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Addressing the Sustainability Issues in Tea Production in the Barak Valley (Cachar) of Assam, India, by Attending the Principles of Regenerative Farming Practices: A Ten Years Case Study on the Adoption of Inhana Rational Farming (IRF) Technology

Bera R. [a*], Datta A [a], Bose S. [a], Barik A.K. [b], Asthana A. [c] and Seal A [a++]

[a] Inhana Organic Research Foundation, 168, Jodhpur Park, Kolkata – 700068, India.
[b] Department of Agronomy, Visva Bharati University, Sriniketan, Bolpur-731235, India.
[c] Goodricke Group Limited, Kolkata- 700019, India.

Authors' contributions

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

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[++] *Former Member, Inhana Organic Research Foundation;*
**Corresponding author: E-mail: Inhana.rftprojects@gmail.com;*

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ABSTRACT

India is the second-largest producer of tea globally, after China. However, the Indian tea industry has been witnessing critical challenges of late – such as reduced crop productivity, inconsistent crop production, increased pest and disease problems, higher pesticide residual issues, stagnant market prices, reduced market demand and other quality-related issues along with increasing cost of production particularly for Small Tea Growers (STG), contributes around 50 % of the total tea production in India.

Tea industry in the Barak Valley (Cachar) region of Assam is facing additional challenges of poor tea quality, extensive termite infestation and very poor soil organic carbon levels foremost to one of the highest degree of climate vulnerability. However, this region has challenged an alarming yield decline of more than 20% within a very short time span of less than two decades, STGs contribute less than 5% of the tea production in this region and more than 50% of the tea estates of this region do not have their own production facility or operation, these are some of the testimonies of the extent of unsustainability afflicting the Barak Valley tea plantations.

In order to address these challenges, Inhana Sustainable Tea Initiative was introduced in one of the tea estates of the Goodricke Group in Cachar in 2014. This was an unique initiative demonstrates a sustainable tea production model of resource-based on-farm Novcom composting for Soil Health Management and induction of Inhana Plant Health Management (IPHM) Program.

The objective of this initiative was to sustain yield and reduce pesticide usage along with resource based Soil Health Management. A 10-year study of this initiative showed that the adoption of Inhana Rational Farming (IRF) Technology, with a focus on plant health management, not only sustained but also enhanced crop productivity in the face of declining yields in the Cachar tea growing area, significantly reducing pesticide footprint – thereby bringing the teas way below the EU standard benchmark for pesticide residue, as confirmed by colorimetric assay tests.

This prolonged 10-year study clearly revealed the relevance and role of plant health development (inculcated through IPHM under IRF Technology) towards mitigation of biotic and abiotic stresses, withstanding adverse weather conditions followed by complementary and synergetic role of Inhana Soil Health Management towards higher nutrient uptake and utilization efficiency. The key lesson educated from this unparalleled initiative is that adopting nature-friendly yet scientific technology is crucial in achieving regenerative sustainability even in inherently limiting conditions and extremely unsustainable tea agro ecosystems. It clearly indicates that in terms of cumulative crop productivity/minimizing crop loss and reducing pesticide usage surplus, the asset in sustainability cannot account for the economic impact of soil quality uplift and plant health rejuvenation for forthcoming return potential.

Keywords: Cachar tea; regenerative farming; Inhana Rational Farming Technology; yield sustenance; pesticide load reduction.

1. INTRODUCTION

The sensitivity of tea plants to the environment in which they grow is part of tea's appeal. However, this also makes crops susceptible to the properties of climate change. The rise in temperature, shifting of seasons and increase in the ambient temperature have wedged tea yields across the board because, due to the C3 carbonic pathway, tea plants are already 1/3rd less efficient in photosynthesis than C4 plants, and photosynthesis in tea occurs only in the incidence of moderate temperature, moderate humidity and moderate sunshine [1-4].

The overall productivity of tea in India has gradually decreased over the years, dropping from 2,165 kg/ha in 2016-17 to 2,016 kg/ha in 2020-21. The Large tea growers have practiced even lower productivity compared to small tea growers due to the aging of their tea bushes. A significant portion, 46%, of the total tea cultivation areas belonging to large tea growers were not economically viable as the tea bushes were over 40 years old and were not commercially productive [5]. The impacts of climate change have made the entire tea industry in India more vulnerable, resulting in declining net returns and increasing issues related to crop sustainability, pesticide residue, and rising labour costs. The situation is particularly dire in the Cachar Tea growing zone, which has the lowest productivity (about 1300 kg/ha) among all tea-growing areas in India, except for Darjeeling and other hilly areas. The Cachar zone also has a high presence of old bushes (30% of the area with bushes over 50 years old, and in some cases, over 80 years old) and a large amount of vacant land (about 5,500 hectares with over 50% vacancy), further complicating the situation [6]. Additionally, the lower plant population due to wider spacing and the lack of replanting and infilling programs, due to economic stress, have gradually reduced the production potential of the tea estates [7].

According to the Climate Vulnerability Index (CVI), Cachar is highly vulnerable to climate change [8]. In recent years, the area has experienced increasing temperatures, longer dry spells, and shifting rainfall patterns. Climate prediction models suggest that by 2050, the maximum daytime temperature in Cachar might increase by 1.8°C, and by 2070, it could rise by more than 2°C, directly impacting the photosynthesis efficiency of the tea bushes, resulting in reduced productivity and deteriorating bush health. The report also states that by 2070, Cachar may barely be suitable for tea cultivation due to the impacts of climate change. As a result, the tea economy of Cachar, which is already in a vulnerable state with low productivity, inferior quality, and below-par price realization, is at risk of collapsing due to the impact of climate change.

Regenerative agriculture is increasingly seen as a potential key solution to the climate crisis, both by reducing its severity by reversing the conditions driving it and by making the world more resilient in the face of it [9]. Some experts estimate that expanding regenerative farming worldwide could remove 15-23 gigatons of CO_2 from the atmosphere by 2050. Recent studies suggest that using multiple regenerative practices together could sequester more carbon at a faster rate than previously expected. During this study, it came to know that, work on soil health management strengthens the nourishment factor but is not pivotal for objectivity accomplishment [10,11]. The availability of measurable organic inputs on a regular basis, the time required for the regeneration of soil to support the desired crop productivity and related economy can be a preventive factor for the large-scale application of regenerative farming. By considering the tea market economy of India and the socio economic outlook of tea growers, regenerative farming practices must be economical and viable, and the addition of tangible value to the end product in a time-bound way could be the most important criterion for achieving the desired work.

2. MATERIALS AND METHODS

2.1 Tea Plantations in Cachar

Tea plantations in Cachar are concentrated in 3 subdivisions Silchar, Karimganj and Hailakandi. However, Silchar subdivision is home to about half of the total estates in Cachar while the remaining estates are located in Hailakandi and Karimganj subdivisions. Tea plantation in this region is reported to have started, around the 1850's, by the British. As per the available information, the tea grown area covers about 36,653 ha and accounts for approximately 6.5% of Assam's total production. Tea production in this zone has declined by 14% in the last 10 years and the compound annual growth rate (CAGR) in the last 10 years was (-)2%. Crop production by the tea estates in Cachar decreased from 45.74 million to 38.19 million in the last 6 years (Fig. 1).

The boundaries of the tea growing zone of Cachar, Assam is multifarious (Fig. 2). Initially, these areas are characterized by high climate vulnerability, and their crop productivity is the lowest. At the same time, a major part of the tea area is in the hilly top and undulating land physiography alone with sandy type of soil with low organic carbon having higher erosion potential which increases the loss of topsoil. So low productivity, poor soil condition, inferior tea quality, inability of price realization, and finally lack of financial strength to support sustainable activity form a Vicious cycle; in which Cachar tea does not crossover, and climate change further increases the complexity and revival of the situation.

There are about 101 tea estates covering approximately 36,653 ha in the Cachar tea growing zone also popularly known as Barak Valley, but presently about 50% tea estates either have no factory or have a factory that is not in operational condition. However, over the last 20 years, the total tea production came down from 53 million to 39 million with a present average productivity of around 1,300 kg/ha. As per the demography of this tea producing zone, 37 tea estates covering almost 50% of the total tea area have productivity of more than 1,500 kg/ha (Fig. 3). But in contrast, about 56 tea estates have productivity less than 1,000 kg/ha or even in some cases it was as low as 500 kg/ha and thus, 50% of the area contributed 28% of total production. Here it clearly shows that, the dismal condition of the tea industry in Cachar where more than 70,000 workers were directly or indirectly dependent on this industry. On the other side of the zone, there are only about 700 ha of area under STG (1.9%) in contrast to more than 50% within the overall Assam zone, indicating the susceptible tea economy of this zone.

As per TRI report, in the last 10 years, there has been a steep increase in some major cost components as indicated by the Compound Annual Growth Rate (CAGR) which was 14.13% in the case of muriate of potash (MOP), 13.15% in case of wages, 8.27% in case of coal, 7.21% in case of diesel and 6.97% in case of electricity.

Especially in recent times pest management costs have risen more than 100% in the last 6 to 7 years (Fig. 6) due to climate change influence which not only contributes to the overall cost of production but more importantly drains both soil and bush health, reduces production potential and increases the risk of pesticide residue above MRL.

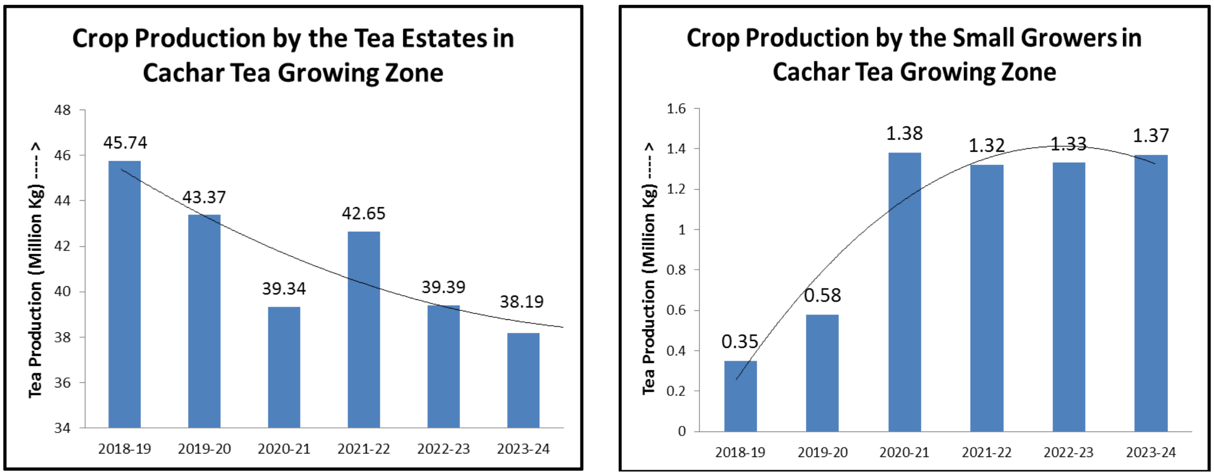


Fig. 1. Trend of crop production by tea estates & small growers in the Cacher tea growing zone

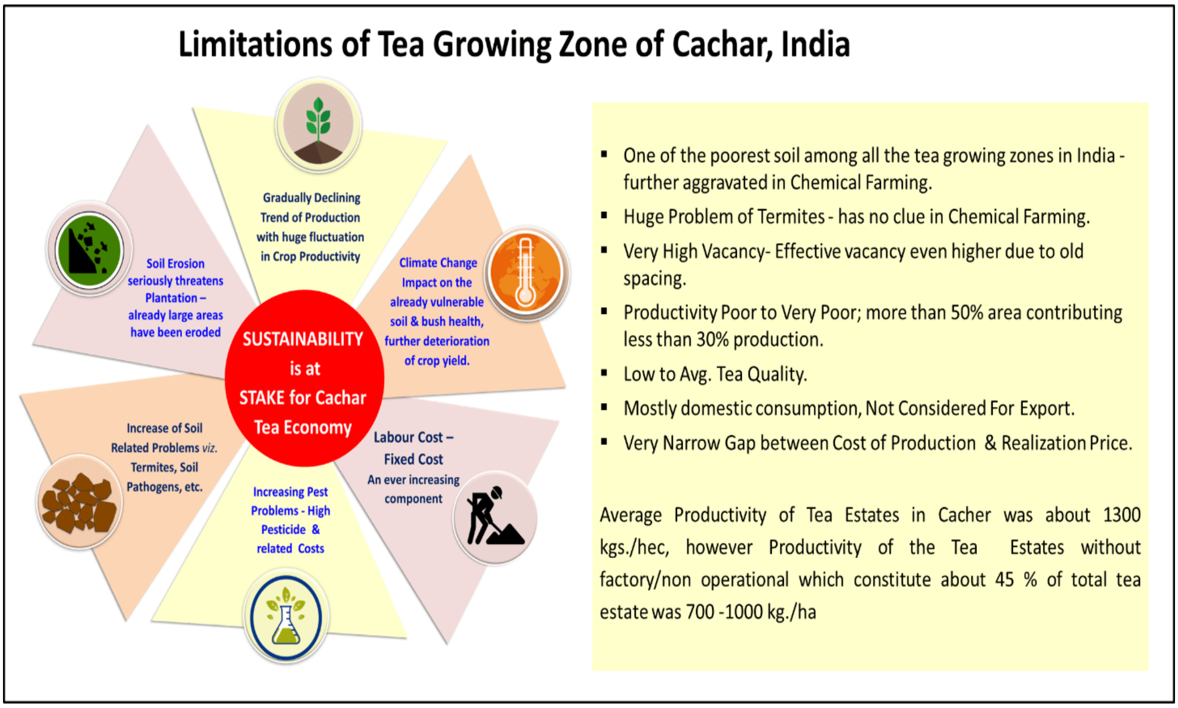


Fig. 2. Inherent & accrued limitations of tea growing zone of Cachar

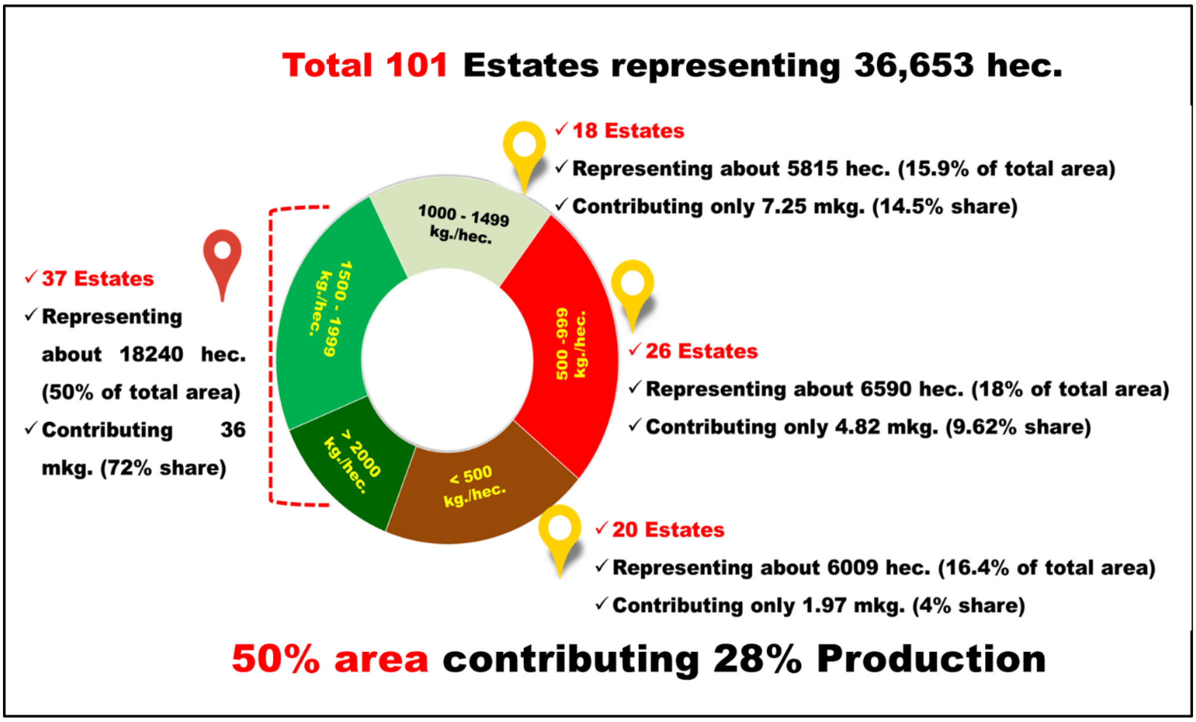


Fig. 3. Dismal in the Tea Estates Productivity in Cachar

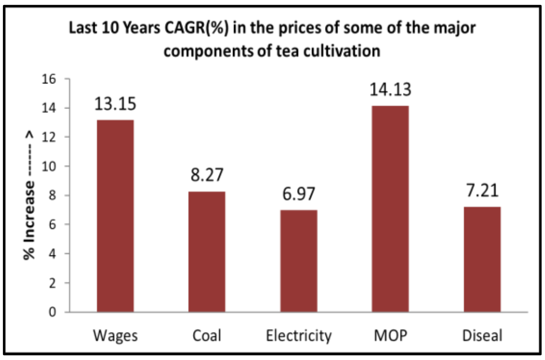


Fig. 4. Compound Annual Growth Rate (CAGR) of some major component of tea cultivation

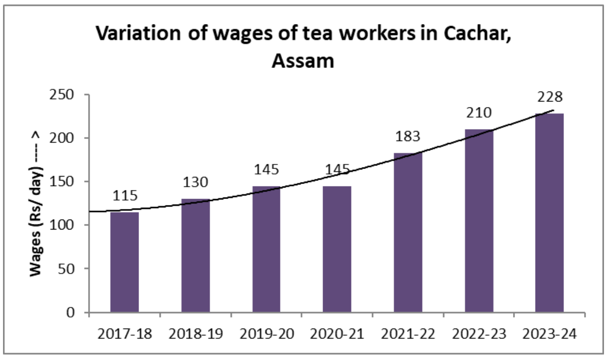


Fig. 5. Variation of wages of tea workers in Cachar, Assam

Otherside, if price realization is considered, it was noticed that only 8% of the tea gets a good return (> Rs 250/ kg) 23% of tea gets a moderate return (Rs 200 – 250/- per kg) and rest 59 % tea get poor to very poor price realization which makes the tea economy more vulnerable (Fig. 7). Analysis of cultivation cost vis-à-vis price realization from 2017-18 to 2023-24 revealed a dismal economic picture of the Cachar tea economy. The graph shows clearly in the past 6 years, there is a clear drift of increasing cultivation cost and reduction price realization due to non-reciprocal realization (Fig. 8). Return on investment (ROI) which is an approximate measure of an investment's profitability decreased sharply in case of both quality tea estates as well as other tea estates. Nevertheless, the rate of reduction in the ROI is more severe in the case of non-quality tea estates where practically gardens are in a hand-to-mouth situation with ROIs as low as 3.5. This economic turmoil in the Cachar tea economy put most of the tea estates in a vicious cycle of unsustainability and threatened the livelihood sustenance of thousands of tea workers (Fig. 9).

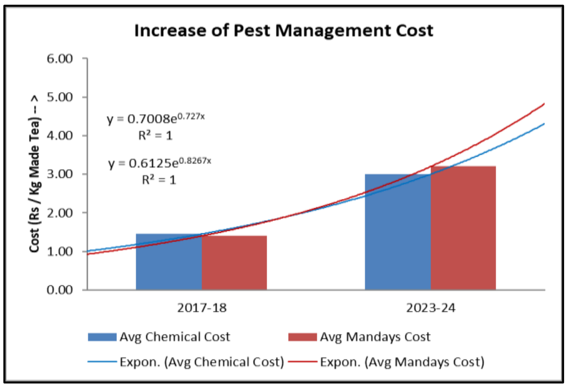


Fig. 6. Increase of average pest management cost in tea estates in Cachar

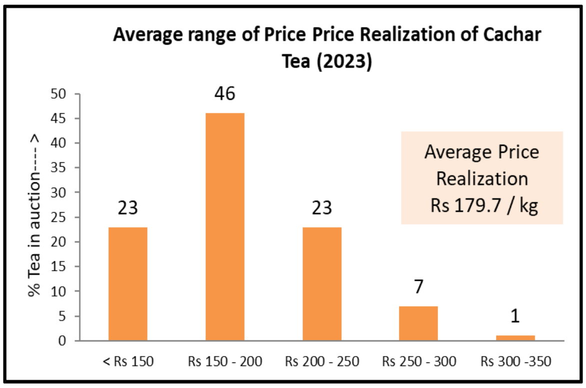


Fig. 7. Average price realization in auction by the tea estates in Cachar

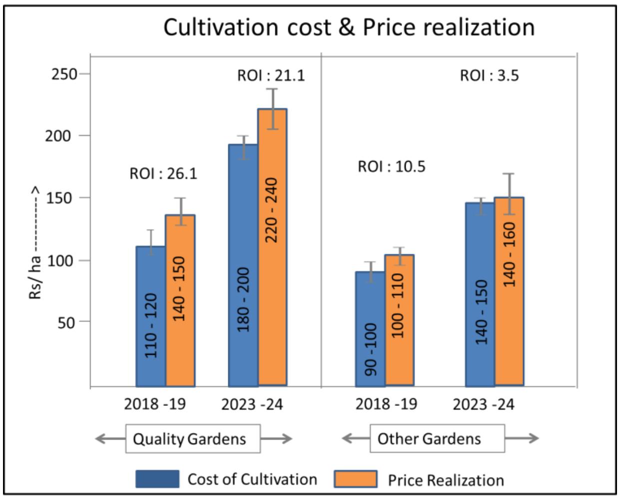


Fig. 8. Variation of cost and price realization of Cachar tea from 2017-18 to 2023-24

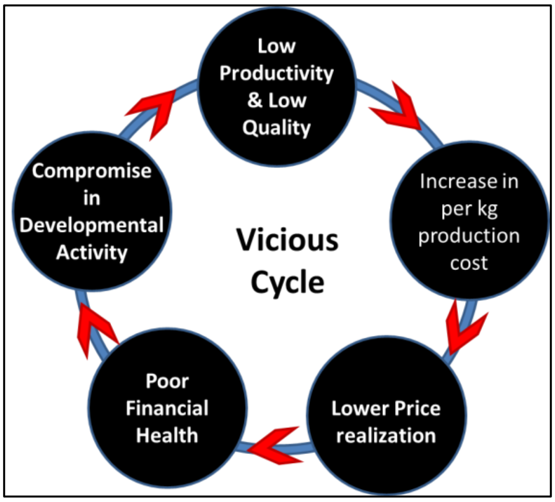


Fig. 9. Vicious cycle of poor financial health of Cachar tea

2.2 Inhana Sustainable Tea Initiative in Cachar

In this scenario, Inhana Organic Research Foundation (IORF), Kolkata initiated a sustainable tea initiative in collaboration with Goodricke Group Limited in Cachar in one of its tea gardens in 2014 with the objectivity of crop sustainability and pesticide reduction through Integrated Soil Management and enhancement of plant physiological efficiency through the application of different potentized and energized botanical solutions developed under the 'Element Energy Activation' principle along with different cultural practices. Within 2 years of the initiation of the project, the whole garden was shifted to orthodox production and initiated export. Under the program, four basic areas were prioritized, namely, (i) SWOT Study, (ii) Soil Health Management (iii) Plant Health Management and (iv) Integrated Pest/Disease Management.

Adoption of Inhana Rational Farming (IRF) Technology aims towards ecological and economic sustainability on a large scale and was initially demonstrated in another tea estate in Cachar called 'West Jalinga' T.E. from 2001-02 to 2018-19. The journey from an ordinary tea estate struggling with production and return to becoming the world's 1st carbon-neutral organic tea estate with the adoption of IRF technology is considered to be one of the greatest milestones achieved by any tea estate in India. The West Jalinga T.E. contributed the largest volume of Cachar tea export – breaking the myth of non-exportability of tea from Cachar due to quality issues.

From the research, it came to know that the finest effort towards on-farm resource recycling with making of more than 3,000 ton on-farm Novcom compost annually leading to enhancement of soil microbial population leading to enhancement of soil carbon sequestration, better nutrient use efficiency and enhanced crop production from 8.50 lakh to 9.90 lakh and that too without irrigation support – a scientific miracle that was made possible only due to the customized Inhana Plant Health Management package of practices, which help to energize the plant physiological system against biotic and abiotic stresses. Therefore, the project garden practically became pest free and needed only 1 to 1.0 organic concoctions to attend external infestations. These results are the best for termite infestation, which was no longer a serious hazard under Inhana management.

2.3 SWOT Study

SWOT study is the internal resource audit that categorizes the problem and potentials of the studied farm through an authenticated index of the analytical parameters leading to scientific guidelines for chemical reduction through integrated soil management or for full organic conversion. It was (Figs. 10, 11) performed through the interpretation of crop performance along with the pruning cycle, pest and disease intensity, shade status, drainage, soil quality, pesticide load and other relevant factors, which led to the differentiation of the sections of the individual gardens into (i) Strength, (ii) Potential Strength, (iii) Opportunity, (iv) Threat & (v) Potential Threat categories, which enabled the development of customized management for problem mitigation (if any) and improvement of crop performance [5]. Hence, SWOT study or resource analysis followed by the development of Resource Maps is the initial step towards sustainable tea cultivation.

2.4 Inhana Rational Farming Technology

Inhana Rational Farming (IRF) Technology is a confluence of ancient wisdom and modern science, the root of which has evolved from the unique "Element Energy Activation (E.E.A.)" principle preserved in the ancient Vedic literature of the Indian subcontinent – which has a documented scientific agricultural tradition of 5,000 years and an undocumented past of another 5,000 years!

The E.E.A principle focusing on the appropriate stimulation of the soil and plant systems (Fig. 12). According to this EEA principle plants produce their food and thereafter they also produce food for all other living beings, through the manifestation of energy – which they derive from the Basic Life Force! Inhana Rational Farming (IRF) Technology and Novcom Composting method is based on the Energy Management (E.E.A.) Principle. Providing Systemic Relief was the primary criterion – be it Soil or Plant – IRF Technology showed the pathway and solutions for reaching this objective.

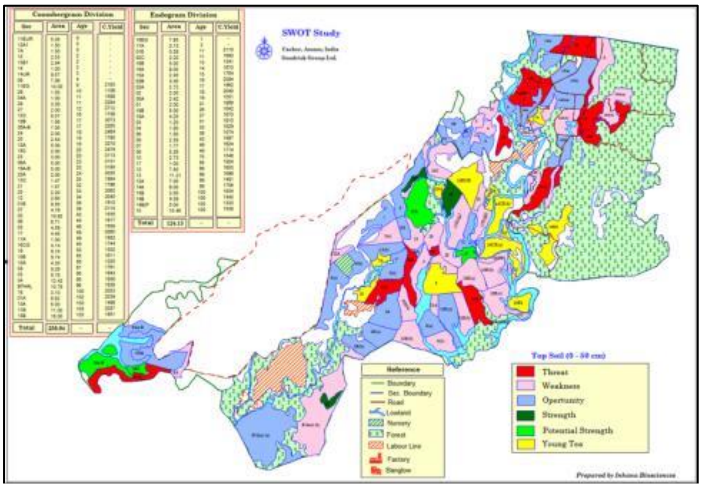


Fig. 10. SWOT Map of the project garden

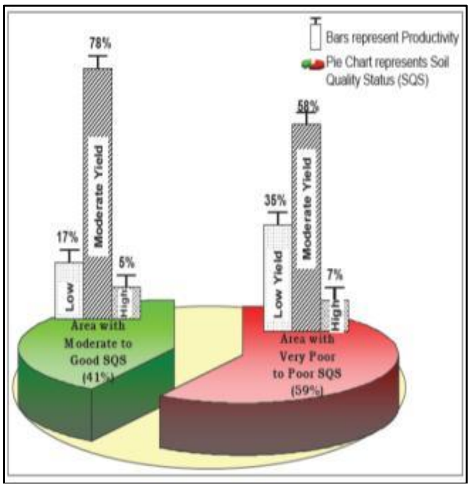
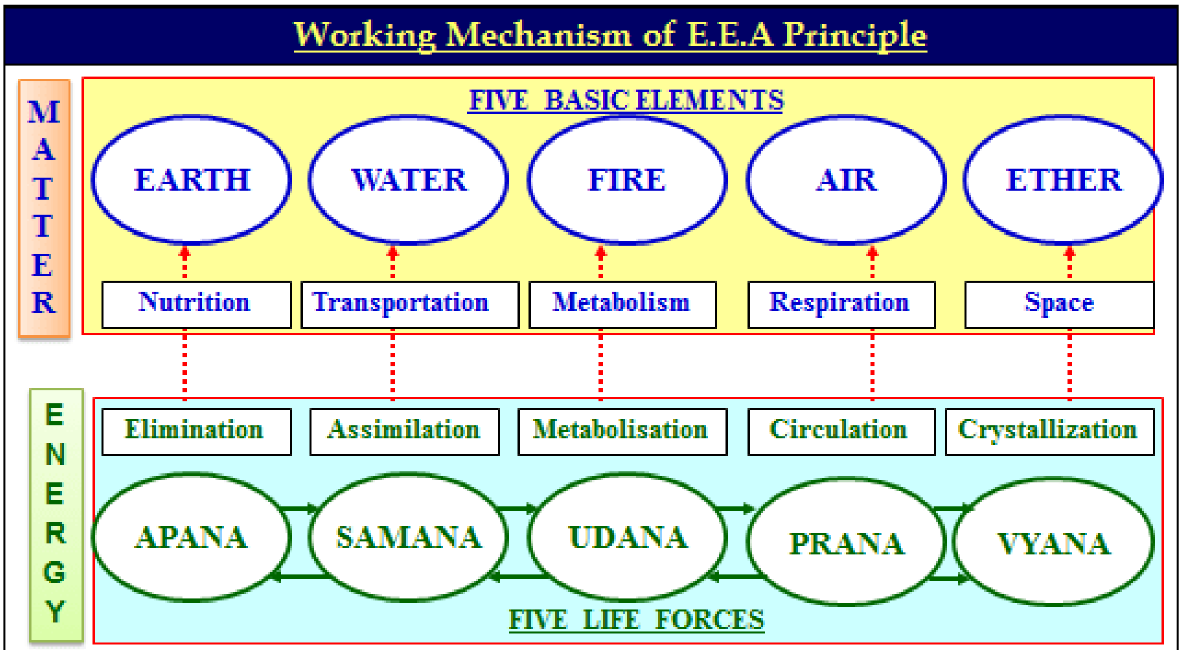


Fig. 11. Yield Performance under varying soil quality in project garden



LIFE FORCES/ ENERGY	PREDOMINANT AREAS	BASIC ELEMENTS
APANA	ROOTS	EARTH
SAMANA	AERIAL PARTS	WATER
UDANA	LEAVES	FIRE
VYANA	WHOLE PLANT BODY	AIR
PRANA	CELLS	ETHER

Fig. 12. Working mechanism of Element Energy Activation (EEA) principle – the guiding philosophy behind Inhana Rational Farming Technology

2.5 Energization of the Soil System

Energization of the soil system aims to permit the soil to function naturally effective growth medium for plants. It also focuses on the rejuvenation of soil micro-flora, is primarily attended by the application of on-farm produced Novcom compost (*that contains a rich population of self-generated microflora to the order of 10^{16}c.f.u*); different types of on-farm produced Soil Energizers and adoption of sustainable agricultural practices. The technology accentuates Plant Health Management as a pioneer for a resilient plant system that can confirm sustainability even under changing climatic patterns.

2.5.1 Novcom compost

Novcom compost was developed by an Indian scientist, Dr. P. Das Biswas (the Founder & Director of IORF). This method involves within 21 days using green matter and cow dung (at 80:20 ratio) as a raw material along with Novcom solution which was biologically activated and potentized extract of Doob grass (Cynodon dactylon), Bel (Sida cordifolia L) and common Basil (Ocimum bascilicum). Total 250 ml Novcom solution is required for 1 ton of raw materials (100 ml on day 1 followed by 75 ml each, on day 7 and day 14).

2.5.2 Preparation of Novcom compost

The preparatory method for Novcom compost, on the day 1, an upland and flat area was selected, and chopped green matter was spread to make a base layer measuring 10 ft. in length, 5 ft. in breadth, and 1 ft. in thickness. The whole layer was sprinkled thoroughly with diluted Novcom solution (5 ml/ ltr. of water) and over this layer, a layer of cow dung (3 inches in thickness) was made followed by a second layer of chopped green material, once again 1 ft. in thickness. The green matter layer was once again sprinkled with diluted Novcom solution (5 ml/ ltr. of water) and the process was continued till the total height reached about 6 ft. After each layer of green matter was constructed, it was compressed downwards from the top and inward from the sides for compactness (Pic. 1). On the 7th day compost heap was ruined and churned properly. The material was next laid layer-wise and after making each layer diluted Novcom solution (5 ml/ltr) was sprinkled thoroughly as done on 1st day. After seven days the volume of the composting material reduced due to progress in the decomposition process. Hence, the process should repeat again to maintain the heap height to about 6 ft.; the length and breadth of the heap was maintained at 6 ft. x 6 ft. respectively. The heap was once again made compact as described earlier. On the 14th day, the same process was repeated as on day 7 and to maintain heap height to about 6 ft., the length and breadth of the heap were further reduced to 6 ft. x 4 ft. respectively. On the 21st day, the composting process was complete and the compost was ready for use [12].

Pic. 1. Onfarm Novcom composting in the project garden

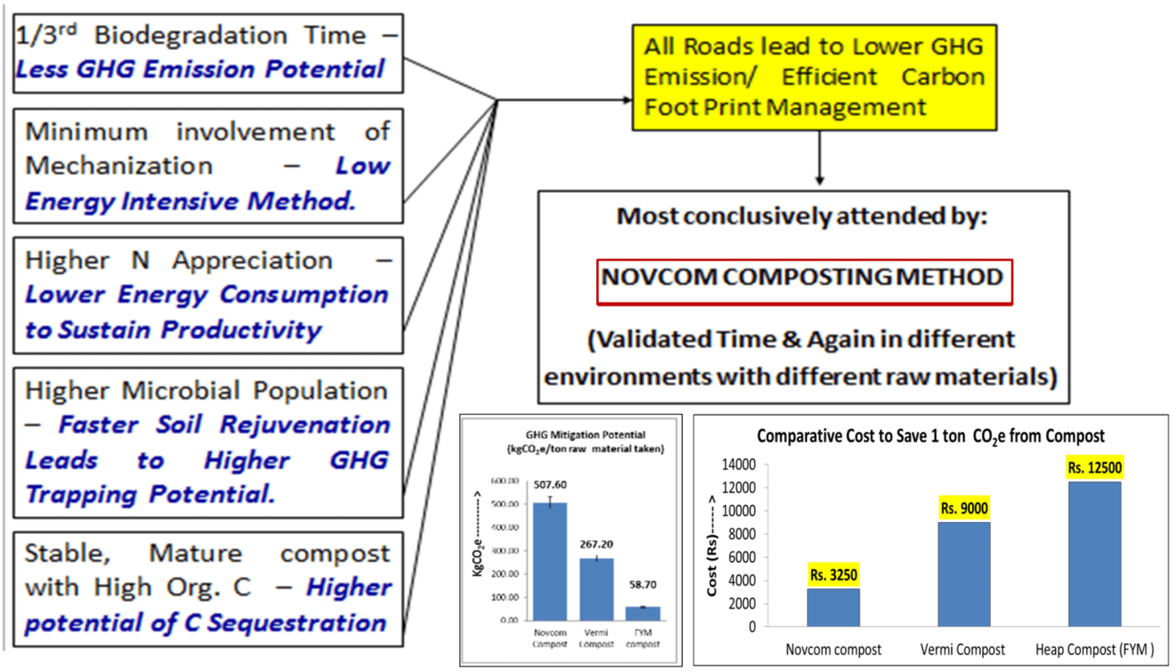


Fig. 13. Potential of Novcom compost towards reduction of carbon foot print in tea

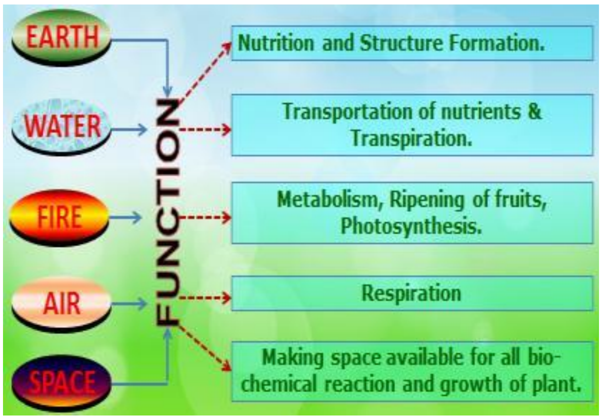


Fig. 14. The mechanism of self- nourishment in the plant system

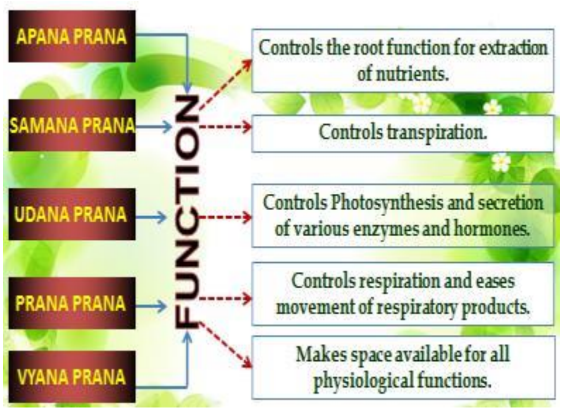


Fig. 15. The Mechanism of self- protection in plant system

2.6 Energization of Plant System

Energization of Plant System is aimed at enabling higher nutrient use efficiency alongside better bio-chemical functions that lead to activation of the plants' host defense mechanism. Under this system of technology a set of potentized and energized botanical solutions developed under the Element Energy Activation (EEA) Principle. The details of the technology mentioned in terms of working principles and spraying protocols of the solutions has been documented by the workers who have followed this technology for organic crop production [12,13,14].

2.6.1 The mechanism of self-nourishment in plant system

Five basic elements (Panchamahabhutas) Soil, Air, Water, Fire, and Space take care of nourishment. The individual element is responsible for a specific mechanism of nourishment. These elements are life forces or energies in all living bodies as well as in the plant system originated from the Basic Life Force i.e. Solar Energy. The Self-Protection mechanism is controlled by the Life Forces and they are also the vehicles of the basic elements and movement of nutrients is impossible without them (Figs. 14, 15).

2.7 Inhana Integrated Pest Management (IIPM)

WE NEED TO OVERCOME THE IDEA OF 'BATTLE' - Prevailing plant protection practices rest on the hypothesise that pests are subjective enemies that will attack crops and stop only when there is nothing left. So we have to fight against them and eradicate them if possible, potent weapons are therefore necessary and chemical poisons or pesticides are the only options. However, it is an established fact (be it the 'Trophobiosis Theory' of F. Chaboussou or noted scientist Wood) that most pest and disease-causing organisms depend for their growth on free amino acids and reducing sugars in solutions in plant cell sap. Not all pests have identical nutritional needs but they all draw from the same pool of soluble substances dissolved in the liquid of the cellular vacuole. Different environmental factors have given converging results with regard to the relationship between plants and parasites. The subject over here is whether it is attacked by an insect/ fungi/ bacteria/ virus, the relationship to the host i.e. the plant is a nutritional one (Fig. 16).

Application of nitrogenous fertilizers especially causes a rapid increase in cellular nitrate, ammonia and amino acids that can be actually used for the synthesis of proteins. Other side the application of pesticides/ herbicides brings about Temporary reduction in protein synthesis. Reduction in the rate of protein synthesis results in temporary accumulation of free amino acids. Therefore while the immediate attack by a pest may be reduced by a pesticide, the Susceptibility of the Crop is increased, and when offered soluble free nutrients; pests grow better and multiply faster. With each infestation, the plant's vulnerability towards fresh infestation increases because of protein breakdown or amylolysis brought about by the pests themselves. Besides the toxic effect of a pesticide will also affect the host plant, making it more rather than less susceptible. At the same time, most of the pesticides kill 90% of non-target organisms, thereby drastically lowering environmental resistance. Eventually, impaired ecology both inside and outside the plant system occurs. Increase in the rate and harder pesticide quite naturally cause larger and larger pesticide treadmill.

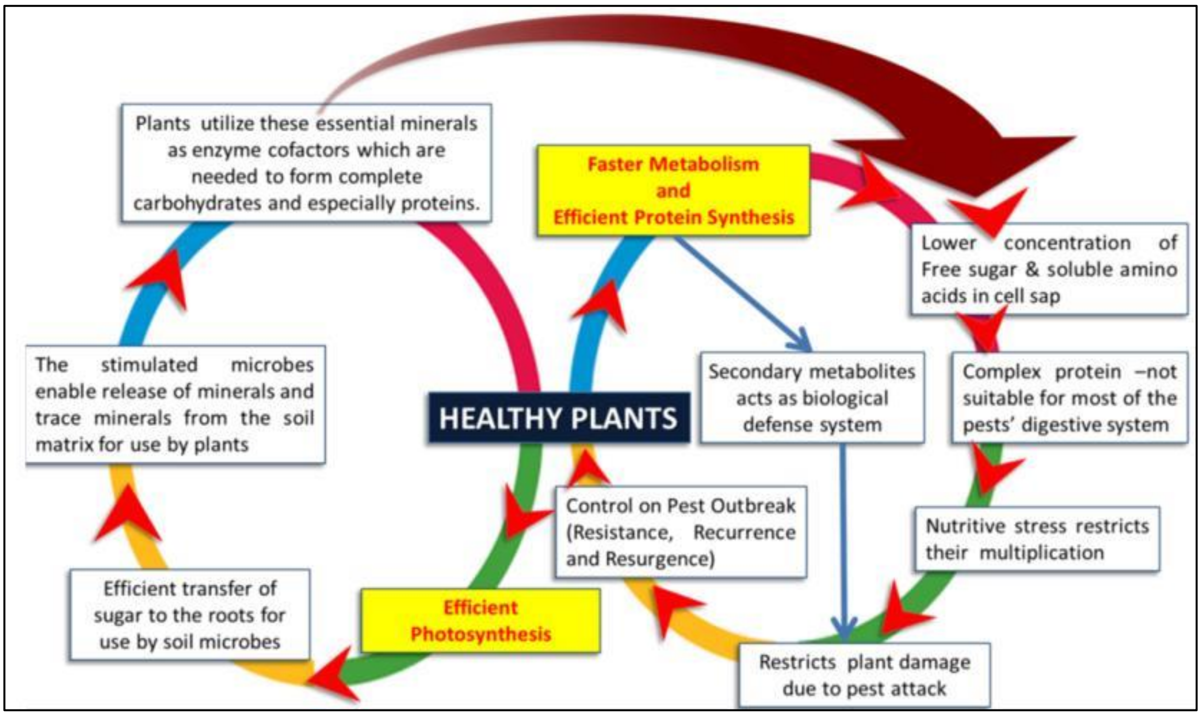


Fig. 16. Pest management through plant health management: The essence of "Trophobiosis theory" behind Inhana Integrated Pest Management (IIPM)

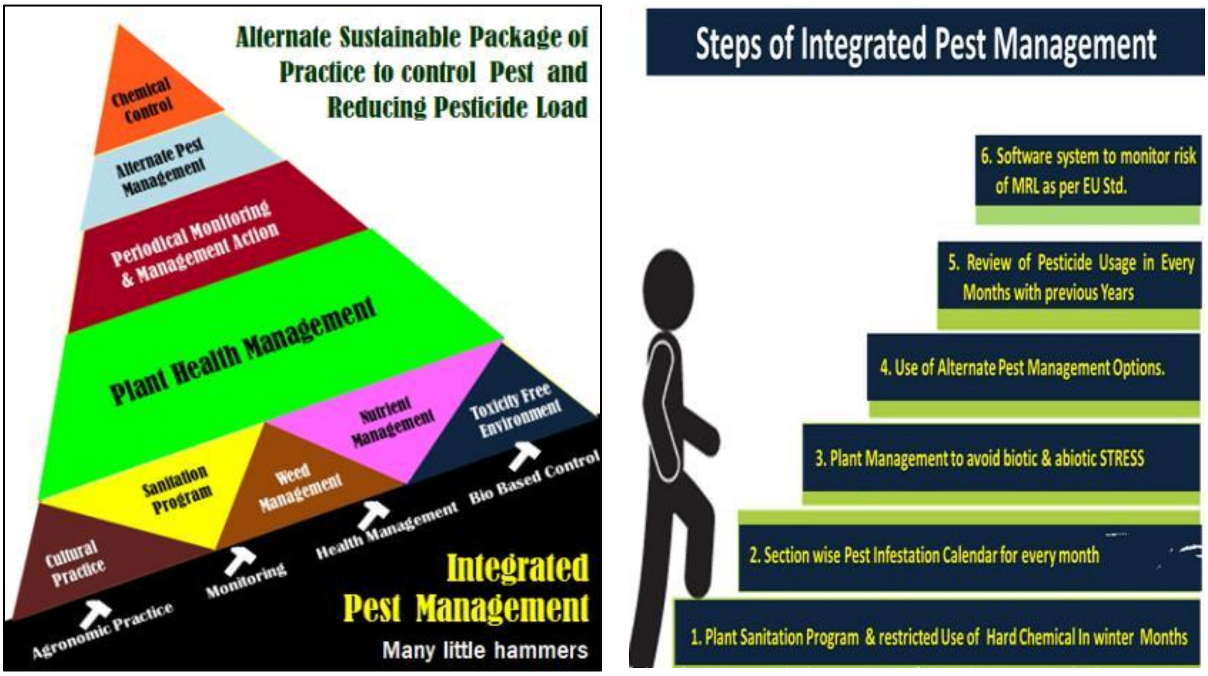


Fig. 17A & 17B. Concept of pest management under IIPM

2.7.1 Steps of Planning and Program Execution under IIPM (Fig. 17A & 17B)

- Develop a quarterly plan regarding sustainable farming
- Planning for compost preparation and preparation of CDS and P5 concoction
- Scheduling Inhana Spray in coherence with the garden's normal spraying schedule
- Prepare pest calendar for December – April and identify the most pest-prone sections (pest-wise)
- Mapping of disease-prone areas
- Calculate regarding requirement of compost, CDS, P5, Neem & Karanj Oil, and Lime sulfur in advance and act accordingly.
- Keep at least 0.5 rounds of Neem and Karanj oil for mid-season pest cycle break up in most critical sections.

2.8 Sustainable/ Regenerative Management Initiatives: Relative Impetus on Soil and Plant Health Management

Soil health is crucial for supporting crop productivity, as deterioration of soil health due to industrial farming and climate change have a devastating impact on crop production. However, there are underlying limitations that have not been widely discussed. Firstly, there is a scarcity of raw materials to develop quality organic manure for large-scale soil health improvement, especially considering the socio-demographic scenario of the Indian ecosystem. Secondly, rejuvenating the soil system to support higher yields, particularly in plantation crops like tea, which have been exposed to decades-long use of toxic chemicals, requires a significant amount of time.

On the other hand, focusing on plant health management, along with supporting soil health management, can quickly improve plant functioning even in less supportive soil conditions to sustain crop yields. Plant health management not only enables plants to expend more energy to produce their own food but also strengthens their internal immunity against increasing biotic and abiotic stress in the external ecosystem. Additionally, plant health management is technology-driven and not resource-dependent, making it applicable on a large scale without major changes to current cultivation practices.

To ensure the practical feasibility and economic viability of large-scale sustainable and regenerative initiatives, we propose allocating 70% of management focus to plant health management and 30% to soil health management. This approach has been implemented in the Inhana Sustainable Tea Initiatives in various tea agro-ecosystems of India through the adoption of the Inhana Plant Health Management practice along with on-farm Novcom composting. Details of the practice have been documented by Bera et al. [15].

2.9 Analysis of Pesticide Load in Tea

Analysis of pesticide load on the crop was done as per the methodology of Bera et al. [12].

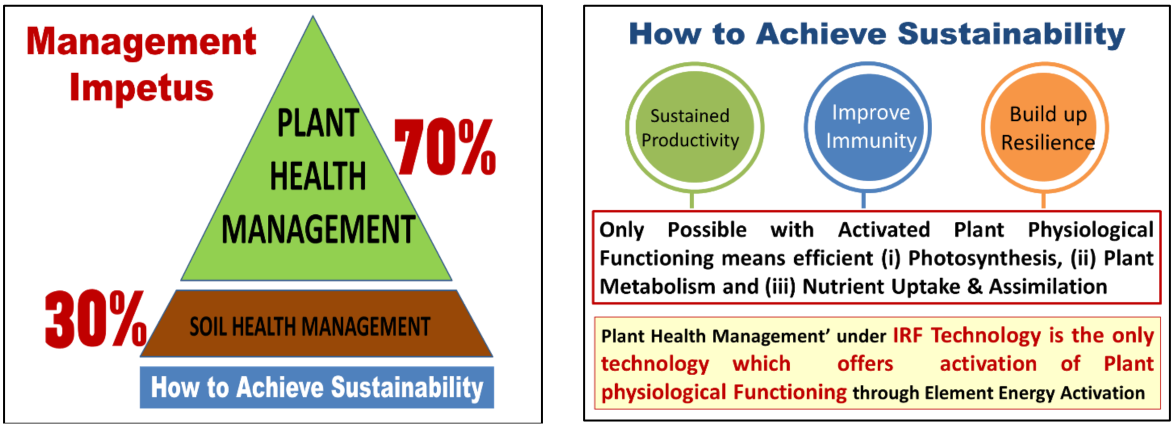


Fig. 18. Management impetus on plant health management helps to attend sustainability

2.10 Analysis of Pesticide Residue

Made tea samples were collected from the project garden and from another different good garden in Assam & Dooars in 2023. Samples were tested for six major pesticide groups viz. Organo-chlorine, Organo-phosphate, Carbamate, Synthetic Pyrethroids, and Neonicotinoids represent more than 650 pesticide formulations covering more than 90% of major insecticides, fungicides, and herbicides used in India [16]. QuECHERs method was adopted for processing of the made tea samples for pesticide residue analysis [17]. Pesticide residue was analyzed as per Colorimetric Assay Test which was jointly developed by IORF, Kolkata, and KVK (Nadia, BCKV, ICAR) [16,18].

2.11 Compost Quality Analysis

Thirty Compost samples were collected for analysis of the physicochemical properties of compost viz. moisture content, pH, electrical conductivity, and organic carbon were analyzed according to the procedure of Trautmann and Krasny [19]. The total N, P, and K in compost were determined using the acid digestion method [16]. Estimation of bacteria, fungi and actinomycetes was performed using Thornton's media, Martin's media, and Jensen's media respectively, according to standard procedure [20]. Stability tests for the compost (CO_2 evolution rate, phytotoxicity bioassay test/germination index) were performed according to the procedure suggested by Trautmann and Krasny [19]. Cress (Lepidiun sativum L.) seeds were used for the phytotoxicity bioassay test.

2.12 Soil Quality Analysis

Samples from 0 to 30 cm soil depth were collected in 2013-14 and 2022-23 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 physico-chemical, fertility, and microbial properties were analyzed as per standard methodology [17]. Estimation of bacteria, fungi, and actinomycetes was done as per plate counting method using Thornton's media, Martin's media, and Jensen's media respectively according to the procedure outlined by [17]. Total phosphate solubilizing bacteria (PSB) count was also done as per plate counting method using Pikovskays's media [17]. Finally, the soil development index (SDI) was evaluated as per the following formula [18].

$$^{2}\text{Soil Development Index (SDI) (Bera } et\ al.\text{, 2013a)} = \frac{a}{n^2}\left\{\sum_{n=1}^{n}\frac{100\,(X_1-C_1)}{C_1}+\frac{100\,(X_2-C_2)}{C_2}+\,\ldots\ldots\ldots+\frac{100\,(X_n-C_n)}{C_n}\right\}$$

Where X = Value of Individual Soil Quality Parameter after Experimentation, C = Values of Individual Soil Quality Parameters before Experimentation; a = no. of Soil Quality Parameters showing increase over initial value.

2.13 Tea Quality Analysis

Tea samples were analyzed for quality parameters *viz.* pH, Electrical Conductivity (EC), Total Soluble Salts (TSS), Total Dissolved Solids (TDS), Free Amino Acids, Total Polyphenols and Total Flavanoids in the laboratory of Inhana Biosciences (a Research Organization based in Kolkata) as per standard methodology [21,22].

3. RESULTS AND DISCUSSION

The study was done towards impact analysis of Inhana sustainable tea initiatives towards crop sustenance, pesticide load reduction, improvement of soil health, and enrichment of intrinsic tea quality.

3.1 Crop Performance under Inhana Sustainable Tea Initiatives

Crop performance is the main barometer of any sustainable initiatives. The performance of any tea production system is dependent on many factors, among which climate is the decisive one. However, if the management practice is effective it definitely shows a positive trend despite all odds in a time scale. Under the Inhana sustainable tea initiatives, year-wise crop productivity shows an a jig jag pattern similar to non-project area which was mostly due to year-wise climatic aberration, along with more quality plucking as the tea estate shifted from primarily CTC to 100 % orthodox tea making and labour problem from time to time. Hence, despite of all odds and the general trend of crop performance in the Cachar zone, the project area has shown an increasing trend of crop productivity under the sustainable practice (Fig. 19).

As shown in Fig. 19, an interesting outcome was observed. The program was initiated in 2014 in both the project and non-project areas the yield potential of the non-project area was quite higher than the project area. However, conversion to the Orthodox style of plucking from the CTC style of plucking has a more severe impact on crop productivity of high-yielding zones. It was recovered with sustainability initiatives in 3 years of time. From 2018 onwards more emphasis was given to weak productive zones under sustainable tea initiatives with a special focus on plant health management and as a result, within 5 years, it surplus the yield potential of the so-called higher productive zone.

The impact of intensive plant health management on comparative crop performance was highlighted on Fig. 20 and it was observed that in the 10 years' time span, there was a significant increase in crop productivity in the project area (Fig. 21) which had comparatively low productivity due to a number of inherent weaknesses like old age of plantation, severe termite problems in number of sections as well as limitations in drainage, etc. Therefore, the impact of sustainable initiatives will not be fully understood still the time while comparing the crop performance of the non-project area during this time frame which project almost 13% reduction in crop productivity which somehow resembles the decreasing trend of crop performance in the entire Cachar tea producing zone. Thus the crop performance indicated clearly that to invest in the sustainability account, it will pay back through better crop performance in a time-bound manner through IRF sustainable tea initiatives.

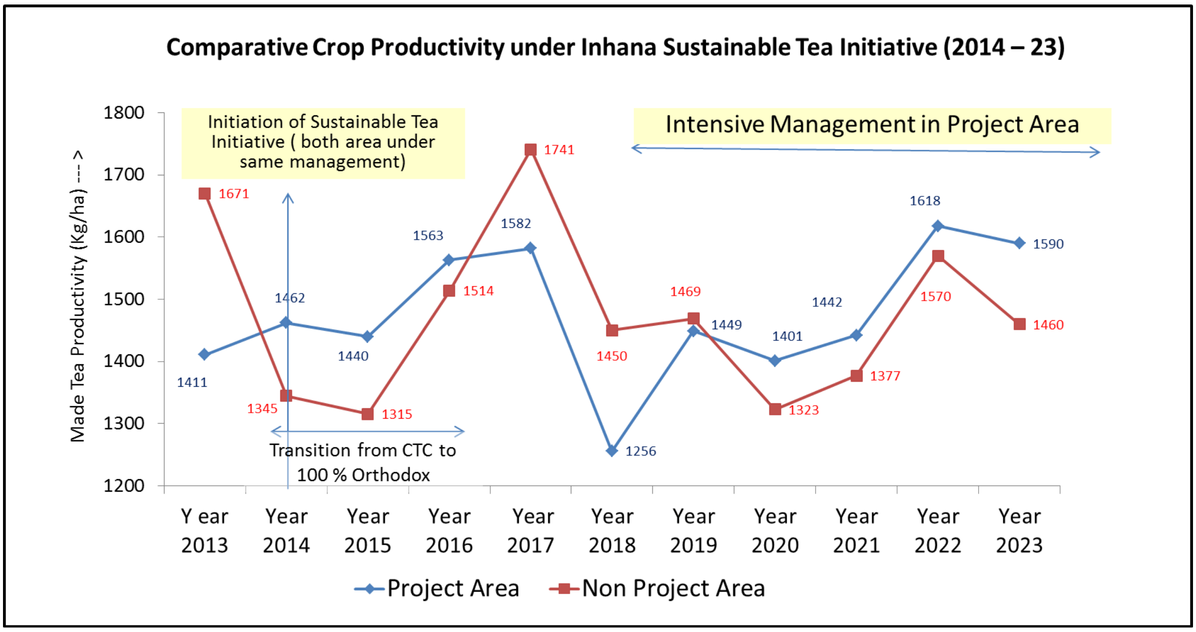


Fig. 19. Comparative crop performance under Inhana sustainable tea initiatives in Cachar, Assam (2014-2023)

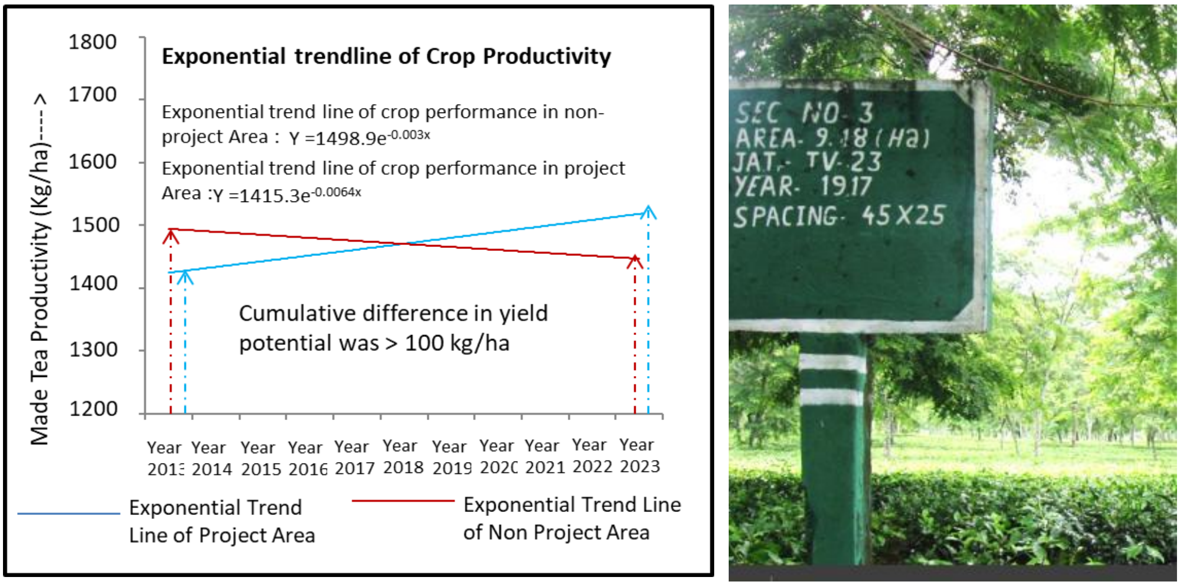


Fig. 20. Exponential trend of change in crop productivity under sustainable tea initiatives in the project garden at Cachar, Assam

Pic. 2. Garden visit for scientific documentation under the program

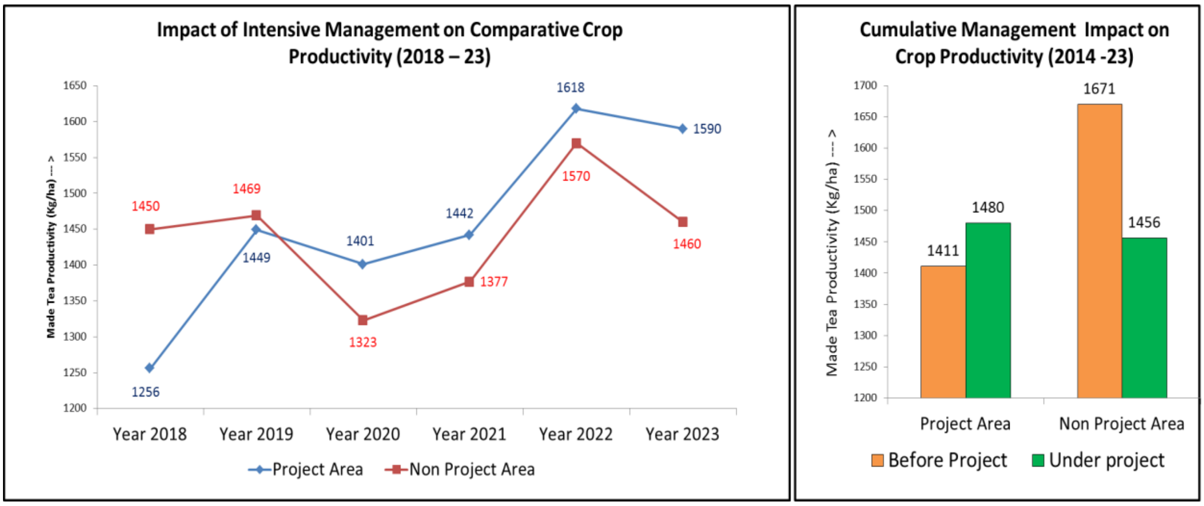


Fig. 21. Impact of intensive plant health management on crop productivity in the project area at Cachar, Assam

3.2 Pesticide Load in Crop and Pesticide Residue

Pesticide load (PLc) in made tea in the project garden was 0.295 ml AI/kg made tea before the initiation of Inhana sustainable tea initiatives and after 10 years of the program it was reduced by more than 76 % and the PLc value was 0.07 ml AI/kg made tea (Fig. 22) which not only indicate the effectivity of the sustainable initiatives but at the same time it will reduce the risk of pesticide residue in tea as also authorize with the pesticide analysis through colorimetric assay test. The increase of pesticide residue in tea is more than 100 % from its usage in the last decades due to climate change impact is considered to be a major challenge to the tea industry, this huge reduction that to a conventional tea estate, having no such habitual criteria to reduce chemical usage indicate reduction of pest/disease pressure due to sustainable management impact. It will happen when plants become healthy enough to strengthen their internal immunity to defend against pest infestation. Inhana Plant Health Management (IPHM) works in this direction which activates plant physiological functioning resulting in efficient plant metabolism and reducing the presence of free amino acid and free sugar pool in the cell sap; restricting pests from simple food sources for faster multiplication. It is noticed that, an importance towards the initiatives to activate plant physiological functioning not only improve internal immunity, in this process, it helps to increase crop production and also enhances the inherent quality of tea.

3.3 Comparative Analysis of Pesticide Residue in Made Tea through Colorimetric Assay Test

In the history of Indian Agriculture first time, a Colorimetric Assay Test of pesticide groups can be used for validating the safety of made-tea under regular batch-wise testing protocol. Four individual validated assay test methods [20,23,24,25] also considered to formulate a comprehensive and conclusive standard to determine four major groups of pesticides (Organo-phosphate, Organo-chlorine, synthetic pyrethroids & Neonicotinoids) and other groups of chemicals covering about 650 different types of pesticides and their combinations. Colorimetric assay tests can confirm pesticide residue up to 0.003 ppm. It shows that this test method can be safely utilized for detecting MRL value of 0.05 ppm for EU compliance and MRL value of 0.01 ppm for compliance with the FSSAI Organic Standard. This test protocol is more stringent than the conventional HPLC test, where, the safety aspect of the food samples are judged based on MRL value of individual chemicals under similar or differentiated groups. However, if the collective MRL value of different pesticides under each pesticide group is considered the value can be much higher.

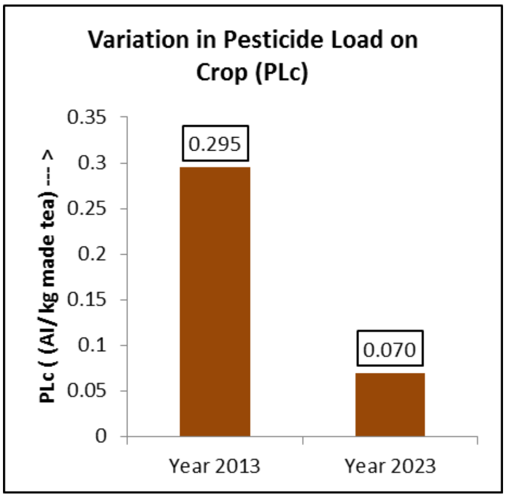


Fig. 22. Reduction of pesticide load on crop under sustainable tea initiatives

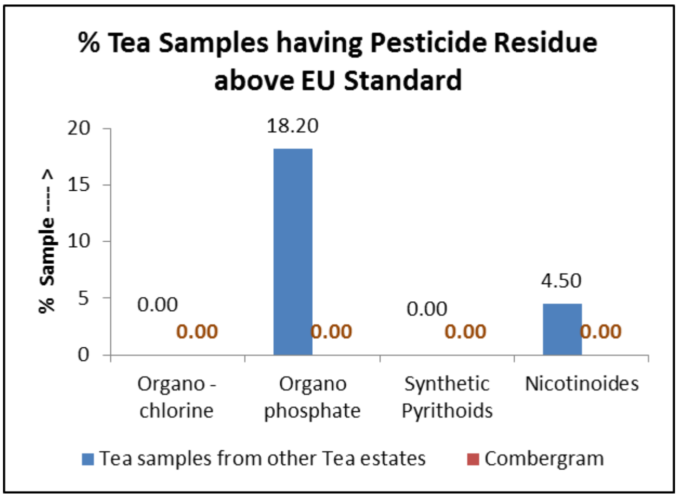


Fig. 23. Assessment of pesticide residue in tea through colorimetric assay test

A total of 44 tea samples from the Dooars and Assam tea estates and 16 tea samples from the project tea estate were analyzed for pesticide residue with a colorimetric assay test. Analysis showed that about 18% of samples had the presence of chemicals of the organo-phosphate group above 0.5 ppm which was acceptable EU standard (minimum tolerance level for any organo-phosphate chemicals) where whereas 4.5% of samples had the presence of chemicals of Nicotinoids group above 0.5 ppm which was acceptable EU standard (minimum tolerance level for any Nicotinoid chemicals). However, any tea samples did not have the presence of organochlorine and synthetic pyrethroids above the stipulated MRL limit (Fig. 23). The comparison to these findings, none of the samples from the project garden had pesticide residue above the MRL limit. These findings corroborated with the very low pesticide load on crops.

3.4 Quality of Novcom Compost and Its Impact on Soil Quality Development in Acid Tea Soils

During the 10 years' time period at least 30 compost samples were analyzed as per the National and International standards to monitor the quality standard of the compost. Compost samples were analyzed for physicochemical properties, nutrient content, microbial properties, maturity and phytotoxicity status.

3.4.1 Physicochemical properties and nutrient content of compost samples

On-farm compost heaps were made primarily with garden weeds and cow dung through Novcom composting method within 21 days. After, a few Novcom compost was also made with tea waste and cow-dung. All the compost samples appeared dark brown in colour with an earthy smell, deemed necessary for mature compost [26]. Average moisture in varied from 55.68 to 65.2 percent, which may be placed in the high value range (40 to 50) as suggested by Evanylo [27]. Organic carbon content in all the compost samples ranged between 21.94 and 36.51 percent, qualifying the criteria for field application (16 to 38) as per the range suggested by USCC [28]. The total nitrogen content in the compost samples ranged between 1.82 and 3.56 percent, which was well above the reference range suggested by Alexander [29] and Watson [30]. The mean value of total phosphate and total potash (0.55 and 1.01 percent respectively) were also higher than the minimum suggested standard. Specially Novcom tea waste compost has a very high value of total N and thus these composts might be more useful for supporting organic tea cultivation. The higher content of nitrogen obtained in the Novcom compost might indicate higher fixation of atmospheric-N within the compost heap under Novcom composting method [31]. Total phosphate (0.74 to 0.93 percent) and total potash content (0.94 to 1.49 percent) were also higher than the minimum suggested standard (0.6 to 0.9 percent and 0.2 to 0.5 percent respectively) reported by Alexander [29]. The C/N ratio varied from 10::1 to 15:1 indicating that all the compost samples were mature and suitable for soil application (Table 1).

3.4.2 Microbial properties, maturity, and phytotoxicity status of compost samples

The microbial status of any compost is one of the most important parameters for judging compost quality because microbes are the driving force behind soil rejuvenation as well as play a crucial role in crop sustenance by maintaining the soil–plant–nutrient dynamics. Microbial population (in the order of 10^{16} c.f.u to 10^{14} c.f.u in case of total bacteria, total fungi, and total actinomycetes count) in Novcom compost was significantly higher (at least 10^{3} to 10^{6} c.f.u times) than the population obtained in case of other compost samples [32,33].

The mean respiration or CO_2 evolution rate of all the compost samples (1.28 to 3.25 mg/day) was more or less within the stipulated range (2.0 - 5.0) for stable compost as proposed by Trautmann and Krasny [19]. The phytotoxicity bioassay test, as represented by the germination index provided a means of measuring the combined toxicity of whatever contaminants may be present [34]. The test value indicated the complete absence of any phytotoxic effect in all the compost samples as per the standard value of 0.8 to 1.0 suggested by Trautmann and Krasny [19].

3.5 Nourishment of Soil Health Post-compost Application

The soil resource base is the critical component of tea agro-ecosystems and future strategies for increasing tea productivity must focus on the restoration of the depleting soil properties to enable more efficient use of soil. Application of Compost in soil is primarily aimed at restoration, proliferation and rejuvenation of the native soil microflora population which are the primary drivers of all positive changes related to soil physicochemical properties and a dynamic soil-plant-nutrient equilibrium. However, to receive the benefits per se, compost application should be continued for a period of at least 3 to 5 years, the more the better, along with a cumulative reduction in the dosage of nitrate fertilizer and more critically herbicide application. This is, due to scarcity of raw material, it will apply for Novcom compost 2 to 3 times @ 2 ton/ha in that time span in the project area, and that too primarily in the pruned years.

While comparing the both project and non-project areas, it observed that the organic carbon status of soil has improved as compared to 2014 (values were in the low range in all the sections), but the rate of increase is definitely higher in the case of the project area., where Novcom compost was applied as opposed to non-project area which received cow dung. In terms of soil available NPKS, an increasing trend was observed in the project area. The substantial progress was observed in soil microbial properties, especially in terms of soil microbial biomass carbon (MBC), Soil Respiration, and FDA. Soil MBC value indicated total microbial population in soil was increased by about 18.7 % in the project area (Fig. 24) and the comparatively higher microbial population (in terms of MBC) in the compost applied plots might have resulted from the higher amount of substrates with potential for microbial degradation, being the source of energy and carbon for the soil microbiota [35]. There were no significant changes in soil microbial respiration but value of FDA hydrolysis (Fig. 25) which indicate soil microbial enzymatic activity [36,37] was increased by 34.5 % in the project Area. This value corroborated with high soil MBC, indicating the increase of soil microbial functioning with sustainable management initiatives.

Table 1. Quality of Novcom compost

Sl No	Quality parameters	Novcom compost from garden weeds	Novcom compost from tea waste
Physico- chemical parameters			
1.	Moisture (%)	55.68 – 62.31	59.8 – 65.2
2.	pH (H2O)	7.58 – 8.20	6.45 – 7.20
3.	EC (dSm-1)	1.78 – 2.27	3.85 – 4.02
4.	Organic carbon (%)	21.94 – 28.52	32.25 – 36.51
Nutrient Parameter			
5.	Total N (%)	1.82 – 1.95	3.05 – 3.56
6.	Total P2O5(%)	0.74 – 0.96	0.81 – 0.93
7.	Total K2O (%)	0.94 – 1.34	1.32 – 1.49
8.	C:N	12: 1 – 15:1	10 : 1 – 11: 1
9.	CMI	0.87 – 2.76	0.90 – 1.30
Total Microbial Count (c.f.u. per gm moist compost)			
10.	Bacteria	66 – 80 x 10^{16}	64 – 83 x 1016
11.	Fungi	12 – 32 x 10^{16}	10 – 51 x 1016
12.	Actinomycetes	10 – 68 x 10^{15}	10 – 21 x 1014
Stability			
13.	CO2 evolution rate (mgCO2–C/g OM/day)	1.28 – 2.32	1.69 – 3.25
Maturity & Phytotoxicity Parameters			
14.	Seedling Emergence (% over control)	89.6 – 100.2	88.2 – 105.1
15.	Root Elongation (% over control)	93.5 – 97.5	89.12 – 92.4
16.	Germination Index (phytotoxicity bioassay)	0.84 – 0.98	0.85 – 0.97

Table 2. Comparative soil quality analysis in the project garden

Soil parameter	Year of assessment	Project area	Non project area
Soil physic-chemical properties			
pH(H_2O)	2022	4.44	4.44
	(2014)	(4.46)	4.29
Electrical Conductivity (dSm^{-1})	2022	0.043	0.051
	(2014)	(0.034)	(0.028)
Organic Carbon(%)	2022	1.77	1.12
	(2014)	(0.98)	(0.94)
Soil nutritional properties			
Available -N (Kg/ha)	2022	455.9	271.2
	(2014)	(432.6)	(361.7)
Available P_2O_5 (Kg/ha)	2022	32.8	21.3
	(2014)	(10.2)	(13.6)
Available K_2O (Kg/ha)	2022	395.7	262.8
	(2014)	(259.9)	(279.8)
Available SO_4 (Kg/ha)	2022	77.6	49.2
	(2014)	(31.0)	(32.2)
Soil microbial properties			
MBC (microgram-C /gm dry soil)	2022	291.7	188.0
	(2014)	(245.7)	(249.9)
Soil Respiration (mg CO_2-C/gm dry soil/day)	2022	0.74	0.83
	(2014)	(0.79)	(0.80)
FDA (microgram /gm dry soil)	2022	268.1	180.1
	(2014)	(199.4)	(180.8)

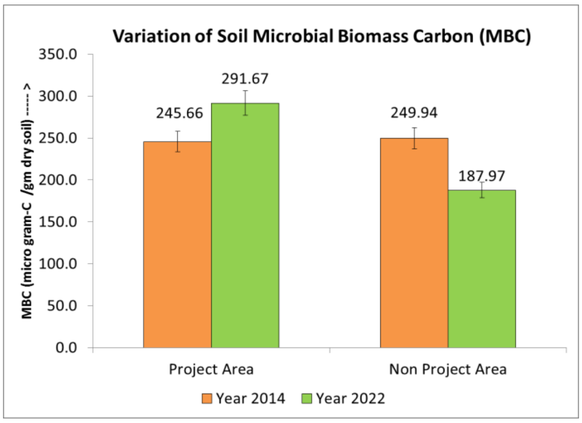


Fig. 24. Comparative analysis of soil microbial biomass carbon

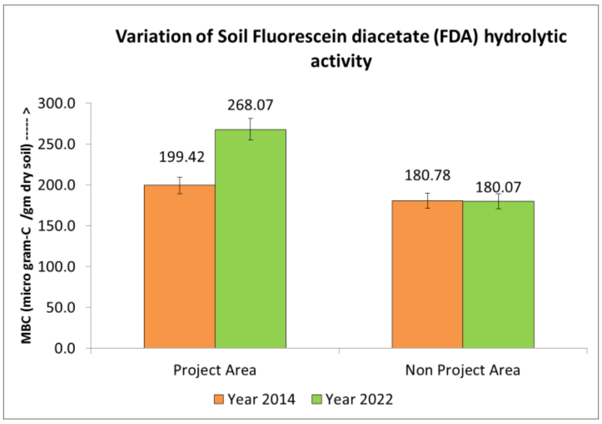


Fig. 25. Comparative analysis of soil FDA hydrolysis which indicate soil microbial enzymatic activity

Soil development index (SDI) is a concept to express the overall soil development by quantifying the extent of growth of different soil quality parameters for easy understanding of the end-users. The soil development index is easy to formulate, understandable, and reflects the impact of soil management undertaken [38]. The comparative study of the soil development index (SDI) (Fig. 26) showed that there was a significant development in soil under sustainable tea initiatives for the last 10 years w.r.to non-project area which itself justifies the need for sustainable management initiatives aimed at restoring soil health.

Pic. 3. Collection of soil samples and soil profile in the project garden

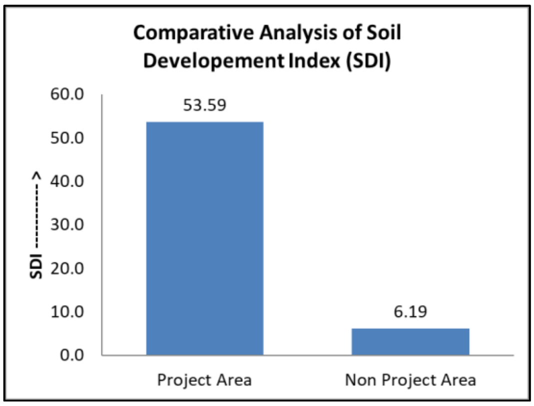


Fig. 26. Soil development index (SDI) indicates the impact of sustainable tea initiatives on soil health

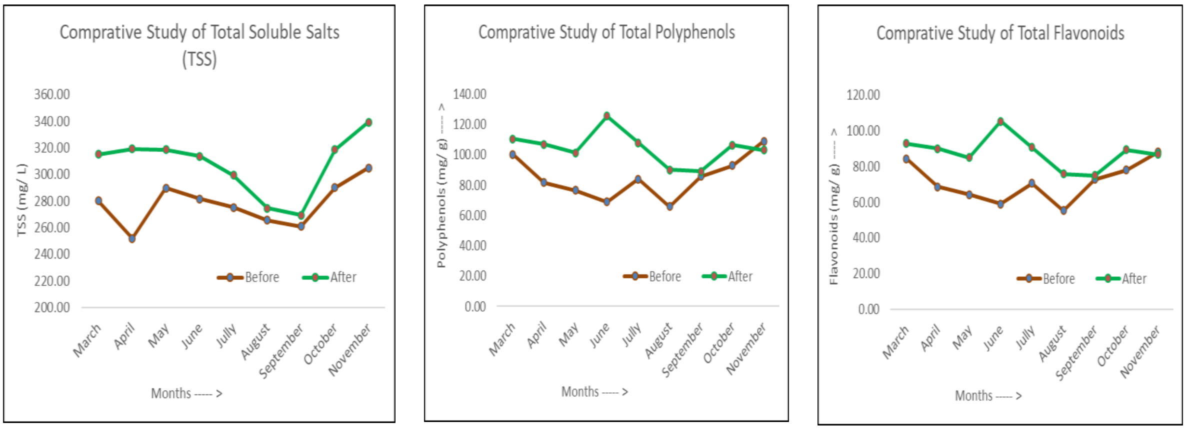


Fig. 27. Impact of sustainable tea initiative on quality components of made tea

3.6 Empirical Observation in Termite Control

In the tea areas of Barak Valley, termites are the major and predominant pests causing considerable damage to tea [39,40]. According to Das [39] at least 15% of the total crop loss in tea is due to termite attack, though Sands [41] mentions that crop losses in agricultural fields could be 50 percent or more over 10 years. Das et al. [42] reported more termites on poorly shaded hot slopes of Cachar tillahs (hillocks of Barak Valley). Termite infestation may be as high as 90% in old tea areas of Barak Valley [43]. With time, the termite problem intensified more in the Barak Valley with the deterioration of soil quality, specifically soil organic carbon reserve and rampant use of agrochemicals. As a result, termites which once a time considered to be friends for soil, become the dominant pest for tea plants. In the present sustainable tea initiative, we had taken up a specific program under IRF management regime to control the termite problem in the project garden, which had the problem of termite infestation in some specific sections like many other tea estates in Cachar zone. Application of on-farm Novcom compost along with specific Inhana Plant Health Management solutions for termite control and related cultural practice was taken up in specific sections that were moderately infested (34 – 66% of the plantation of the section infested as classified by Choudhury et al. [44] by termites. The empirical observation specified that continuous management for one cropping cycle (LP-UP-DS-UP) positively impacted the constraint of termite infestation and damage.

3.7 Comparative Analysis of Made Tea Quality

The need for antioxidant-rich food products is becoming relevant in present times to prevent oxidative damage in humans arising out of environmental pollution, food toxicity, and especially stressed lifestyle [45]. Numerous epidemiological studies have indicated that food and beverages rich in antioxidants (polyphenols) are a significant factor in preventing diseases and slowing down the aging processes [46]. The present study was conducted to assess the impact of sustainable tea initiatives on the intrinsic quality (polyphenol and flavonoid content) of tea in the project garden.

The total soluble salt (TSS) content of made tea samples reflects the nutritional and mineral management of tea plants. A higher TSS value indicated a better soil-plant-nutrient relationship due to management impact. Total polyphenol and flavonoid content in made tea are of major interest, considering that they reflect its antioxidant/ health giving potential. In the present study, it was indicated that both total polyphenols and flavonoids increased post-sustainable management initiative was undertaken (Fig. 27).

4. CONCLUSION

The Indian tea industry primarily large Tea Estates are currently undergoing challenges from declining and inconsistent crop productivity, low tea-quality, increasing cost of production and low net returns, high pesticide usages leading to MRL issues etc. The current issues have been further exacerbated by the impact of climate change. Inhana Sustainable Tea Initiatives was introduced by a climate resilient package of practice under Inhana Rational Farming (IRF) Technology. This approach follows the principles of regenerative farming – more clearly, regenerative sustainable farming practices through plant health development for their best effectivity to ensure crop sustainability and reduce pesticide usage. Over a 10-year period, studies have shown that this approach not only sustain but actually improves crop productivity and also reduces the need for pesticides, improves soil quality and has a positive impact on the overall quality of tea.

Similarly, application of Novcom compost most conclusively revealed that highest soil development was achieved with lowest quantity application in the shortest time period. The significance of Novcom compost has been established in soil microbiology development and enhanced nutrient availability which was complemented by higher nutrient utilization efficiency through IPHM of the IRF Technology. The study most conclusively revealed the relevance of plant health management for and sustainable a regenerative practice, especially when large-scale organic soil management remains a challenge for many tea estates.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that No generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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