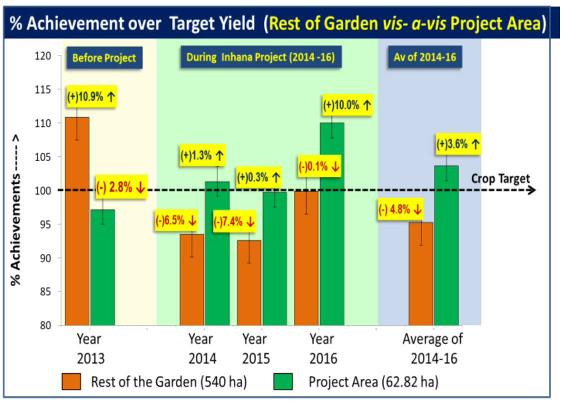

Fig. 3. Comparative crop production in project area & rest garden area at Lakhipara T.E

3.3 Comparative study of crop performance under project area *vis-a- vis* rest garden area at Lakhipara Tea Estate, Dooars

Comparative study was done to assess the crop performance in the project area w.r.t. the rest garden area. Prior to initiation of sustainable management program in 2013, the rest garden achieved 10.9% higher crop over target, whereas the project area remained 2.8% behind the same. As both the areas received similar management, hence; the poor performance in the project area indicated unfavourable factors which limited the bush response here. However, post initiation of the program crop productivity not only improved, it was found to be better than the rest garden area, moreover; performance over budget was documented that too under reduction of Chemical- N in varying quantities. This is corroborated by the excess made tea production of 76 kg/ha/year over the crop target during 2014-16 in the project area, where as in the rest garden area, there was crop loss of 118 kg/ha/year, during the same period (Fig. 3). The findings conclusively pointed out the relevance of 'Plant Health Management' towards crop yield sustenance irrespective of the biotic and abiotic stress factors. Year wise comparative study showed that in terms of the crop budget, total production in the general garden was 6.5, 7.4 and 0.1 % lower in 2014, 2015 and 2016 respectively. In contrast, the crop productivity in the project area was 1.3, 0.3 and 10.0 % higher in 2014, 2015 and 2016 respectively. This performance holds special relevance considering that the project area represented the low productive zone within the garden (as per the *average productivity of last pruning cycle),* majority of the bushes were aged around 42 years and 100 % the project area suffered hail damage for two consecutive years (2014 & 2015) apart from being highly prone to pest as well pest migration from neighboring gardens; as indicated by the pesticide use database of 2013. The study clearly indicates that, plant health management can play a pivotal role in regenerative-sustainable tea cultivation through optimization of plant photosynthetic efficiency, which is especially relevant considering the inherent limitation of Tea as a C_3 plant.

3.4 Reduction of Pesticide Load under Regenerative Farming Models

The Indian Tea Board launched the 'Plant Protection Code' as a policy on usage of Plant Protection Formulations in the tea plantations of India to restrict rampant use of pesticides. 'Trustea' is one such Indian sustainability code and verification system for the tea sector, which encompasses all aspects of tea production and seeks to embrace sustainability principles to boost productivity and maintain safety standards in order to produce "certified" safe, healthier and more environmentally friendly teas. However, restriction on agro-chemicals and bringing the cultivation practices under higher surveillance is not enough to curb the high use of agrochemicals. There is need to resolve the root causes that lead to recurrence/ resistance and resurgence of pest/ disease and consequently higher usage of pesticides. Successful implementation of regenerative farming principles through specific package of practice that rejuvenates the soil-plant interrelationships and improves plant resilience can significantly alter the conditions that favour higher pest incidence, thereby reducing the requirement for pesticides.

Unlike organic farming, under the sustainable management program the synthetic pesticides are not replaced by organic alternatives (except lime sulphur for red spider management), but the reduction of pesticide is directly proportional to the reduction of actual pest intensity. So to understand the reduction of pest intensity, as well as its toxic effect on soil and plant, different pesticide indices were calculated based on the pesticide use data and compared among experimental protocols as well as rest garden area.

As per pesticide usage data base, average usage /ha in the project area was 11.71 ltr/ha in 2013, which reduced to 3.83 ltr. in 2016. In totality, about 7.88 ltr. of pesticide has been reduced (70.35 %) per ha in the project area within 3 years' time span through the adoption of sustainable management program (Table 5). The reduction has occurred naturally indicating the impact of this program towards the development of plant immunity as well as restoration of the micro-level environmental resistance.

Among the different experimental protocols, the highest (74 %) reduction in pesticide use was observed under Exp-5, in 2016 as compared to the pre-experiment year 2013. The highest response from these plots might be due to higher bush vitality (as indicated by the concurrent high crop productivity) which was perhaps further activated due to plant health management, leading to faster protein synthesis and therefore very little formation of free amino acid and sugar pool in the plant cell sap, which minimized the source of ready food for pest and there by the pest infestation.

However, total pesticide usage (in ltr.) does not always indicate the actual pest intensity as the ingredient percent and dose/ha varies with the type of pesticide used even for the control of a particular pest. So pesticide usage in terms of active ingredients/ha (we call it Pesticide Load or PLs) is a more logical unit towards representation of the actual pest intensity of a particular area. In the present study, the trend of decrease in the pesticide load(PLs) was same as that observed in the case of pesticide usage/ha (Fig. 4). However, the percent decrease in pesticide load from year 2013 to year 2016 was higher than the decrease observed in the case of pesticide usage/ha, except in the case of Exp-3. The finding indicated that the pesticides used during 2016 had lower percent of active ingredient than that used during 2013.

Pesticide load on crop (PLc) expressed in ml active ingredients / kg made tea indicates the amount of toxic chemical used to produce 1 kg of made tea. Higher the PLc values, more risk of pesticide contamination in tea. Majorly two factors *viz*. the extent of pesticide usage and the crop productivity influence the PLc values. The highest reduction of PLc values from year 2013 to year 2016 were recorded under Exp-4 (68.47 %) followed by Exp-5 (65.90 %) (Fig. 5). Significant reduction of PLc values in case of all the experiments indicated the production of Safer Tea under the program.

CPPI stands for Crop Pesticide Pollution Index which indicates the potential risk associated with active ingredient of synthetic pesticides in terms food safety and human exposure and most importantly the risk of suppressing plant physiology, which increases plants' vulnerability towards the biotic and abiotic stress factors. Increasing CPPI value also means the increasing risk of pesticide residue in tea, leading to the reduction of its export potentials. Comparison of the CPPI values in the different experimental plots in the year 2016 vs. 2013 indicated a significant decrease of 51.7 to 77.4 % (67.5% on an average) (Fig. 6). This indicated that under sustainable management program, crop toxicity load decreased rapidly which not only helped in producing Safer Teas, but also reduced the ecological contamination and the negative impact on plant physiology which simultaneously helped in improving the plant's productivity potential.

Reduction in SPPI values also influence soil health restoration especially due to the reduction in the negative impacts on the soil biological activities. In the project area, there was a considerable improvement in the soil microbial population as well as their activity irrespective of compost application which might have contributed towards the reduction of the toxicity load on soil. And this in turn helped towards better nutrient mineralization and plant uptake.

3.5 Comparative Study of Pesticide Load in the Project Area vis-à-vis Rest Garden Area

Comparative study has been done between the project area and rest garden area to minimize the impact of seasonal effect and evaluate the impact of management change on the pest intensity. The evaluation showed that in the rest garden area, from year 2013 to 2016; the pesticide load (PLs) decreased by 36.7% , where during the same time period, there was 69.7 % reduction in pesticide load in the project area.Where as comparative evaluation of the pesticide load on crop (active ingredient used/kg made tea) showed that while there was only 29.5% reduction in PLc value in rest garden, the reduction was significant (61.0 %) in the project area. The finding indicated that the sustainable management program, which focuses on the development of plant health; can effectively reduce the pest infestation and there by the usage of pesticides. In case of CPPI, there was about 30.4% decrease in rest of the garden the time period as against a reduction of 67.4% in the project area. The findings substantiate the exclusive impact of plant health management' under the sustainable management program; towards the above phenomenon.

The findings documented in respect of the various models for Regenerative tea production revealed that apart from enabling reduction of chemical pesticides which helps to minimize risk of pesticide residue in made tea, it also substantially impacted the field management cost. The study showed that the adoption of Inhana sustainable tea initiative enabled approximately 40 percent reduction of pest management cost (from Rs. 18.9/- per kg under conventional practice to Rs. 10.9/- per kg under sustainable program) which on the other hand created opportunity to invest the saving in the sustainability account; without increasing the overall management cost. Thus the study indicated that adoption of a comprehensive

Table 5. Pesticide usage in the Experimental plots under different Regenerative Farming Models at Lakhipara T. E., Dooars

Expt.	Plot	Area (Ha)	Age (Yrs)	Pesticide Load under Regenerative Farming Models									
				Total Pesticide Usage (ltr / ha)		Pesticide Load (PLs) (ltr / ha)		Pesticide Load on Crop (PLc) (ml/kg made tea)		Crop Pesticide Pollution Index (CPPI)		Soil Pesticide Pollution Index (SPPI)	
				2013	Avg. 2014-16	2013	Avg. 2014-16	2013	Avg. 2014-16	2013	Avg. 2014-16	2013	Avg. 2014-16
Expt-1	BB-1A	1.83	47	8.42	5.07 (-39.71)	1.81	0.96 (-46.78)	0.755	0.49 (-35.36)	0.15	0.10 (-32.89)	0.331	0.183 (-44.60)
Expt-2	BB-1BC	11.26	47	8.42	5.07 (-39.71)	1.81	0.96 (-46.78)	0.755	0.49 (-35.36)	0.15	0.10 (-32.89)	0.331	0.183 (-44.60)
Expt-3	BB-2	16.89	47	11.99	4.11 (-65.72)	2.14	0.78 (-63.40)	0.908	0.40 (-55.91)	0.18	0.06 (-66.30)	0.391	0.142 (-63.73)
Expt-4	BB-3C	5.75	47	9.66	2.98 (-69.15)	2.32	0.59 (-74.71)	0.893	0.28 (-69.17)	0.17	0.05 (-72.90)	0.400	0.075 (-81.29)
	BB-3D	5.00	27	13.72	4.27 (-68.88)	3.34	0.90 (-73.15)	1.223	0.38 (-68.77)	0.23	0.07 (-71.84)	0.571	0.127 (-77.74)
Expt-5	BB-3AB	11.26	51	12.56	4.86 (-61.27)	2.91	1.07 (-63.34)	1.109	0.61 (-44.57)	0.22	0.15 (-29.77)	0.504	0.163 (-67.70)
	BB-3EXT	10.83	26	14.53	4.31 (-70.35)	6.68	2.14 (-68.01)	1.30	0.70 (-46.41)	0.23	0.09 (-61.90)	1.148	0.159 (-86.13)
TOTAL	-	62.82	42.5	11.71	4.39 (-62.51)	3.10	1.10 (-64.69)	1.00	0.50 (-50.65)	0.19	0.09 (-53.79)	0.544	0.150 (-72.46)

Note: PLs and SPPI value was calculated without taking the value of herbicide application, Figure in parenthesis represent % decrease of pesticide load over year 2013

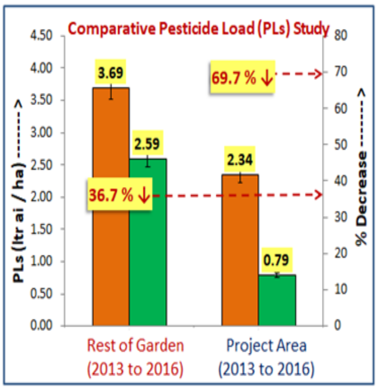

Fig. 4. Comparative pesticide load in project area vis-à-vis rest garden area

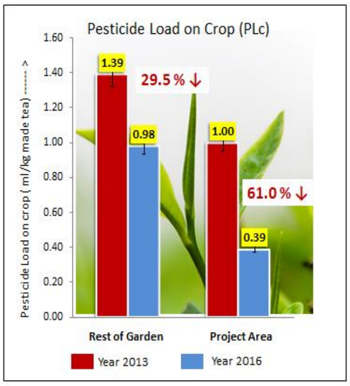

Fig. 5. Comparative value of PLc (2013 vs 16) in project area vis-à-vis rest garden area

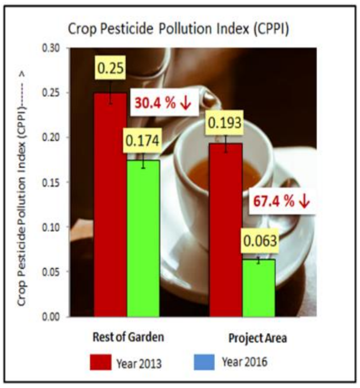

Fig. 6. Comparative value of CPPI (2013 vs 16) in project area vis-à-vis rest garden area

sustainable practice like IRF Technology that resembles the principles of regenerative farming and focuses on soil and plant health management; could sustain crop yield, minimize risk of pesticide residue and open up the scope for value added marketing and higher revenue generation. The study could be a benchmark for developing different resource based Regenerative Farming Models in tea towards mitigating climate change impact on crop sustenance, increase of pest/disease infestations and other abiotic stresses.

4. CONCLUSION

The project outcomes highlighted that pest management through plant health management not only reduced the pesticide load and related cost, it also created the opportunity for soil health management towards sustainable/ regenerative tea production without any extra investment; which most often forms the single most limiting factor towards adoption of any sustainable initiative.

The other impacts of the various models of Regenerative tea production, like 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 evaluated in the 2nd part of the research article which will give some more interesting insights towards the significance of regenerative agricultural practices in ecologically and economically sustainable tea production.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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