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Sustainable Tea Initiatives with the Adoption of Inhana Rational Farming Technology to Address the Principles of Regenerative Farming for Crop Sustainability and Reduction of Pesticide Usage

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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

The tea sector faces daunting economic challenges stemming from reduced yields due to climate impacts, increased pest and pesticide use, inferior quality and low tea prices, rising production costs and shifts in worker availability. Adoption of sustainable cultivation practices addressing the

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principles of regenerative farming can build resilience in tea production and also lessen the negative impact on the environment. A sustainable initiative was taken by Goodricke Group Limited in collaboration with Inhana Organic Research Foundation (IORF) towards restoration of soil quality, crop sustainability and reduction of pesticide usage. To meet the set targets Inhana Rational Farming (IRF) was the adopted as the crop technology, which focused on soil and plant health management. The study encompassed two time periods, i.e., the pre-COVID era (2013–2019) and post-COVID era (2020–2022), during which crop performance, pesticide usage and soil quality development were documented. The findings clearly showed the impact of sustainable initiative in terms of better crop performance, lowering of pesticide use and improvement of soil health (where ever soil management was continued). This study clearly indicated that an investment in the sustainability account not only ensures crop sustenance and improvement in the long run and enable a reduction in the requirement for agrochemicals, of higher importance is the regeneration of soil health and improvement of resilience towards climate impact, which is critical for both present and future sustenance of the plantation as well as better economic security.

Keywords: Tea; SWOT study; novcom compost; trophobiosis; inhana integrated pest; management (IIPM).

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 vulnerable to the effects of climate change. An increase in temperature, shifting of seasons and increase in the ambient temperature have impacted tea yields across the board because, due to the C_3 carbonic pathway, tea plants are already 1/3rd less efficient in photosynthesis than C_4 plants, and photosynthesis in tea occurs only in the presence of moderate temperature, moderate humidity and moderate sunshine [1-4]**.** An increase in the incidence of pests related to an increase in the ambient temperature has caused an unwarranted increase in the use of pesticides. The deterioration of soil health, especially the loss of 'Soil Microbiological Barrier' due to decades of chemical fertilization and herbicide application, has slowly carved out a pathway for disease ingression, which is reflected in the sharp rise in the use of fungicides. Climate change also impacts the concentration of secondary metabolites, which are most important for the quality of tea [5]. Increasing droughts increase the susceptibility of tea plants to insect pests, and heavy rainfall restricts root growth and favours disease proliferation. There is no choice other than to adopt chemical plant protectants, but the fact remains that over a period, they increase plant vulnerability to biotic and abiotic stresses, resulting in a loss of both quantity and tea quality.

In this context, adoption of sustainable initiatives that address the principles of regenerative agriculture can mitigate root cause of problems and increase resilience of the tea plantations towards biotic and abiotic stress factors. Alleviation of these stress factors are crucial to counter yield susceptibility and prevent pests and diseases. The traditional concept of regenerative agriculture primarily focuses on improvement of soil health, But apart from improvement of soil functionality, Inhana Rational Farming (IRF) Technology also provides impetus towards plant health management because improvement of plant health can actually eliminate the threat of crop loss and enable a reduction in the requirement chemical inputs. Soil health management which is carried out in tandem, strengthens the sustenance factor but is not decisive for objectivity accomplishment. Because of the availability of quantifiable organic inputs on a regular basis, the time required for regeneration of soil to support the desired crop productivity and associated economy can be a deterrent factor for the large-scale implementation of regenerative agriclture. Considering the tea market economy in India and the socioeconomic conditions of the tea growers, regenerative farming practices need to be economically viable. Addition of tangible value to the end product, in a time-bound manner, also forms an important criterion for achieving the desired objectives.

The Goodricke Group recognized the need for key strategies to ensure long-term sustainability of plantations, among which the improvement of tea bush resilience was a primary agenda. The 'Sustainable Tea Initiative' was an important endeavour in this direction; which the group took up from 2014 onwards with technological assistance from the Inhana Organic Research

Foundation (IORF). The objective was to produce quality, safer and sustainable teas.

2. MATERIALS AND METHODS

2.1 Present Situation of Indian Tea Cultivation with Special Emphasis on Dooars Tea Growing Region, West Bengal

Tea production in West Bengal specially in the tea estates has declined by about 13% in the last 6 years due to weather extremities, weather adversities and weather unsuitability, which occurred due to climate change. The small growers have suffered equally as their tea area and total production value increased parallelly.

Climate change impact has triggered biotic and abiotic stresses with an upsurge of pest and disease which is clearly evident from pest management cost, that has increased by about 150% within 6 years span. Pesticide cost which shared about 5.4% of total cost of production increased to about 9% of CoP during this period. Cost incurred on Pesticides increased by about 102% during the same period.

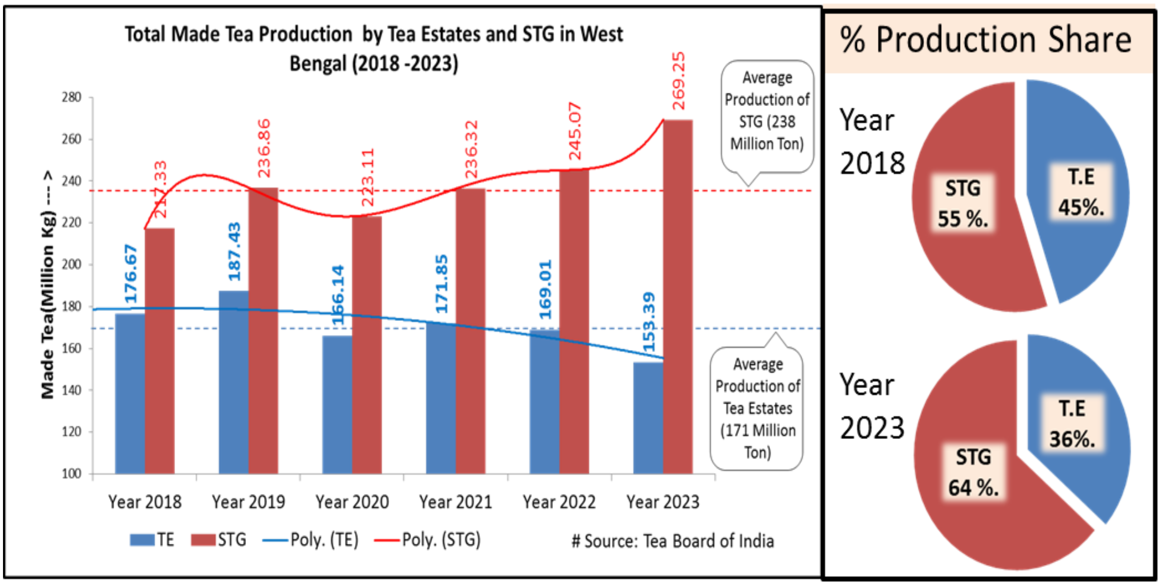


Fig. 1. Comparative tea production by estates and Small Tea Growers (STG)

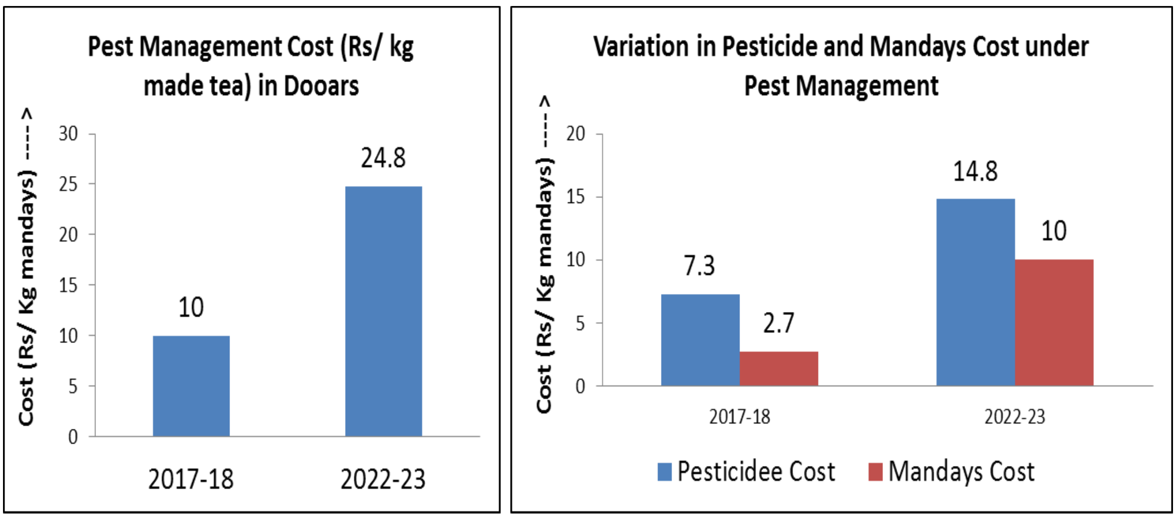


Fig. 2. Variation of pest management cost in Dooars, West Bengal

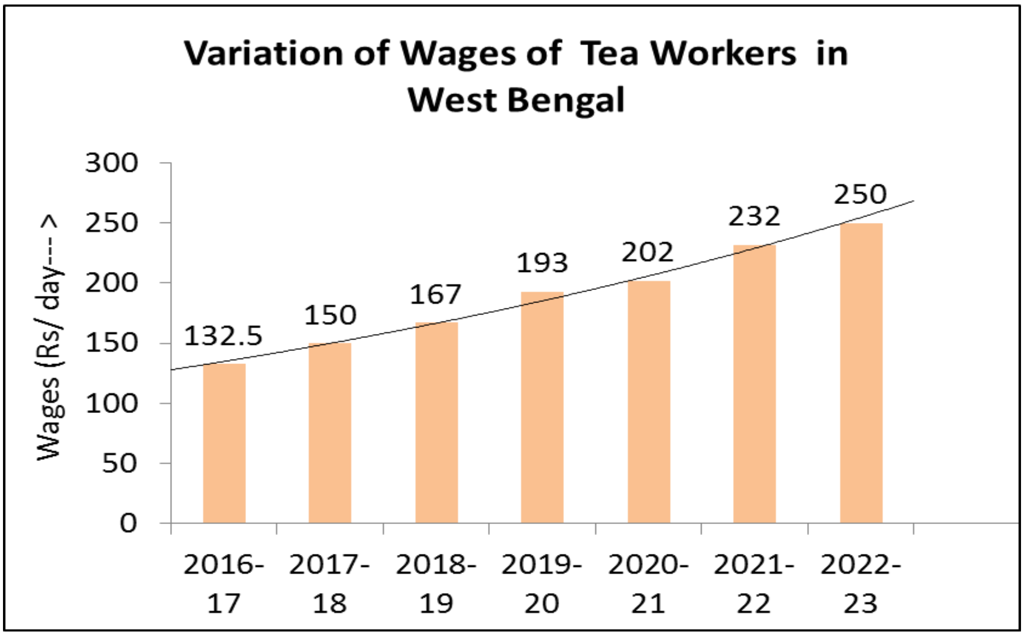


Fig. 3. Increase of wages of Tea workers in West Bengal

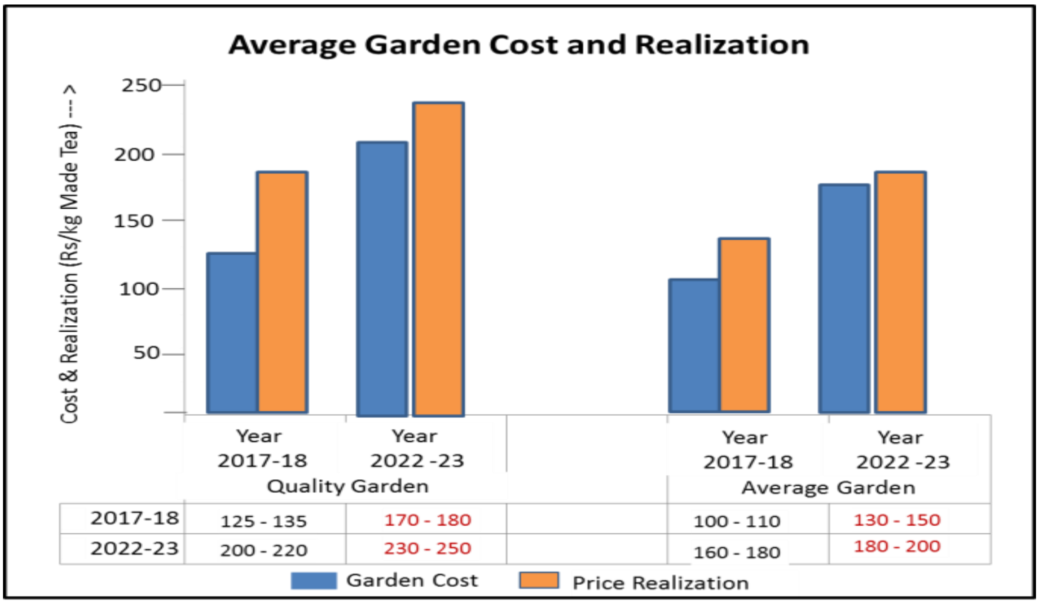


Fig. 4. Changes in average garden cost and realization in Dooars, West Bengal

During this same period the cost of production per kg made tea increased by approximately 46%, but there has been only about 33% growth in price realization (from Rs 150 – 180 per kg to Rs 200 – 240). Considering the decline in productivity, the net return has come down furthermore, from an average margin of Rs. 40 to 50/- to Rs. 20 - 30/- per kg made tea in case of quality gardens. This picture is more gloomy in case of non quality gardens (from an average margin of Rs. 30 to 40/- to Rs. 10 - 20/- per kg made tea) i.e. down by a whopping 45 – 60 % on an average.

The scenario is relatively better for quality teas, but their share is less than 20% of the total estate tea production, of an area. Auction sale price shows the gloomy picture more vividly considering an increase of only about Rs. 24/- per kg made tea, as compared to a steeper increase in CoP. Green leaf from STG farms contributes a major chunk of auction teas, can however sustain even at such price extremities, because of small landholding/ smaller liabilities and simultaneously low cost of green leaf production. But their major insecurity is inconsistent leaf price fueled by absence of agreed price between STG and BLF, and the presence of middlemen.

The price stagnancy in auction for the last 3 years also substantiates a higher bulk of average quality teas and simultaneously lower sale price. The existing scenario has lowered the profitability of the tea estates; as a result the budget allocation for sustainability practices has come down to a trickle.

Climate change has also impacted the export figure. During the past 6 years the quantity of tea export has reduced by 11.3 % or 30 million kgs with the realization value increasing by only about Rs. 57/- per kg made tea. Issue of Pesticide residue in tea definitely plays a major role for the decline in export. Share of Dooars tea in exports is practically nil mostly due higher pesticide load and corresponding inferior quality.

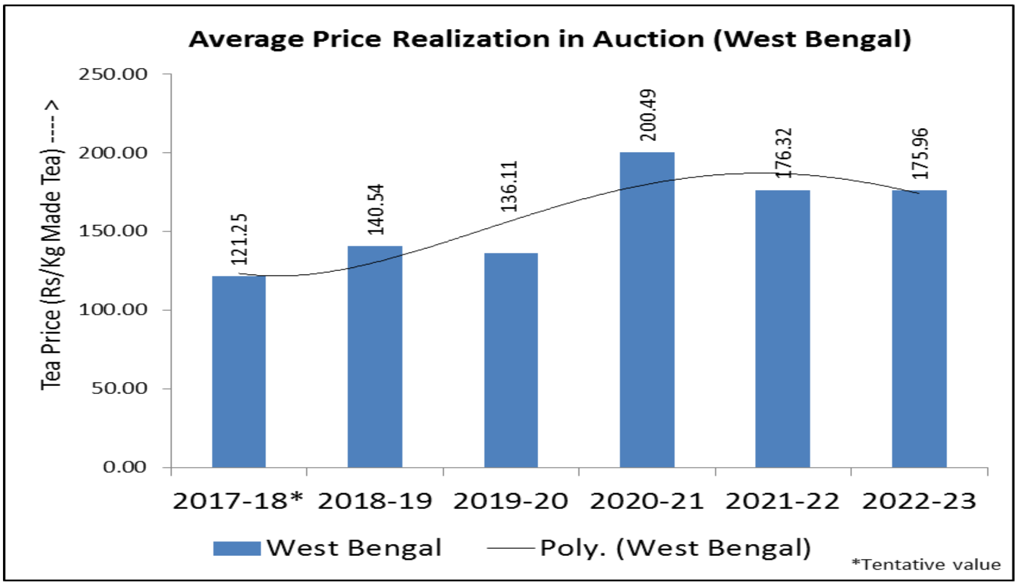


Fig. 5. Average price realization in auction

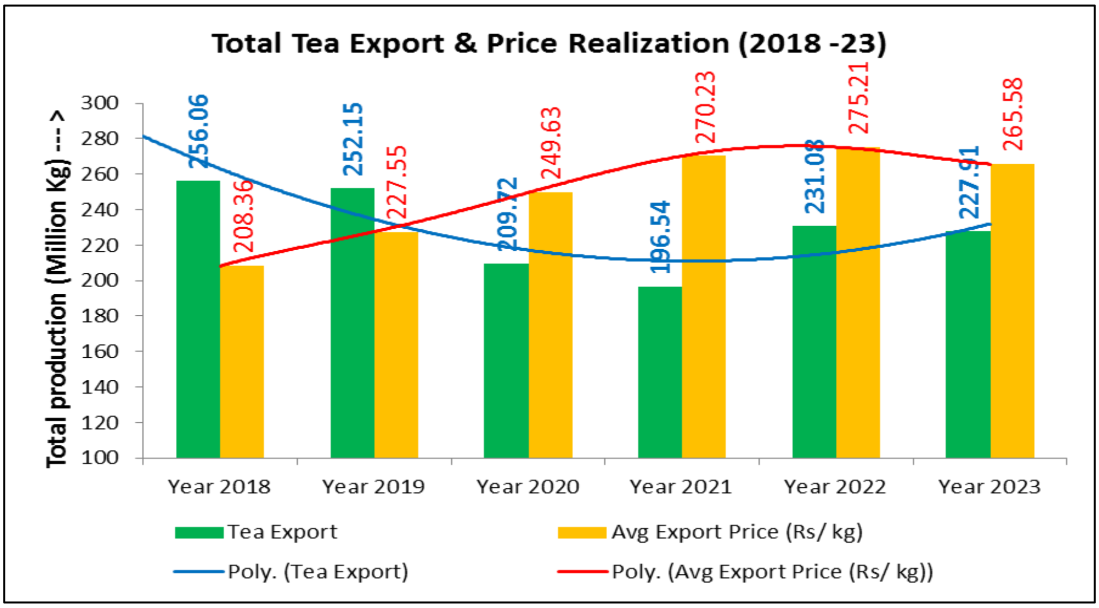


Fig. 6. Total tea export and price realization

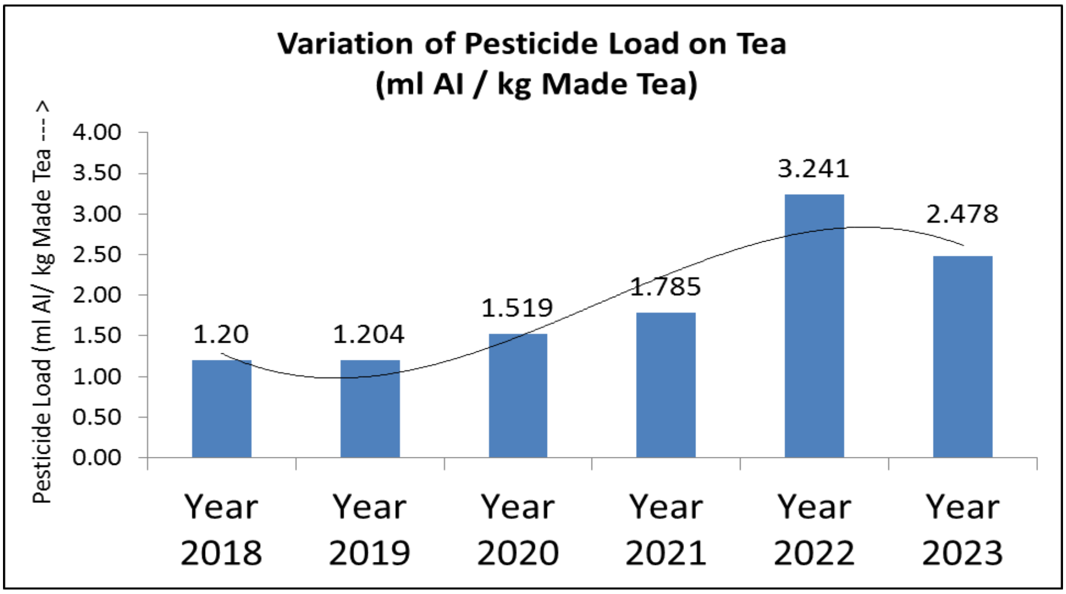


Fig. 7. Variation of pesticide load in Dooars

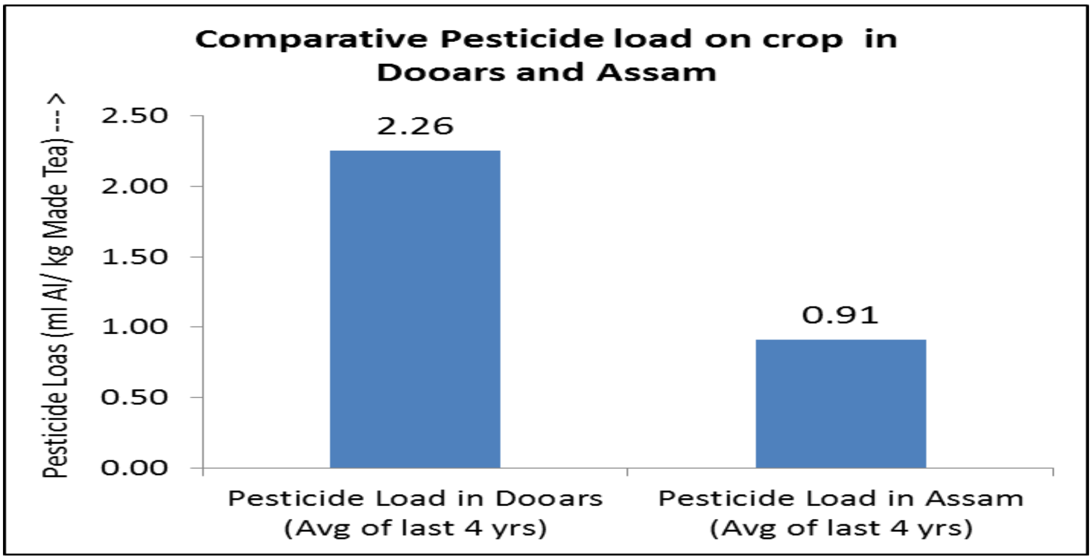


Fig. 8. Comparative pesticide load in Dooars and Assam Tea

To summarize, the CoP is rising steadily, the realization is comparatively flat or proportionately lesser and productivity is on a decline. Volume share of STGs and tea estates has just reversed when compared with their respective contribution 20 years back (presently 64% and 36 % respectively in West Bengal). Competitiveness of Indian teas is reducing, as a result sustainability of the estates is being increasingly compromised with each passing year. Most importantly, budget allocation for sustainability practices has almost dried up. Also, the awareness level regarding the relevance and need of such practices for building up resilience of plantations towards climate impact and future security, and adoption capabilities in respect of new technologies and science- based innovations, is also lacking. Thus, as the return per hectare gradually reduces, more and more tea estates become economically vulnerable or in other words lose long term sustainability.

2.2 Inhana Sustainable Tea Initiative

The sustainable tea initiatives were initiated in 5 group gardens of the Goodricke Group in different tea agro-ecosystems of Dooars and Assam in 2014. The objective of this initiative was to improve plant health and restore soil quality towards crop sustainability and reduce pesticide use. 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.

2.3 SWOT Study

This study serves as a potent tool for sustainable crop production under limited resources and budgetary constraints. The SWOT study (Fig 9) was 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.

2.4 Soil Health Management

Soil health management focused on restoring the native soil microflora population and dynamics through integrated soil management. To address the problem of resource scarcity in tea plantations, efficient resource management was undertaken through on-farm Novcom compost production. Priority sections identified through the SWOT study, along with all young tea sections (0–4 years), were earmarked for compost application @ 2 -4 ton/ha based on the analysis report.

2.5 Plant Health Management

Plant health development, which has been completely ignored under conventional farming, is the most crucial component for crop sustainability and environmental protection and can boost economic development. The United Nations declared 2020 as the International Year of Plant Health (IYPH). The 'Sustainable Tea Initiative' imparted a maximum focus on this very component through the adoption of the Inhana Plant Health Management (IPHM) schedule, which utilizes various potentized and energized botanical solutions as well as on-farm-developed Plant Tonic and Plant Elixir for the activation of plant physiology. The adoption of this schedule has had a three-phasic impact on crop yield improvement, the improvement of bush immunity to pest interference and the development of bush host defence mechanisms to reduce infection by disease-causing pathogens. Improving the plant resilience to biotic and abiotic stresses is also a major objective of plant health management programs.

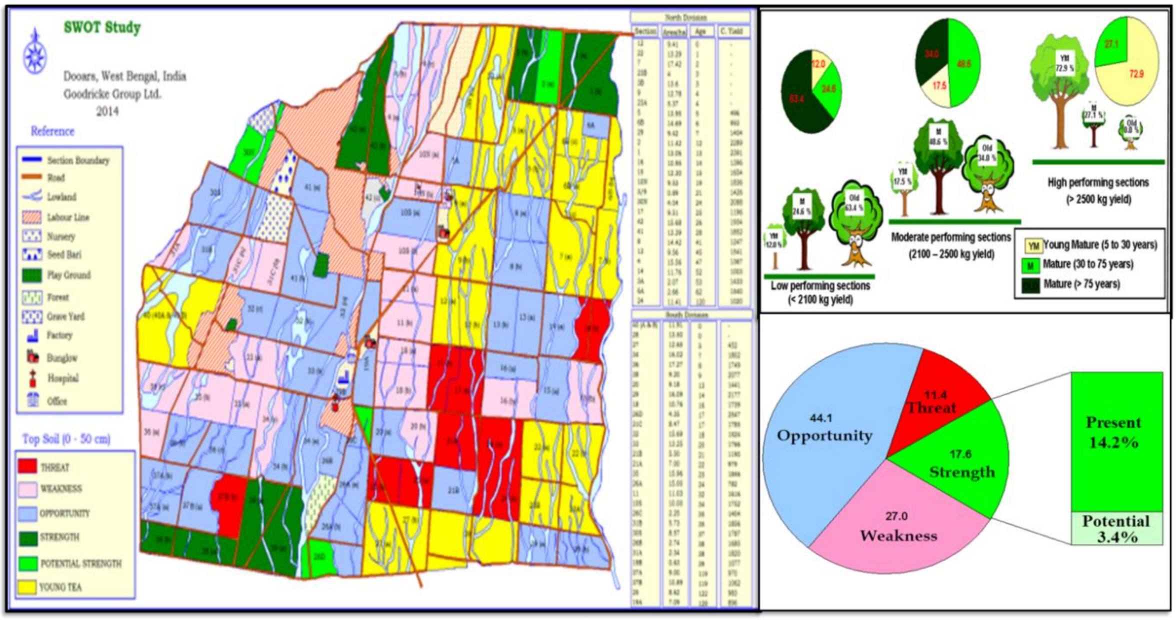


Fig. 9. SWOT map of a project garden which identifies the sections as per their problem and potential under Inhana Sustainable Tea initiatives

2.6 Sustainable Pest Management

The adoption of a customized schedule for soil and plant health management is the primary step toward effective pest management using fewer chemicals, considering that the 'Pests Starve on Healthy Plants'**.** In addition, Goodricke is probably one of the few tea groups that has implemented the PPC code in its entirety in its tea estates since 2014. In addition, adherence to some basic Double's and Don'ts as per the Guidelines of the 'Sustainable Tea Initiative' as well as the inclusion of on-farm-produced organic concoctions, Neem-based oil combinations and Lime-S have helped reduce the pesticide load of the project gardens in a consistent manner.

2.7 Inahana Rational Farming (IRF) Technology

Inhana Rational Farming Technology was developed by Dr. P. Das Biswas, an Indian scientist who pioneered sustainable organic tea cultivation in India [6]. The technology is based on the Element Energy Activation (EEA) principle, which is a perfect blend of ancient wisdom and modern science. Through the dual approach of Plant Health and Soil Health Management, the technology works towards the reactivation of the inherent physiological, metabolic and biochemical functions of the plant system to aid improved nutrient utilization as well as enhanced immunity against pests and disease [7].

2.7.1 Plant Health Management

The two main objectives of plant health management under IRF technology are as follows:

(i) Restoration of the Deficient Energies in Plant Systems leads to Activated Plant Physiological Functioning, leading to Plant Health Development. This is primarily done through the application of a package of 'ENERGIZED & POTENTIZED' Botanical Solutions, which are developed on the 'Element Energy Activation' (E.E.A.) principle. The solutions contain isolated energy forms extracted from energy-specific plant sources that store the radiant energy or the basic life force in differential forms. The Isolated Energy Forms are easily Absorbed by the Plant System and Deliver the deficient energies to the specific sites within the Plants that control the different metabolic and biochemical functions.

(ii) Activation of the Plant Immune System: Activated plants with increased photosynthetic efficiency produce complex carbohydrates such as pectin, which reduces susceptibility to soil borne pathogens. Activated plants also store surplus energy in the form of lipids, which aid in the formation of the phospholipid cell membrane, the plant's mechanical barrier, especially against airborne pathogens. Moreover, the activation of plant physiological functions leads to the desirable secretion of phenolic compounds, which invoke biochemical defences against disease infections.

2.7.2 Concept of Energy Management behind Inhana Rational Farming (IRF) Technology

A key disparity between plants and other members of the animal kingdom lies in their unique ability to independently acquire, convert, and utilize energy. Plants have a unique ability to harness solar energy and exhibit a remarkable ability to self-nourish and self-protect**,** drawing from their environment without external intervention. Plants capture a small fraction of solar radiation to fuel their vital processes, self-generate energy, and synthesize organic compounds necessary for growth, a process that sustains entire ecosystems. This ability is crucial for their survival and pivotal for their role as primary producers. Ancient spiritual scientists, delving into the essence of life, recognized the pivotal role of plants as providers of sustenance for the world. In their pursuit of understanding the intricate workings of plant systems, they elucidated a profound concept known as the "Element-Energy-Activation (E.E.A.) Principle." This principle, embedded within the framework of Inhana Rational Farming (IRF) Technology, delineates the inner mechanisms governing energy management within plants.

In essence, all living or non-living entities are composed of five fundamental elements—earth, water, fire, air, and ether—referred to as "Pancha Mahabhutas" in ancient teachings. While recognizing that plants are made of these elements, the emphasis on activation highlights the mechanisms through which energies manifest and operate within matter. Unlike energy, which merely operates within material forms, activation involves the enlivenment of matter by subtle energy forces. There are five life forces in total—Apana, Samana, Udana, Vayna, and Prana—with Prana being integral to each one (Fig 10). The Element-Energy-Activation (E.E.A.) Principle offers profound insights into the interplay between subtle energies, elemental composition, and material manipulation. By understanding and harnessing these principles, ancient spiritual scientists laid the foundation for a holistic approach to agriculture and life, emphasizing respect for the inherent intelligence and vitality of the natural world.

These life forces work independently yet interdependently, ensuring the seamless functioning of the plant organism. Each element and its associated Prana contribute uniquely to the overall vitality and well-being of plants. Understanding these interrelationships provides insight into the intricate mechanisms of plant physiology and growth. In plant physiology, two key points are crucial. First, elements are naturally present in plants according to specific logic, and altering their balance affects function, not deficiency. The focus should be on activating elements and their associated energies, which requires an understanding of the plant's energy dynamics. Second, adding elements does not necessarily address energy deficiencies, as these additions operate at the grosser level and cannot harness the subtler energies needed for optimal growth. Addressing deficiencies thus requires a holistic approach, emphasizing balanced energy intake from food and water.

Inhana Plant Health Management Solutions are developed on the ‘Element Energy Activation (E.E.A.)’ Principle - The Vehicle of IRF Technology.

These solutions are vastly different from any other herbal formulation considering that they contain energy components in activated forms. ‘Inhana Energy Solutions’ potentized and energized botanical extracts are utilized by employing the principle of “Energy Management”, without the aid of external agents, but only provide the necessary ENERGIES for the activation of plant physiology towards better nutrient uptake/utilization and better host-defence mechanisms of the plant system.

Radiant solar energy is stored in plants that are extracted from energy-rich plant parts by a specific extraction procedure and subsequently potentizes to release the energy components when sprayed on the plant system. [8] The various Inhana Plant Health Management Solutions supply the energy required to control various physical, biochemical and microbiological processes in the plant system and thereby activate plant growth and defence systems.

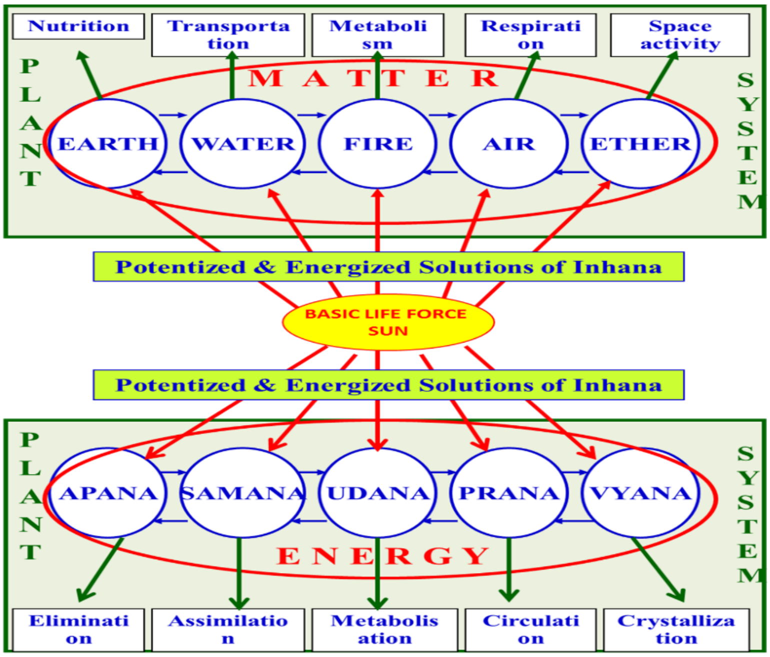


Fig. 10. Working mechanism of Inhana solutions developed under Element Energy Activation (E.E.A.) principle

Upon spraying, the solutions infiltrate the plant body through stomata and other openings and are distributed throughout every part of the plant organ. This process ensures that the necessary energy reaches various systems within the plant, promoting balanced growth. This mechanism lies at the core of fostering plant equilibrium and health. Inhana Plant Health Management Solutions are tailored to different growth stages and conditions, providing regulatory support without inhibitory action. This approach, part of the IRF Technology, aims for perpetual and prosperous farming by aligning with plant physiology and philosophy, offering a comprehensive therapy from seed treatment to harvest.

2.7.3 Guiding philosophy of EEA principle behind development of Inhana Solutions

Inhana solutions are developed under the Element Energy Activation (E.E.A.) Principle. Radiant solar energy is stored in plants and this binding stored energy components are extracted from energy rich plant parts by a specific extraction procedure and subsequently potentised in the order of 10^3 to 10^4, so that the activated energy forms release the energy components when sprayed on the plant system (matter). Now according to the requirement, different extracted energy components are combined in desired proportion to make different solutions; which regulate sequential physiological activities to attend the root cause. So a numerous number of solutions can be prepared as per requirement, guided by the Element Energy Activation Principle.

2.7.4 Process flowchart of Inhana Solutions under E.E.A Principle

STEP 1 : Selection of specific plants (Specific days and time)

Radiant energy from the Basic Life force (Solar Energy) is stored in plants. As the specific energies are stored in specific parts of the different plants, selection of the plants or more precisely selection of specific plant parts are most important. Not only that, specific days and time are also important as the energy storage potentials of the plants varies with various star occurrence. So the astronomical parameters are important to extract maximum stored energy [8].

STEP 2 : Alcoholic Extraction (Specific plant parts in specific time and procedure)

Specific plant parts viz. roots, stem, leaf, root hair, leaf vein etc. are taken for extraction as early as possible from the collection time, before the living parts become inert and stored radiant energy is dissipated. Since the energy components are extremely subtle and abstract in nature and simultaneously they need a medium (matter) and after / during extraction they should be transferred to a medium which is less gross and the same time has higher surface tension. Alcohol is used for the extraction process because it has the potential to isolate the bound energy in gross form and stored within it. [8]

STEP 3 : Energization (Isolation of Energy Components)

Energization is the process through which energy components are isolated from its gross form and stabilize in alcoholic medium. Both extraction and energization process operates simultaneously as the extracted gross components should be immediately transferred to a medium from which these can be liberated easily. The total energization procedure continues for several days up to 21 days to extract maximum stored energy to this medium. Still only a part of the stored energy can be isolated from its plant source. [8]

STEP 4 : Potentization (Release of Bound Energy in order of 10^3 to 10^4 times)

Potentization is the process through which the extracted bind energy is activated to perform in desired order when applied in plants. In this process specific energy is transformed to its nearly original source or more specifically as it was transformed to differential energy from Basic Life Force. This form is Lifetrons, which are much subtler than electron, proton or atom. The bind energy manifests when it is separated from the binding agents. In this process the medium used is pure filtered water free from heavy particles. The potentization is done in the order of 10^3 to 10^4 times according to the specific energy components and the objectives of the specific role. Potentized energy components are actually in the binding form but are separated from other differential energy and posses a huge liberating potential than its previous stage [8].

Hence when they are applied on the plant system they enters primarily through the stomatal opening and they are being accepted by the plant system because of this primary (Subtler) form. Thereafter they can reach to the desired sight more quickly as no transformation of that energy form is required.

STEP 5: Combination of the Potentised and Energized extracts

Combination of this potentised and energized extract are done according to the specific objectivity of the solutions. As all solutions have regulatory role and no inhibitory action, these are applied to regulate specific plant functions in desired and successive order. These solutions try to solve any problem leading to the root cause of the problem. For example IB-2 has been developed for disease management of crop [8]. For effective disease management, both structural and biochemical defence of plant is a must. Simultaneously, any cidal approach to fungal pathogens is not only ineffective, this is

Table 1A. Details of Inhana Plant Health Management Solutions [8]

Plant Health Management (for plant physiological development)		
Solution Name	***Biologically activated & potentised extract of***	**Role in Plant Physiological Development**
IB 1	*Hyoscyamus niger, Ficus benghalensis & Dendrocalamus strictus Nees.*	▪ Organic growth promoter, activator and regulator ▪ Energizes and stimulates the plants system for the best use of nutrients both applied and stored in the soil. ▪ Regulates every stage of the Grand Growth Period influencing growth correlation.
IB 2	*Ocimum sanctum, Calotropis procera R. & Cynodon dactylon*	▪ Silica induced immunity against fungal attack ▪ Activates plants' host defence mechanism through silica management providing structural defence against fungal pathogens. ▪ It also stimulates plants immune system by activating the biosynthesis of different phenolic compounds having fungi-toxic property.
IB 3	*Adhatoda vasica Nees, Zingiber officinale Roscoe & Embellia ribes.*	▪ Organic solution for potash absorption and utilization ▪ Increases the efficiency of potash uptake through energized root capacity, so that gradual reduction in application is ensured. ▪ It activates suction pressure by influencing diffusion pressure deficit.
IB 4	*Calotropis procera R., Dendrocalamus strictus Nees & Bombax malabaricum D. C.*	▪ Ensures biological absorption of atmospheric-N directly by plant. ▪ Helps the plant to utilize the atmospheric nitrogen. It also balances the quantity of nitrogen in the plant system at the right time, thereby preventing deleterious effect on quality of the produce. ▪ Ensures gradual reduction of chemical nitrogen application.
IB 5	*Cynodon dactylon & Calotropis gigantea.*	▪ Energizes the various biochemical process of plant resulting in harmonious grand growth period. ▪ Regulates and stimulates the cellular oxidation process. ▪ Energizes the phloemic function resulting in encouraged translocation of organic solutes. Stimulates the hydrolysis of starch to D-Glucose units by enhancing the enzymatic activity.
IB 6	*Hyoscyamus niger & Solanum verbascifolium*	Energizes and activates respiration and photosynthesis activity and plays complementary role of solution-I ▪ Energizes respiration by activating the protoplasmic factors and the concentration of respiratory substrate. ▪ Stimulates the rate of photosynthesis by quick translocation of carbohydrates.

unscientific and unethical. Modern research reveals that silica can provide structural defence against fungal pathogens. But most of the plants can not uptake the silica from the soil to the desired level that is required to elevate their structural defence. Two physiological processes are involved in the silica absorption – anaerobic glycolysis and aerobic respiration. IB-2 gives specific energy components which hastens the intensity and quality of these processes. Root systems need to be energized hence 'Apana Prana' is provided; then silica should be translocated where water element is involved, so 'Udana Prana" is provided and so on. So according to the sequential regulatory plant functions and their required intensity specific energy components are combined in different proportions to develop individual solution. [8]

Table 1B. Details of the inhana plant health management solutions

Plant Health Management (for plant physiological development)		
Solution Name	**Biologically activated & potentised extract of**	**Role in Plant Physiological Development**
IB 7	*Ocimum sanctum*	Stimulates the root function, activates root growth/penetration and energizes soil in the root zone thus improves soil–plant relationship. ▪ Develops the CEC of soil & Improves the degree of base saturation to the desired level. ▪ Energizes the production of microflora and bioflora around the root zone. ▪ Enhances the Root Cation Exchange Capacity. ▪ Stimulates the root growth and penetration by activating the Contact Exchange Capacity of the Root.
IB 8	*Solanum verbascifolium, Prosopis spicigera & Ocimum bascilicum.*	Organic solution for termite management. ▪ It has both controlled and contained action. It restricts the movement of termites. ▪ Repels termite activity by influencing thermostatic environment of the soil.
IB 9	*Albizzia maranguihses, Bischofia javanica & Erythrina variegata Linn.*	Ensures enhanced photosynthesis and balances respiration ▪ It influences the action spectrum and absorption spectrum of plants. ▪ It enhances or activates Xanthophills.
IB 10	*Costus speciosus sm. & Tylophora indica mer.*	▪ Improves plant transport by deliberating essential substances to the various internal mechanism.
IB 11	*Solanum xanthocarpum schard & Aristolochia indica Linn.*	▪ Improves the movement of solutions by providing systemic presence to give structural integrity.
IB 12	*Sida Cordifolia Linn. & Berberis asiatica Roxb. Ex. De.*	▪ Improves the plant's capacity for starch synthesis.
IB 13	*Ficus racemosa Linn. & Calotropuc procera R.*	▪ Activates hypersensitive defence system by disintegrating the hypha.
IB 14	*Ocimum sanctum & Costus speciosus sm.*	▪ Improve root health and activates apoplastic and symplastic mechanism.
IB 15	*Vernonia cinerea Less. & Solanum verbascifolium (Root &stem)*	▪ Improves and fortifies the cow dung and cow urine concoction towards better toxicity removal and plant sanitization effect.

Pic. 1. On-farm Novcom composting at project gardens under Inhana Sustainable Tea Initiatives

Table 1C. Details of inhana plant health management solutions

Plant Health Management (for plant physiological development)		
Solution Name	**Biologically activated & potentised extract of**	**Role in Plant Physiological Development**
IB 30	*Cocculus hirsutus (L.) Diels & Butea monosperma*	▪ Facilitating higher photosynthetic efficiency
IB-31	*Cynodon dactylon, Ocimum basilicum & Sida cordifolia Linn.*	▪ Provide energies for the orderly, intensified and rapid thermophilic, mesophilic and normophilic stage through microbial generation from attenuated stage
IB32	*Sida cordifolia Linn., Cynodon dactylon, Solanum xanthocarpum schard & Aristolochia indica Linn.*	▪ Provide energized environment for speedy breakdown of complex carbohydrate chains through generation of autotrophic bacteria and cellulose degrading fungi
IB 33	*Sida cordifolia Linn, Ocimum basilicum & Ficus hispida Linn.*	▪ Enhances radiant energy manifestation towards speediest thermophilic response and speeding breakdown of organic carbon.
IB 34	*Bombax ceiba & Embella ribs.*	▪ Enhances geotropic response of plant
IB 35	*Solanum verbascifolium & Cynodan dactylon*	▪ Stimulates various anaerobic processes for higher cellular materials
IB 36	*Butea monosperma, Ocimum sanctum & Calotropic gigantea*	▪ Enhances differential activities and synthesis of the distinctive protein clusters
IB 37	*Costus speciosussm & Berberis asiatica roxv.*	▪ Enhances the transportation system across protoplasmic membranes
IB 38	*Ficus recemosa linn & Tinospora crispa*	▪ Stimulates the imbibition of water through diffusion and capillary action
IB 39	*Calotropis procera R. & Ficus religiosa*	▪ Increases hydrostatic pressure by the contains of cell on the cell wall
IB 40	*Hyoscyamus niger & Prosporis spicigera*	▪ Fortification of five basic elements into an equilibrium along with enrichment of plant growth activator with biological enhancement.

Note: These solutions are applied singly or in combination at different growth stages according to the seasonal variance of the plantation (as in the case of tea) for the energization of plant physiological activity towards crop sustainability and plant immunity development

Table 1C. contd.

Plant Health Management (for plant physiological development)		
Solution Name	**Biologically activated & potentised extract of**	**Role in Plant Physiological Development**
IB 16	*Vernonoa cinerea Less. & Solanum verbascifolium (Root)*	▪ Improves and fortifies cow dung and cow urine concoction for faster organic activity in the surface soil.
IB 17	*Prosopis cinerea & Costus speciosus sm.*	▪ Activates karanj seed and cow urine concoction for anti-ovulatory effect on Helopeltis Theivora.
IB 18	*Barberis asiatica Roxb. Ex. De., Ficus racemosa Linn., Ocimum sanctum & Cynodon dactylon*	▪ Influences the cell wall swelling, thereby inhibits host penetration and infection by pathogens.
IB 19	*Bombax malabaricum D.C., Calotropic procera R & Ocimum bascilicum.*	Organic pest management ▪ An organic pest repellent with anti-feedant action. ▪ It activates the Plants Host Defence Mechanism & ▪ It enhances Environmental Resistance and reduces the Biotic Potential.
IB 20	*Bombax malabaricum D.C., Calotropic procera R, Ocimum bascilicum. & Bischofia javanica*	▪ Activates plant system for enhanced secretion of phytoalexins particularly pisatin and orchinol.
IB-21	*Ficus hispida Linn.*	▪ Provides necessary metabolic energy and helps in cell differentiations
IB-22	*Erythrina Variegata Linn.*	▪ Enhances the metabolic activation of a growing cell (or tissue/organ)
IB 23	*Alstonia scholaris R. & Bombax ceiba*	▪ Enhances development process which encompass the activities resulting from growth and differentiations
IB24	*Fumaria indica pugsley* & *Tylophora indica mer.*	▪ Stimulates the genetic information to cause changes in metabolic activity and structural organization
IB 25	*Aristolochia indica Linn.* & *Ficus racemosa Linn.*	▪ Helps in achieving the autotrophic conditions with a well developed root system
IB 26	*Ficus racemosa Linn.* & *Sida cordifolia Linn.*	▪ Ensure synthesis of macro molecules at the expanses of metabolic energy
IB 27	*Sida cordifolia Linn.* & *Cocculus hirsutus*	▪ Enhances the cell division and the synthesis of nuclear DNA
IB 28	*Caeslpinia crista Linn.* & *Ficus racemosa Linn.*	▪ Influences the movements of locomotion through both autogenetic and paratonic movement
IB 29	*Arbus precatorius Linn.* & *Veronica cinerea Less.*	▪ Higher and faster plant growth, differentiation and development.

2.7.5 Soil health management

Soil health management is primarily performed using Novcom compost, a technological innovation for better and more rapid effectiveness and economic viability. The uniqueness of the Novcom composting technique lies in its rapid biodegradation, high-quality end products with microbial richness, high GHG mitigation efficiency and high cost effectiveness.

Novcom composting technology is a unique biodegradation system that can convert any type of biodegradable material, including toxic and hard-to-biodegrade materials, into high-quality compost. Through the erection of the Novcom composting heap, we tried to create an environment for the self-generation of diverse micro flora. The application of Novcom solution served to provide the desired energy sources in the most pure and subtle form for the rapid multiplication of micro flora and increased activity efficiency. This energy management approach is based on the 'Element Energy Activation' (E.E.A.) Principle, inspired by the Vedic philosophy.

Novcom solution accelerates the biodegradation process by orchestrating mesophilic, thermophilic, and mesophilic stages in a synchronized manner. Each stage is completed before the next stage begins, resulting in stable, mature, and nonphytotoxic compost in a short time. This method creates an environment conducive to each step's completion without the need for specific inputs or agents. Interpreted under the Element Energy Activation (E.E.A.) Principle, Novcom composting technology offers a novel system for quality compost generation, energizing the environment for soil fauna regeneration. Even a small quantity of compost can noticeably improve soil quality quickly. Providing the right environment for microbes is crucial, making Novcom's effectiveness evident in its ability to create the necessary conditions for microbial growth and function.

(i) Enables quality compost within 21 days :. Most composting methods take 60 to 120 days, and the Novcom composting method takes only 21 days. [9]
(ii) Post-soil application effectiveness through 10,000 times higher self-generated microbial population: When most of the composts have a microbial population on the order of 10^{10} to 10^{12} c.f.u./gm moist compost, compost prepared under Novcom composting Technology has a microbial population on the order of 10^{16} c.f.u./gm moist compost, which ensures rapid microbial rejuvenation in soil and enhances soil–plant nutrient dynamics towards higher crop production without any time loss. [10]
(iii) Wider applicability with less application requirement: Novcom composting method can use any type of biodegradable waste, including complex materials such as press mud, poultry litter, coir pith, paper mill waste, and municipal solid waste; as a raw material, the qualitative superiority of Novcom compost ensures less application for similar crop targets w.r.t. other conventional compost.
(iv) 1/10th GHG emissions w.r.t. the Windrows composting method: Higher biodegradability potentials enable less GHG emissions under the Novcom composting process, making this method suitable for any GHG mitigation program [11].
(v) 1/3rd cost of the vermi compost: With no infrastructure requirement, less sensitivity, less monitoring time and better recovery percent, the cost of Novcom compost is less than 1/3rd the cost of the vermi compost.[12].

2.7.6 Preparation of novcom compost

At a selected upland and flat area, chopped green matter was spread to make a base layer measuring 10 ft. in length, 5 ft. in breadth and 1 ft. in thickness. This 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 continued until the total height reached approximately 6 ft. After each layer of green matter was constructed, it was compressed downwards from the top and inwards from the sides for compactness.

On the 7th day, the compost heap was demolished, and the heap was properly churned. The material was subsequently layered, and after each layer was diluted, the Novcom solution (5 ml/ltr.) was sprinkled thoroughly as on the 1st day. After seven days, the volume of the composting material decreased due to progress in the decomposition process. Hence, once again, the heap height was maintained at approximately 6 ft. The length and breadth of the heap were maintained at 6 ft. x 6 ft., respectively. The heap was once again made compact, as described earlier. The same process was repeated on the 14th day as on day 7, and to maintain the heap height at approximately 6 ft, the length and breadth of the heap were further reduced to 6 ft. x 4 ft., respectively. A total of 250 ml of Novcom solution is required for 1 ton of raw material (100 ml on day 1 followed by 75 ml each on day 7 and day 14). The composting process was complete, and the compost was ready for use after 21 days [9].

2.8 The Hypothesis of Integrated Pest Management

2.8.1 We need to overcome the idea of 'Battle'

Prevailing plant protection practices rest on the postulate that pests are arbitrary enemies that will attack our crops and stop only when there is nothing left. Therefore, we have to fight 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 the noted scientist Wood, 1972) that most pest- and disease-causing organisms depend on the growth of 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. The various environmental factors have given us converging results with regard to the relationship between plants and parasites. However, whether the issue is attacked by an insect, fungus, bacterium or virus, the relationship to the host, i.e., the plant, is nutritional (Fig 11).

Pic 2. Application of novcom compost at project gardens under inhana sustainable tea initiatives

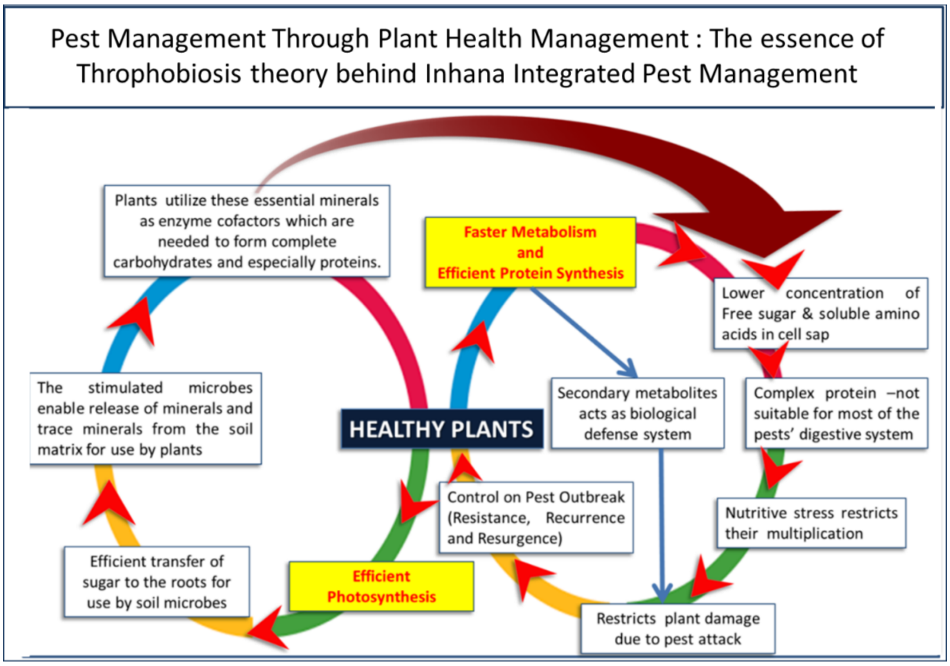


Fig. 11. The science behind pest management through plant health management

Application of nitrogenous fertilizers especially causes rapid increases in cellular nitrate, ammonia, and amino acids, which can be used for the synthesis of proteins. The application of pesticides/herbicides results in a temporary reduction in protein synthesis. A reduction in the rate of protein synthesis results in the temporary accumulation of free amino acids.

Therefore, while 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, plant vulnerability to fresh infestation increases because of protein breakdown or amylolysis caused by the pest. In addition, the toxic effect of a pesticide will also affect the host plant, making it more susceptible. At the same time, most pesticides kill 90% of non-target organisms, thereby drastically lowering environmental resistance. Eventually, impaired ecology both inside and outside the plant system occurs. An increase in the rate of exposure to harder pesticides naturally leads to the use of larger and larger pesticide treadmills.

Thus, a focus on soil and plant health management is directly linked to pest management. Rejuvenation of soil health not only makes the soil–plant nutrient cycle more dynamic but also leads to the development of a soil microbial barrier in the root rhizosphere zone to prevent the attack of any soil borne pathogens. On the other hand, emphasis on plant health management helps to activate plant physiological functioning, which in turn not only promotes nutrient uptake and assimilation but also the generation of secondary metabolites, which develop plants' own immune system against biotic and abiotic stress. Thus, to address pest problems, the root cause of pest infestations must be attended, and once pest pressure is reduced, other practices will be more effective and can help to reduce pesticide use (Fig 12).

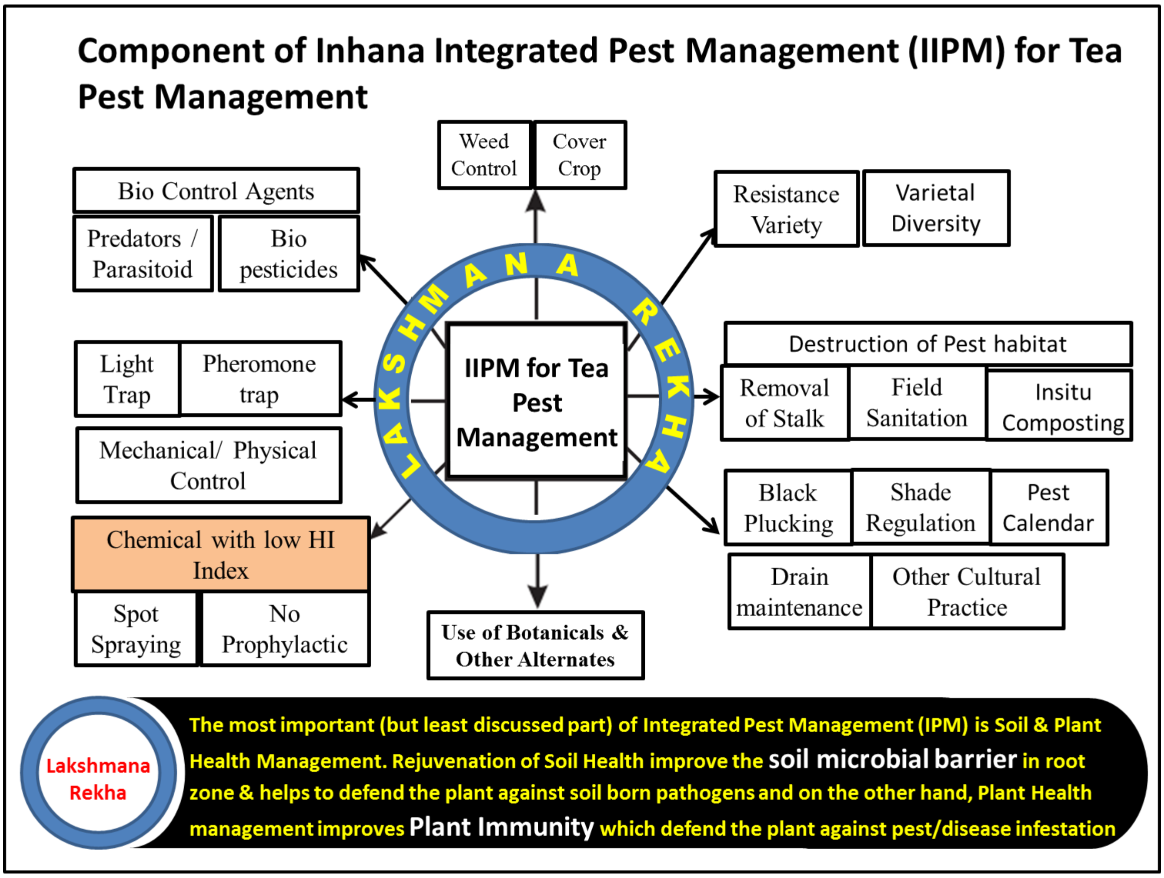


Fig. 12. Component of Inhana Integrated Pest Management (IIPM) under inhana sustainable tea initiatives

2.9 Framework of the Management Schedule for Inhana Sustainable Tea Initiatives

Comprehensive plant health management approaches under IRF Plant Health Management (IIPM) start with an understanding of sectional behaviour with seasonal changes and interactions with other ecological components. IPHM covers all possible problematic areas of a plantation, and the intensity of the management depends upon the extent of problematic areas and existing bush health. Plant health management includes pre-pruning and post-pruning health management, drought management, water stress management, hail management, prophylactic disease management, disease management, post pest infestation recovery programs, stress management in waterlogged areas, sanitation programs and, most importantly, bush health rejuvenation for crop sustenance (Fig 13).

Fig. 13. Program schedule under inhana sustainable tea initiatives

Pic 3. Preparation of on-farm lime sulphur- wide scale applicability apart from red spider management under Inhana Sustainable Tea Initiatives

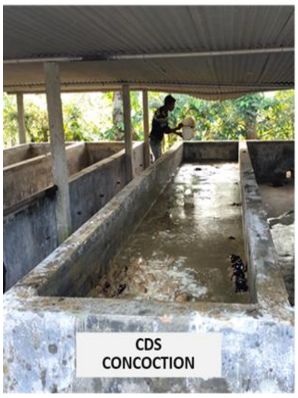
2.10 Preparation of Inhana Organic Concoctions

2.10.1 Inhana Cow Dung Slurry (CDS) concoction

Inhana CDS concoction is an effective combination of cow dung, cow urine and some other organic ingredients; it is processed under a special fermentation pathway and primarily acts as a soil and plant health energy booster. Inhana Solution-IB15 enhances the potency of the CDS concoction for faster action and better effectiveness towards plant and soil health management

Inhana CDS Concoction has a profound role in both plant and soil health management. The role of Inhana CDS concoction in plant health management is to help towards the sanitization of plants, nutrient supplementation to support plant metabolic processes, reduction of salt toxicity from foliar nutrients, and pest repellent and nourishment of predator populations and to provide a food source for leaf microbes that influences tea quality. In the area of soil health management, Inhana CDS concoction helps to rejuvenate the soil microbial population, especially by (i) increasing soil–plant-nutrient interactions, (ii) reducing herbicide toxicity in soil, (iii) reducing the virulence of soil borne pathogens and (iv) increasing microbial activity in soil organic manure and post soil application effectiveness.

Preparation Method: All the materials described above (Pic 4) were mixed in a wide-mouthed cemented/plastic tank. The mixture was stirred for 20 minutes twice daily. Inhana CDS Concoction will be ready in 5 days.



Raw Materials Required for spraying in 1 ha

Sl.	Ingredients	Quantity
1.	Fresh Cow Dung	15 kg
2.	Fresh Cow Urine	15 ltr.
3.	Jaggery	500 g
4.	IB-15	200 ml
5.	Water	50 ltr.

Pic 4. Onfarm CDS preparation in project gardens under inhana sustainable tea initiatives

A. Ingredients	Req. for 100 ltrs
2 parts of Cow Ghee	2 kg
2 parts of Cow Milk Curd	5 kg
2 parts of Cow Milk	5 ltr.
40 parts of Cow Urine (fresh)	40 ltr.
48 parts of Cow Dung(fresh)	48 kg
100 Parts	100 ltr.
B. Additives	
2 % Common salt	2 kg
2 % Jaggery	2 kg
0.1 % Yeast	100 gm
C. Energiser	
P- 5 Solution 5 %	5 ltr.

Pic 5. Onfarm preparation of P5 concoction in project gardens under Inhana Sustainable Tea Initiatives

2.10.2 Inhana P5 concoction

Inhana P5 Concoction is a plant elixir for the revitalization of Plants from Stress that increases immunity to fight pests and accelerates vegetative growth. P-5 elixir is an assembly of five cow products that are economical, multifunctional and easy to prepare and convenient for agricultural operations. Addition of P-5 solution (*potentized botanical extract of specific plants*) to cow products accelerates the fermentation process by unlocking the energy components within the raw materials to obtain properly fermented, quality end products within a short time period Inhana P5 Concoction helps to restrict plant transpiration loss, supplies the required macro- and micronutrients as well as growth-promoting hormones for rapid recovery from drought, improves photosynthetic efficiency by lowering the chlorophyll a/b ratio and increases the leaf microbial population for better N uptake and utilization.

Preparation Method: The ghee and cow dung were mixed together on the 1st day and incubated for 3 days on plastic. On day 4, all other ingredients (Pic 5) were mixed thoroughly and stirred well. yeast and jaggery were mixed in lukewarm water at a 1:10 dilution and then added. P-5 solution @ 2 ltr was added, and the concoction was made to 100 ltr. by adding the required water. Add 2 ltr. P5 solution on the 5th day and stirred well. Add 1 ltr. P5 solution on the 6th day and stirred well. Finally, on the 10th day, the P5 Elixir was ready for spraying.

3. RESULTS AND DISCUSSION

3.1 Crop Performance in the Pre-COVID Era

Crop performance under the Inhana Sustainable Initiative has been evaluated in comparison to that under other non-project gardens of the Goodricke Group. Before the initiation of the project in 2013, the average productivity of the project area was comparatively lower (1914 kg/ha in comparison to 2155 kg/ha in the non-project area). The year wise crop productivity trend line was subsequently developed (Fig. 14), and yearly crop gains/losses were studied. After 6 years of the program, it was found that under the Inhana sustainable tea program, crop productivity significantly increased to 2216 kg/ha, which was 302 kg/ha more than its productivity in 2013. In comparison, the productivity of the rest of the gardens remained almost the same. This study clearly indicated that the sustainable tea initiative with the adoption of IRF technology has a profound impact on plant health development and increases crop yield. At the same time, fluctuations in crop productivity in non-project areas due to climate change impacts, were greater despite intensive management intervention, which also indicated that without the adoption of sustainable initiatives, conventional chemical farming cannot ensure crop sustainability under increasing climate change impacts.

Pic. 6. Spraying of inhana plant health management solution in the project gardens

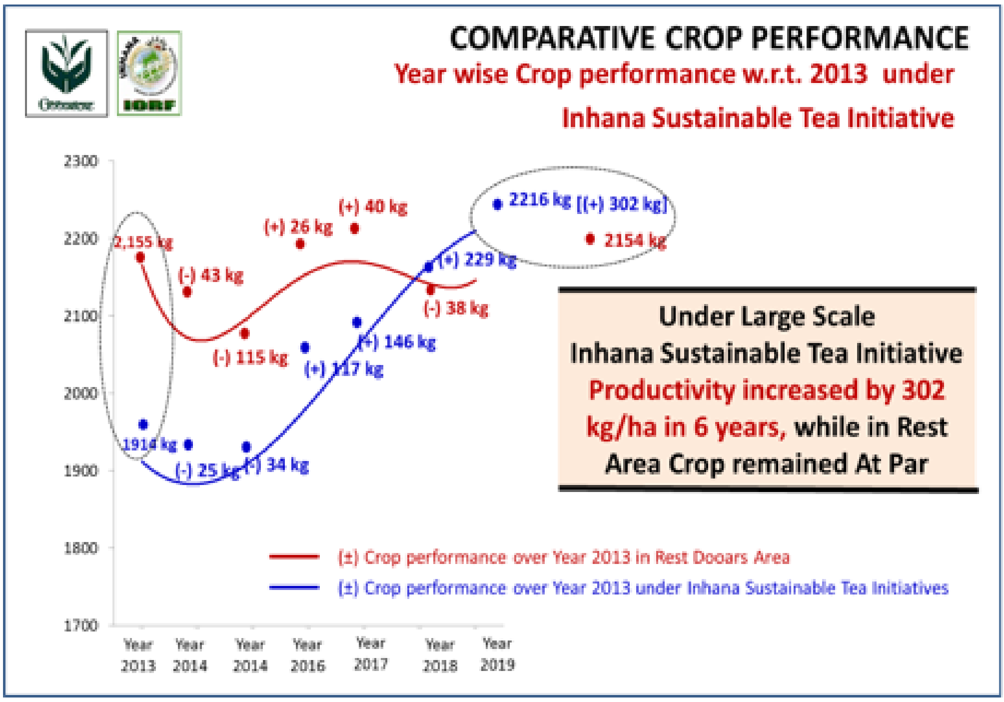


Fig. 14. Comparative crop performance in Inhana Project Area and rest Dooars gardens during 2013 to 2019

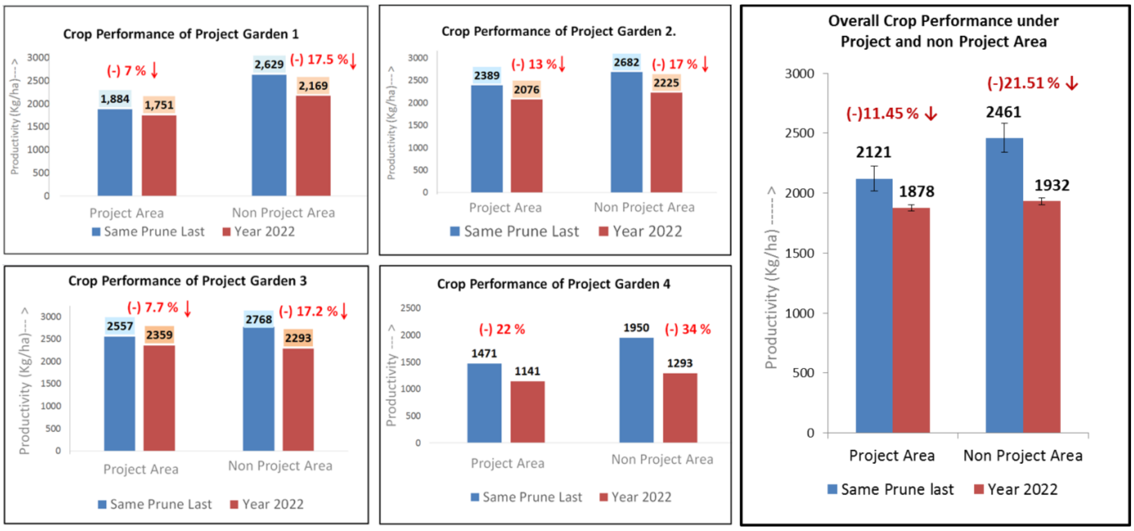


Fig. 15. Comparative crop performance in post covid era at project and non project area (2019-20 – 2022)

3.2 Crop Performance in the Post-COVID-19 Era

Post-COVID-19, overall crop performance decreased due to climatic aberrations, increased disease/pests, management flaws and increased efforts concentrated on quality plucking. A comparative study of crop performance in project and non-project areas revealed that crop productivity decreased in all areas, but crop loss was more pronounced in non-project areas. Comparing the productivity of 2022 with that of the same prune last, there was an overall 11.45% reduction in crop productivity in the project area (Fig 15), whereas in the same period, crop productivity decreased by 21.51% in the non-project area. Despite the limited scope for proper implementation, the project area performed comparatively better than the non-project area (loss of 529 kg made tea/ha), which is the greatest justification for investment in this sustainable program.

Thus, comparing crop performance in the pre-COVID era (2013 to 2019) and post-COVID era (2019-20 to 2022), it was clearly indicated that in favourable times, sustainable initiatives help to increase crop productivity and minimize the impact of biotic and abiotic stress due to climate change. At the same time, when the crop season was not conducive to better crop yield, crop loss was far lower under the sustainable program, as resilient soil–plant ecosystems can absorb the shock generated due to biotic and abiotic stresses.

In terms of cost economics, considering the average sale price Rs 280/kg, the project helps to save crops amounting to Rs 80186/- per ha in comparison to crop loss in non-project areas against an investment of approximately Rs 10,500/- per ha (not considering the cost savings due to comparative pesticide reduction in project areas) under sustainable initiatives.

3.3 Comparative Study of Pesticide Usage

Pesticide usage is an index of the sustainability quotient for a tea estate. Tea estate works like a specific ecosystem, and an increase in pests/diseases indicates an imbalance in its ecological balance and system vulnerability. Thus, the greater the pesticide usage is, the greater the vulnerability of the system.

3.3.1 Pesticide usage in the pre-COVID-19 era

Study of comparative pesticide usage in project and non-project areas clearly indicated that non-project areas were more vulnerable. At the same time. It was clearly indicated from the study that with climate change impact, the incidence of pests/diseases increased with time, but the rate of increase was significantly greater (116%) in the non-project area. In terms of pesticide usage, where there was an increase of approximately 3.5 ltr/ha in the project area, it was 10.4 ltr/ha in the non-project area during the same period (Fig 16). In terms of active ingredient usage, there was a 1.44 ltr/ha greater increase in the non-project area, which indicated the toxicity load. Thus, this study clearly indicates that the adoption of sustainable initiatives helps to maintain the ecological balance that reduces abiotic stress resulting from climate change mitigation.

It was beyond our scope to study the impact of the large chemical load that increased in the non-project area on soil productivity, plant health and production potential; however, the large chemical load increased the vulnerability of the system, which was corroborated by the increased frequency of sudden spat of pest/disease invasion in those areas. In terms of cost economics, by the year 2019, the pest management cost was approximately Rs 4800/ha more in the non-project area.

Pesticide usage in the post-COVID-19 era: In the post-COVID-19 era, we have an exact database of two project gardens regarding pesticide usage, and based on these data, we have calculated the pesticide usage of project and non-project areas in 2022, which clearly showed that there was significantly high usage in non-project areas.

3.4 Soil Quality Development under Novcom Compost Application

Improving soil health through effective soil resource recycling through the Novcom composting method is an important step toward Inhana sustainable tea initiatives. More than 1000 tons of Novcom compost were generated in the project area in the initial 3 years of project initiation, but in later years the quantity was reduced due to hikes in mandays and other costs. Novcom compost was prepared primarily with garden weeds collected from sections during cold weather practice and cow dung from nearby labour lines. Compost samples were collected from all the project gardens and analysed according to standard methods [13].

3.5 Analysis of Compost Quality

All the compost samples were dark brown in colour with an earthy smell, which is deemed necessary for mature compost [14]. The average moisture in the compost samples varied from 45.37 to 56.28%, which may be within the high range (40 to 50), as suggested by Evanylo [15]. The organic carbon content in all the compost samples ranged between 22.1 and 30.22%, meeting the criteria for field application (16 to 38) as per the range suggested by the USCC [16]. The compost mineralization index (CMI), expressed as ash content/oxidizable carbon, varied from 1.31 to 2.16, indicating that all the samples complied with the standard range (0.79 to 4.38), as suggested by Rekha et al. [17]. The total nitrogen content in the compost samples ranged between 1.73 and 2.23%, which was well above the reference range (1.0 to 2.0%) suggested by Alexander [18]. The highest content of nitrogen (Avg 1.92%) obtained in the case of Novcom compost might indicate greater fixation of atmospheric N within the compost heap under the Novcom composting method [9]. On the other hand, 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 and play a crucial role in crop sustenance by maintaining soil–plant–nutrient dynamics. The microbial population (in the order of 10^{16} c.f.u. in case of total bacteria, total fungi and total actinomycetes count) in the Novcom compost was significantly greater (at least 10^3 to 10^6 times) than that in the other compost samples [5,19,20]. The compost quality index is an overall evaluation method [11] for easy understanding and perception of the qualitative aspects of any compost, indicating that the compost samples were mostly in the good to very good class.

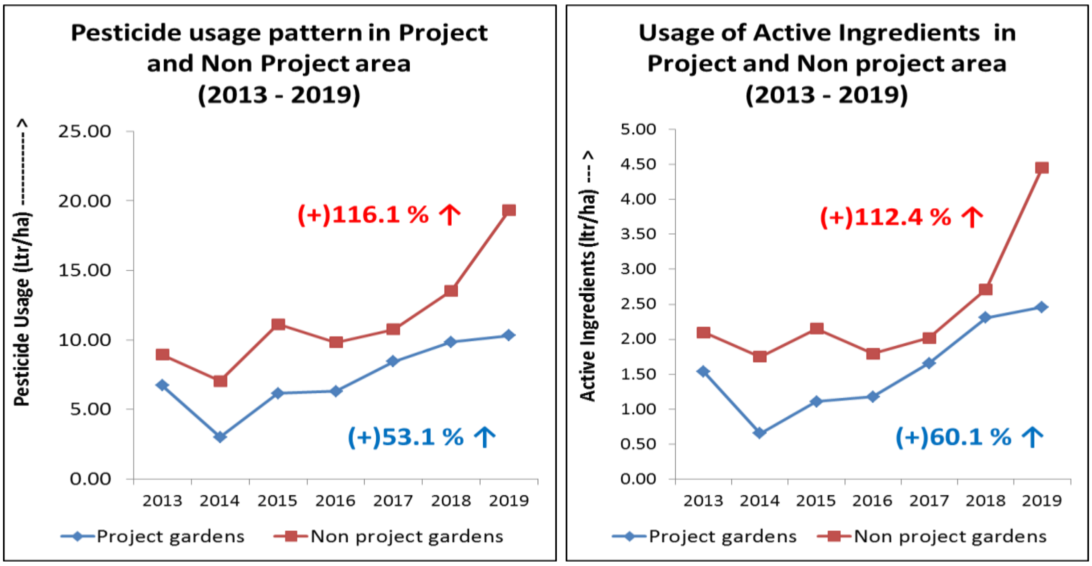


Fig. 16. Comparative study of pesticide usage in project and non-project areas

Table 2. Analysis of Novcom compost quality parameters as per national and international standards

Parameters	Ideal range	Range value	Mean Value ± Std. E
Moisture (%)	35.0 - 55.0	54.30 – 67.20	57.8± 0.71
pH_{water} (1 : 5)	7.2 - 8.5	6.31 – 7.79	6.83± 0.06
EC (dSm^{-1})	< 4.0	1.32 - 2.49	1.73± 0.05
Organic carbon (%)	16.0 - 38.0	22.1 – 30.22	26.4± 0.41
Total nitrogen (%)	1.0 - 2.0	1.73 – 2.23	1.92 ± 0.06
Total phosphorus (%)	> 0.5	0.61 – 0.88	0.71± 0.02
Total potassium (%)	> 0.5	0.76 - 1.21	0.89± 0.02
C/N ratio	10.0-20.0	13.1 – 15.4	14.6± 0.21
CMI[1]	0.79 – 4.38	1.31 – 2.16	1.73± 0.03
Total bacterial count	> 10 x 10^{12}	21 – 116 x 10^{16}	$40 \times 10^{16} \pm 4.1 \times 10^{16}$
Total fungal count	> 10 x 10^{12}	11 – 41 x 10^{16}	$27 \times 10^{16} \pm 1.73 \times 10^{16}$
Total actinomycetes count	> 10 x 10^{12}	8 -31 x 10^{16}	$14 \times 10^{16} \pm 1.15 \times 10^{16}$
CO_2 evolution rate ($mgCO_2$ – C/g OM/day)	< 5.0 – stable	1.65 – 3.67	2.93± 0.11
Phytotoxicity Bioassay	>0.8	0.97 – 1.26	1.09± 0.02
Compost Quality Index (CQI)	>4.0	3.72 – 6.34	4.58± 0.07

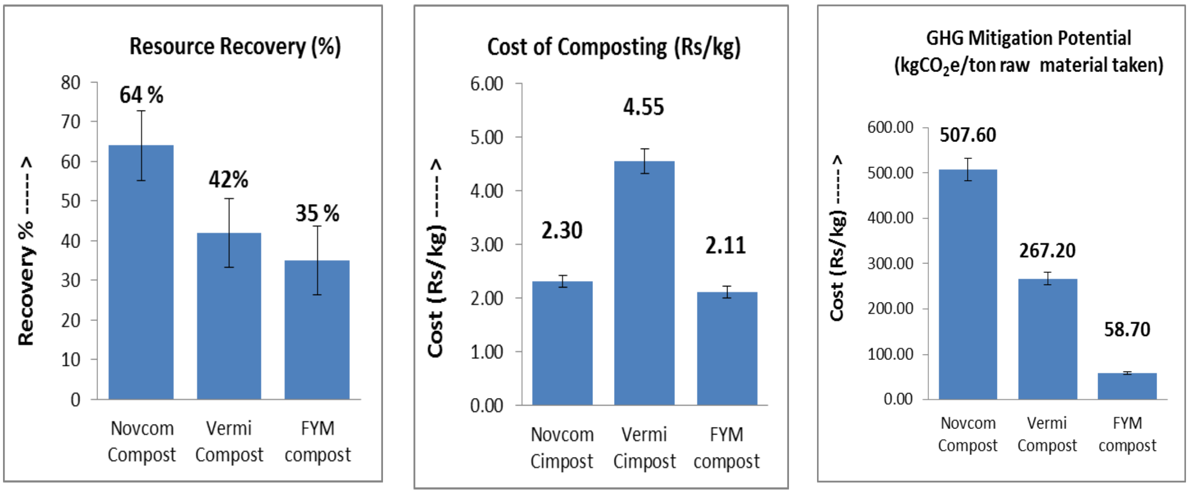


Fig. 17. Comparative study of resource recovery, cost of composting and GHG mitigation potential (per ton wet raw material) under different composting method

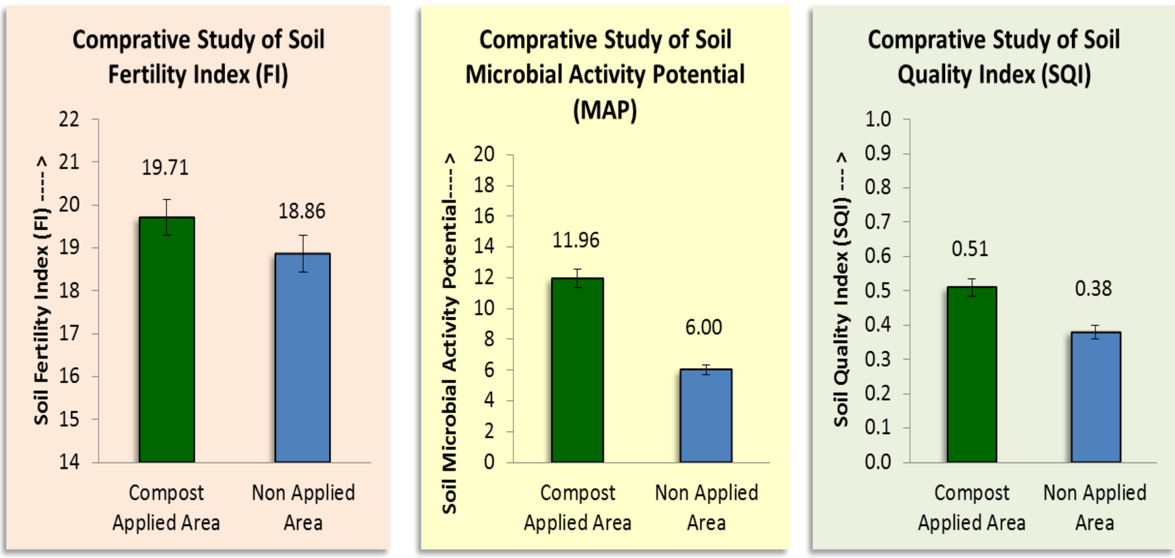


Fig. 18. Comparative study of soil quality in terms of Fertility Index (FI), Microbial Activity Potential (MAP) and Soil Quality Index (SQI) in the compost applied & non applied area

A comparative study of resource recovery, cost of composting and GHG mitigation potential (per ton wet raw material) under different composting methods (Fig. 17) revealed that Novcom compost had the highest resource recovery (64%), followed by Vermi compost (42%) and FYM compost (35%). However, the cost of on-farm vermi compost (excluding infrastructure development costs) was almost double the cost of on-farm Novcom and FYM compost. However, most significantly, the GHG mitigation potential (done through ACFA version 1.0) in terms of $KgCO_2e$/ton of raw material taken for composting was highest in the case of the Novcom compost (507.60 $kgCO_2e$), which was 90 % higher than that of the vermi compost (267.20 $kgCO_2e$) which can have decisive impact on soil carbon sequestration and carbon mitigation program.

3.6 Analysis of Soil Quality

In these graphs, the compost applied area represents the sections that received Novcom compost (*very limited area*) @ 2 ton/ha during the initial three years (mainly from 2014–16). The soil fertility index (FI) represents the overall status of the soil organic carbon, and the available N, P, K, and S in the soil increased by 4.5% in the compost area. However, it is important to study the status of soil microbial properties, and the soil microbial activity potential (MAP) represents both the presence of microbes and their functional dynamics in the soil, which increased by 99.3% in the compost-amended soil. This was perhaps the most crucial outcome of compost application, as an increase in the soil microbial population not only helps to make the soil–plant nutrient relationship more dynamic but also helps to develop a soil microbial barrier in the root rhizosphere zone, eliminating the risk of soil borne disease infestations, such as fuserium and poria. The soil quality index (SQI) represents the overall soil quality with respect to physicochemical properties and fertility, and most importantly, the soil microbial status also increased by 34% in the compost area.

The graphs (Fig 18) indicate the positive impact of applying organic amendments to the soil, especially in terms of microbial functions. However, to attain quantifiable development, especially in problematic areas where the risk of hindering plant productivity potential due to low soil quality is greater, the dosage should be a minimum of 3-4 ton/ha, and the application needs to be performed for 3 consecutive years as a part of the soil correction measure. At the same time, minimizing herbicides as much as possible will help determine the cause. In the case of conventional tea gardens, where the use of herbicides and chemical fertilizers cannot be stopped, compost application should be taken up from a more realistic objective of restricting soil degradability to sustain soil properties, which is crucial for maintaining inherent soil productivity potentials.

4. CONCLUSION

The impact of climate change on tea is clearly reflective in the decreasing crop yields and increasing pest/disease infestations, *vis a vis* the rising agro-chemical cost. The situation demands a scientific crop management policy that can ensure long-term sustainability. The 'Sustainable Tea Initiative', which adopted the principles of regenerative agriculture and included a new dimension of plant health management, was undertaken by Goodricke Group Limited in its various tea estates in 2014. The program has shown its effectiveness in all the related aspects, i.e., crop sustenance, soil health rejuvenation and reduction of the pesticide load, which have contributed positively to environmental preservation. Thus, the ten-year study conclusively demonstrated that adoption of Inhana Rational Farming (IRF) Technology, which complies the core philosophy of regenerative agriculture and focuses on both soil and plant health management, can enable the achievement of ecological and economic sustainability in a time-bound manner.

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 manuscripts.

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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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