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Soil Microbial Rejuvenation through Soil Resource Recycling as a part of Sustainable Management Programme: A Case Study from Lakhipara Tea Estate, Dooars, West Bengal, India

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Abstract

Quest for sustainability in the Indian tea industry starts on a serious note in the backdrop of several key issues such as impact of climate change on crop productivity, higher intensity of pest and diseases, rampant use of agrochemicals, issue of pesticide residues, increasing man-days cost etc. In this difficult time when most of the tea producers are looking for areas for cost curtailment, Goodricke Group Ltd., initiated the Sustainable Management Programme with the objectivity of producing sustainable teas with low pesticide footprint from the year 2014 onwards. The present study was conducted as a part of the above programme, to evaluate the effectiveness of on-farm generated compost towards soil microbial enrichment. Large-scale composting was done using Novcom composting method and end product quality was analyzed as per International Standards. Total N, P, K in the mature compost was 1.97%, 0.75%, and 0.87%, respectively but most important was the presence of self-generated microbial population in the order of 10^{14}*–*10^{16} *c.f.u. The rate of* CO_2 *evolution, nitrification index and phytotoxicity bioassay value confirmed end product maturity and absence of any toxicity towards root growth. Assessment of Soil Development Index (SDI), one year post-compost application showed maximum soil development under organic soil management followed by soils receiving integrated soil management whereas nominal variation was documented under conventional soil management. Biological properties of soil were found to play a major contributory role towards variation of SDI value indicating the importance of microbial rejuvenation towards soil quality development.*

Keywords: *Tea, Novcom compost, phytotoxicity, soil development index (SDI)*

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INTRODUCTION

In today's agriculture, there has been a growing conviction that organic soil amendment is the best option available to restore and enhance soil potential in order to restrict the continuous decline of productivity [1, 2]. Application of organic soil amendment/compost in soil is basically aimed at increasing the proliferation and activity of indigenous population of soil microbes, which being the prime drivers behind all soil ecological processes ultimately restore soil quality. Research has conclusively established that long-term application of organic manure competes well in production with direct application of chemical fertilizer [3]. At the same time compost application has also been found to influence the microbial-induced suppression of soil borne plant pathogens and diseases [4, 5]. Apart from that, compost plays an important role in breakdown of pesticide in soil. According to Fogarty and Tuovinen [6], some microorganisms, which rely on the feedstock for food and energy may cometabolize pesticides, while breaking down an adjacent pesticide.

In the pretext of climate change impact on crop production, tea, in particular Indian tea industry, is already marred with severe problems and facing tough challenges for its survival and growth. Declining crop productivity, increasing cost of agrochemicals due to rising pest and disease infestation as well as increasing labour cost has led to sharp increase in tea production cost. This has not only shaken the sustenance of tea industry, but also influenced the budgeting of development programme of tea estates, which is the key for future sustainability. At this crucial juncture Goodricke Group Pvt. Ltd., a leading tea producer of India, launched Sustainable Management Programme in technical association with Inhana Organic Research Foundation in its group tea estates to produce 'sustainable teas' with low pesticide footprint, from 2014 onwards. The present study was conducted as a part of this on-going Sustainable Management Programme using Inhana Rational Farming (IRF) Technology at Lakhipara tea estate—one of the Goodricke Group's quality tea estate at Dooars, West Bengal, India. Under this study, impact of soil resource recycling or on-farm produced compost using Novcom composting method was evaluated in terms of soil microbial rejuvenation and overall soil quality upliftment.

MATERIALS AND METHODS

Study Area

The study was conducted at Lakhipara Tea Estate, Dooars, West Bengal, India during crop year 2013–2014 to 2015–2016. The study area was situated in the hot, moist, subhumid agroecological situation having annual rainfall between 2900 to 3780 mm (mean 3476 mm), of which 75–85% was received during June to September (Figures 1 to 3).

Experiment

The study was conducted to evaluate the soil quality development under application of on-farm produced Novcom compost. Novcom composting method is a part of IRF Technology developed by an Indian Scientist Dr. P. Das Biswas; it is a complete package of practice for organic cultivation primarily conceptualized from Indian mythology and vedic philosophy [7]. The compost under this process was prepared within 21 days using green matter and cow dung as raw materials as described by Seal *et al*. [8].

However, maximum size of the compost heap was attempted with the objective of higher man-days utilization efficiency as well as towards reduction of per kg compost cost. Novcom compost heap was made with an average size of 12 ft. x 10 ft. x 9ft; which was termed as Novcom Jumbo compost heap. Compost making process has been demonstrated in Figures 4 to 11.

Fig. 1: *Lakhipara Tea Estate Situated in Rich Biodiversity Zone of Dooars, where Coexistence of Plantation and Wildlife Echoes Nature's Beautiful Bonding*.

Fig. 2: *More than 100 ha of Social Forestry Around Lakhipara Tea Estate was Developed by Goodricke Group Ltd. for their Commitment Towards Sustainability.*

Fig. 3: *Birds Resting on Lush Green Leaves in Lakhipara Tea Estate—a Positive Indication Towards Effectivity of Sustainable Management Programme.*

Experiment was setup in mature tea plantation with three different treatments, *viz.* organic soil management with application of compost @ 9 ton/ha, integrated soil management with compost @ 4 ton/ha plus chemical fertilizer (N:P:K @ 60:25:40 kg/ha) at 30:70 ratio and conventional soil management (N:P:K @ 130:35:130 kg/ha). Intercultural operations were done as per standard practice and similar plant and pest management protocol was followed as per the guidelines of IRF Package of Practice [9].

Analysis of Compost Samples

Twenty heaps were selected randomly from eighty Novcom jumbo compost heaps, and total twenty compost samples were drawn out from the selected heaps for their quality assessment. Physicochemical properties of compost, *viz.* moisture content, pH, electrical conductivity and organic carbon were analyzed according to the procedure of Trautmann and Krasny [10]. The total N, P and K in compost were determined using the acid digestion method [11]. Estimation of total bacteria, fungi and actinomycetes was done using Thornton's media, Martin's media and Jensen's media, respectively, according to the standard procedure [12]. Compost stability (CO_2 evolution rate, phytotoxicity bioassay test/germination index) was evaluated according to the procedure suggested by Trautmann and Krasny [10]. Cress (*Lepidium sativum* L.) seeds were used for the phytotoxicity bioassay test. Compost Quality Index (CQI) was calculated as per the methodology [13] represented by the following equation:

$$\text{Compost Quality Index (CQI)}: \frac{NV_{NPK} \text{ x } MP \text{ x } GI}{C/N \text{ ratio}}$$

Where, NV_{NPK} = Total nutrient value in terms of total ($N+P_2O_5+K_2O$) percent.

MP = $\log_{10}$ value of total microbial population in terms of total bacteria, fungi and actinomycetes.

GI = Germination Index.

Classification of Compost as per Compost Quality Index

Compost Quality Index (CQI)		Compost Quality Classification
< 2.00	:	Poor
2.00–4.00	:	Moderate
4.00–6.00	:	Good
6.00–8.00	:	Very Good
8.00–10.00	:	Extremely Good

Fig. 4: *Use of Rotary Slasher (Jungle Jim) for Green Matter Collection.*

Fig. 5: *Collection of Green Matter from Nearby Places.*

Fig. 6: *Initial Phase of Erecting of Novcom Compost Heap.*

Fig. 7: *Cow Dung Layer Being Laid.*

Fig. 8: *Spraying of Inhana Solution During Heap Erection.*

Fig. 9: *Final Phase of Heap Erection.*

Analysis of Soil Samples

Samples from 0 to 50 cm soil depth were collected from all the experimental plots before compost application, i.e., in 2013–2014 and after two years, i.e., in 2015–2016. The soil samples were divided into two parts, one part was kept in the refrigerator at 4 ºC 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. The physicochemical, fertility and microbial properties of soil was analyzed as per standard methodology [12]. Comparative values of selective soil quality parameters were used as per the formula of Bera *et al.* [14] to calculate soil development index (SDI) under different treatments.

RESULTS AND DISCUSSION

Physicochemical Properties of Compost

At field level, compost maturity was evaluated using subjective indicators such as color, smell, and feel [15]. Moist with dark brown colour, earthy smell and finely divided end product that lack sour smell of ammonia were indication of adequate maturity to promote plant growth. The criteria were fulfilled by all the composts, which were more than 30 days old. Moisture between 45 and 50 percent is an optimum range for any quality compost [16]. Bacterial activities get limited at less than 30% moisture content while above 65% porosity of the compost decrease results in anaerobic growth and unpleasant odour emissions [17]. Average moisture in the compost samples varied from 55.30 to 66.40 percent, which may be placed in the high value range (40–50%) as suggested by Evanylo [18].

Ideally pH of compost should be neutral to alkaline, which substantiates an effective fermentation process and also preferred for controlling pathogenic fungi [19]. The pH of compost samples varied from 6.51–7.59, which was well within the stipulated range as indicated for good quality compost as well as maturity [20]. Electrical conductivity value ranged between 1.39 and 2.32 dSm^{-1}, indicating high nutrient content while being safely below (< 4.0 dSm^{-1}) the stipulated range for saline toxicity as per USCC [18, 21].

Fertility and Nutrient Content of Compost

Organic carbon content in compost samples ranged between 25.5 to 31.21 percent with mean value of 28.4, qualifying even the standard value of >19.4% [22] as suggested for nursery application (Table 1). In comparison with the standard suggested range for N, P, K [23], the value obtained for Novcom compost were in the upper range, which clearly authenticated its rich nutrient status. High C/N ratio indicated the presence of unutilized complex nitrogen [24], whereas completion of the process (compost maturity) was indicated by the ratio of less than 20 [20]. C/N ratio varied from 13.5:1 to 14.9:1 indicating that all the compost samples were mature and suitable for soil application. Compost mineralization index (CMI) expressed as ash content/ oxidizable carbon, varied from 1.34 to 2.15 indicating that all samples complied the standard range (0.79–4.38) as suggested by Rekha *et al*. [25].

Fig. 10: *Worker's Team who Produced Novcom Jumbo Compost at Lakhipara T.E.; Largest On-Farm Heap Compost (12 ft. x 10 ft. x 9 ft.) Production so far by Any Tea Estate.*

Fig. 11: *Landscape View of Mature Novcom Compost Heaps at Compost-Making Site of Lakhipara Tea Estate, Dooars, West Bengal, India*.

Microbial Potential of Compost

Microbial status of any compost is one of the most important parameter for judging compost quality because microbes are the driving force behind soil rejuvenation and also play a crucial role towards crop sustenance by maintaining soil–plant–nutrient dynamics. Microbial population in Novcom compost was significantly higher (at least 1000 to 10000 times higher c.f.u.) than the population obtained in case of other compost types as also found by other workers [7, 8, 26] while doing a comparative study with Novcom compost.

Table 1: *Analysis of Compost Quality Parameters as per National and International Standards.*

Parameters	Ideal range	Range value	Mean value ± Std. E
Moisture percent (%)	35.0–55.0	55.30–66.40	59.8±0.76
pH_{water} (1:5)	7.2–8.5	6.51–7.59	7.03±0.07
EC	< 4.0	1.39–2.32	1.79±0.08
Organic carbon (%)	16.0–38.0	25.5–31.21	28.4±0.48
Total nitrogen (%)	1.0–2.0	1.76–2.23	1.97±0.06
Total phosphorus (%)	> 0.5	0.64–0.87	0.75±0.02
Total potassium (%)	> 0.5	0.79–1.18	0.87±0.02
C/N ratio	10.0–20.0	13.5–14.9	14.4±0.27
CMI	0.79–4.38	1.34–2.15	1.72±0.07
Total microbial population (log_{10} value)	> 13.00	17.17–17.58	17.43±0.31
CO_2 evolution rate (mg CO_2–C/g OM/ day)	< 5.0–stable	1.45–3.56	2.89±0.12
Nitrification index	0.03–18.9	0.22–0.40	0.36±0.06
Phytotoxicity bioassay	>0.8	0.97–1.26	1.09±0.03

CMI: compost mineralization index; EC electrical conductivity

Stability and Phytotoxicity of Compost
Microbial respiration is an important criterion for determination of compost stability [27]. CO_2 evolution rate of all the compost samples (1.45–3.56 mg/day) was more or less within the stipulated range (2–5) for stable compost as proposed by Trautmann and Krasny [10]. Nitrification index, which is expressed by the ratio of NH_4-N/ NO_3–-N ranged between 0.22 and 0.40, which was in optimum conformity with the standard reference range (0.03–18.9) for compost maturity [21, 28].

The phytotoxicity bioassay test, as represented by germination index, provided a mean for measuring the combined toxicity of whatever contaminants may be present [29]. Study indicated absence of any phytotoxic effect in all the compost samples as reflected by the standard value of 0.8–1.0 [10]. At the same time germination index value of >1.0 as obtained in case of most of the Novcom compost samples (mean value 1.09) indicated not only the absence of phytotoxicity [30] but moreover, it confirmed that Novcom compost enhanced rather than impaired germination and root growth [8].

Compost Quality Index
Compost quality index (CQI) is an evaluation method for easy and overall understanding regarding quality of specific compost; developed by Bera *et al*. [13]. The index was developed with four specific quality parameters *viz*., nutrient content, microbial population, C:N ratio and phytotoxicity value; which alone as well as in combination regulate nutrient mineralization from compost as well as its post soil application effectivity. Value of these parameters was used in an empirical formulation to develop CQI. CQI value varied from 3.74 to 6.36 with a mean value of 4.74 indicating moderate to very good compost quality class (Figures 12).

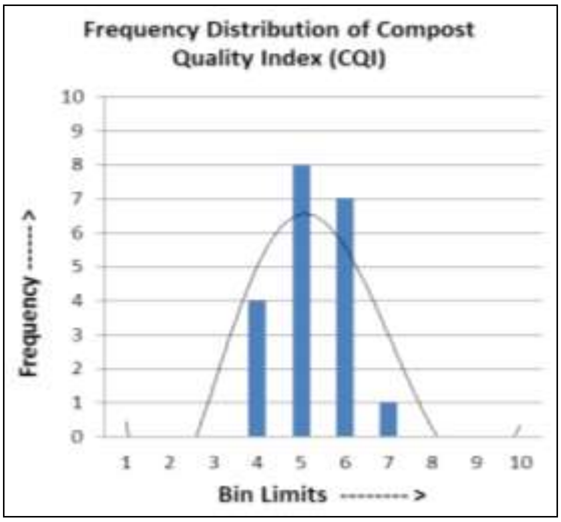

Fig. 12: *Frequency Distribution of CQI at Lakhipara T.E.*

Soil Quality Analysis
To study the impact of compost application on soil quality, soil samples were analyzed (Fig. 13) for physicochemical, fertility and microbial parameters as per the standard

procedure; before initiation of experiment and post two years of experimentation. Soil of the experimental plots was found to be medium textured (loam to sandy clay loam) with bulk density ranging from 1.01 to 1.06 gcm^{-3} (Table 2).

Bulk density reflects the soil's ability to function for structural support, water and solute movement as well as soil aeration. Surface bulk density of 1.00–1.20 gcm^{-3} has been found suitable for supporting high yield and good quality test [31]. In this respect soil of Lakhipara tea were found to meet the required conditions [32]. Maximum water holding capacity of soil, which provides information on the ability of soils for storing water and its subsequent availability to the crops varied between 53.61 to 55.37 percent. No significant variation in soil physical properties was noted post experiment. pH of the soil was also found to increase only slightly (with few exceptions) and varied from 4.57 to 4.64.

Table 2: *Soil Quality Variation Under Different Forms of Soil Management.*

Parameters	Organic soil management		Integrated soil management		Conventional soil management	
	2013–14	2015–16	2013–14	2015–16	2013–14	2015–16
Soil physicochemical parameters						
pH_{water} (1:2.5)	4.57	4.59	4.62	4.64	4.61	4.51
[1]EC (dSm^{-1})	0.017	0.032	0.012	0.027	0.023	0.028
Sand (%)	46.74	45.78	48.68	46.37	51.39	50.04
Silt (%)	22.10	23.43	22.62	21.27	22.1	20.12
Clay (%)	31.16	30.79	28.7	32.36	26.51	29.84
Texture	Loam	Loam	Loam	Loam	Sandy clay loam	Sandy clay loam
Bulk density	1.04	1.02	1.02	1.06	1.00	1.01
[2]MWHC (%)	54.21	54.36	53.61	53.65	55.27	55.37
Soil fertility parameters						
Organic carbon (%)	2.06	2.16	1.58	1.59	1.52	1.5
Available N ($kgha^{-1}$)	363.78	368.68	366.91	374.96	429.63	434.78
Total P_2O_5 ($kgha^{-1}$)	28.66	29.79	21.49	31.96	39.4	44.36
Total K_2O ($kgha^{-1}$)	162.62	166.62	154.86	169.07	176.18	183.28
Available SO_4^{-2} ($kgha^{-1}$)	31.99	45.63	38	44.05	38.34	46.33
Soil biological parameters						
[3]MBC (µg CO_2 C/g dry soil)	158.39	178.03	158.25	164.98	161.63	160.12
[4]BR **(**$mgCO_2$–C/g OM/day**)**	1.27	0.88	1.28	1.08	1.34	1.38
[5]SIR **(**$mgCO_2$–C/g OM/day**)**	3.95	4.44	3.94	4.11	4.03	3.99
[6]FDAH (µg/g dry soil)	192.60	222.79	214.01	229.03	194.55	196.05
[7]qMBC (%)	0.77	0.82	1.00	1.04	1.06	1.07
[8]qCO_2	8.02	4.94	8.09	6.55	8.29	8.62
[9]qFDA	121.60	125.14	135.23	138.82	120.37	122.43
[10]Q_r	0.32	0.20	0.32	0.26	0.33	0.35

Note: [1]EC: electrical conductivity, [2]MWHC: maximum water holding capacity, [3]MBC: microbial biomass carbon, [4]BR: basal respiration, [5]SIR: substrate-induced respiration, [6]FDAH: fluorescein di-acetate hydrolyzing activity, [7]qMBC: microbial quotient, [8]qCO_2: microbial metabolic quotient, [9]qFDAH: FDAH per unit MBC, [10]Q_r: microbial respiration quotient.

Variation in Soil Fertility Parameters

The organic carbon content in the experimental plots ranged from 1.52 to 2.06 percent and an overall increase in its value was noticed post application of compost. The soils were found to be medium in available-N, which varied from 363.78 to 429.63 $kgha^{-1}$. Post experimentation available-N content in soil was found to increase (although nonsignificant) in both organic and integrated experimental plots.

Available -P_2O_5 in the treatment plots were of medium status ranging between 21.49 and 39.4 $kgha^{-1}$ with highest enhancement recorded in the integrated treatment plots. Singh *et al*. [33] and Chettri and Bandopadhyay [34] also reported increase in available phosphate in soil under integrated soil management. Available -K_2O varied from154.86 to 176.18 $kgha^{-1}$ in different treatment plots and showed increasing trend post experimentation. Available -SO_4, which varied from 31.99 to 38.34 $kgha^{-1}$ in different treatment plots, was also found to increase (although nonsignificant) post application of different organic soil inputs.

Percentage increase in the value of different soil fertility parameters under different management has been represented in Figure 14. Highest increase in soil fertility was noted under integrated soil management.

Fig. 13: *Analysis of Soil Fertility Parameters in the Laboratory of Inhana Organic Research Foundation, Kolkata.*

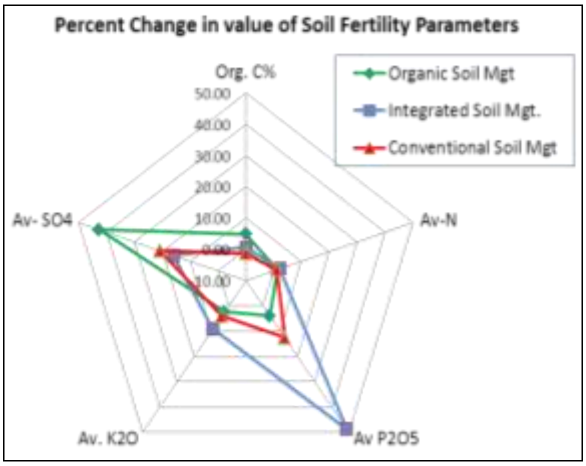

Fig. 14: *Percent Increase in Value of Soil Fertility Parameters Under Different Soil Management.*

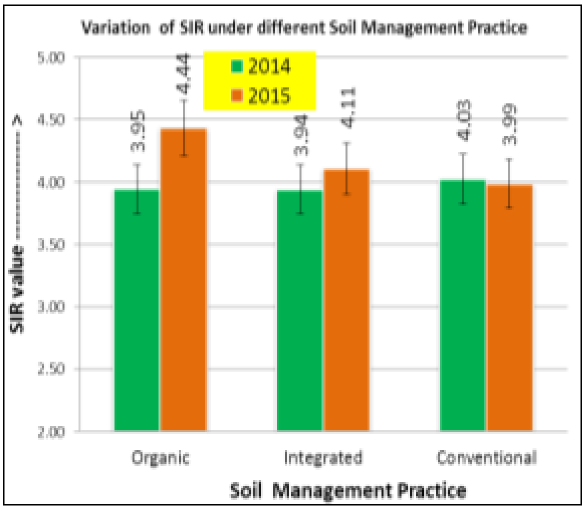

Fig. 15: *Variation of Substrate-Induced Respiration (SIR) Under Different Soil Management.*

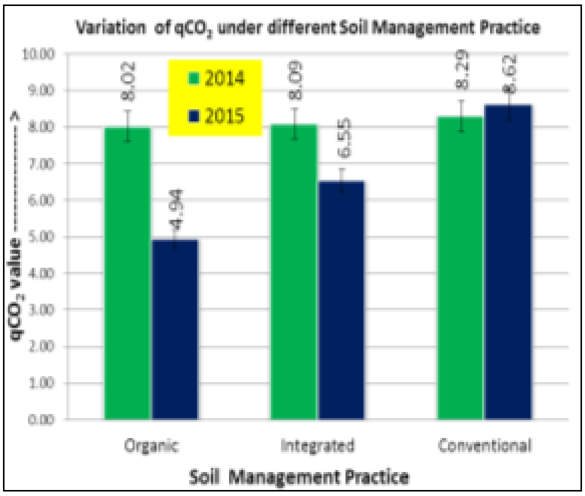

Fig. 16: *Variation of Microbial Metabolic Quotient (qCO_2) Under Different Soil Management.*

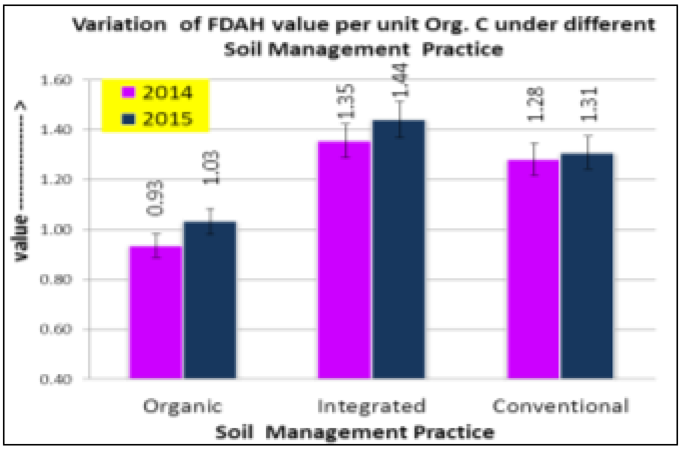

Fig. 17: *Variation of FDAH Per Unit Organic Carbon in Different Experimental Plots.*

Fig. 18: *Young Shade Trees in the Sections. Silver Oak Trees Planted Along the Boundary to act as Buffer Strip to Prevent Pest Drift.*

Fig. 19: *Compost Application and Spraying of Plant Management Solutions as Part of the Programme.*

Fig. 20: *Cow Urine Collection in Labour Line and On-Farm Preparation of Different Concoctions Under Sustainable Management Programme.*

Variation in Soil Microbial Status

Microbial Biomass Carbon (MBC) and Microbial Quotient (qMBC)

Microbial activity is probably the most important factor that controls nutrient recycling in soil. This is especially relevant for organic agriculture where efficient soil nutrient dynamics is the key towards maintenance of crop productivity [35]. Improvement in soil microbial population in organically managed soil indicated the relevance of compost towards soil quality development *vis-a-vis* crop support, as also indicated by the findings of Bot and Benites [36]. Results indicated that microbial biomass carbon increased in case of organic and integrated soil management plots.

However, under conventional soil management, soil microbial biomass value decreased from initial. Comparatively higher microbial properties (in terms of MBC) under compost application might have resulted from higher amount of substrates with potential for microbial degradation, being the source of energy and carbon for the soil microbiota [37]. Microbial quotient (*q*MBC) i.e., the ratio of C_{mic}/C_{org} has been used as an indicator for future changes in organic matter status that might occur in response to alterations in land use [38]. It is the ratio that expresses how much soil carbon is immobilized in microbial biomass [39]. Higher increase of *q*MBC was recorded in compost applied soils as compared to conventionally managed plots. However, the lower *q*MBC values under organic soil management might reflect lower use of carbon by soil microbiota and this behavior may be associated with nutrient limitation or with organic matter quality [40].

Soil Basal Respiration (BR), Substrate-Induced Respiration (SIR) and Microbial Metabolic Quotient (qCO_2)

Soil respiration is considered to represent the overall microbial activity reflecting mineralization of organic matter in soil. Soil respiration value decreased from its initial value in organic and integrated management plots while increase in soil respiration under conventional management plots might be due to microbial stress following applications of synthetic soil inputs. Similar observation was also made by several other workers [41, 42]. Substrate-induced soil respiration (SIR) increased in case of all the treatments (Fig. 15); however the rate of increase was highest under organic soil management followed by plots receiving integrated treatment. Soil basal respiration (BR) is generally attributed to the metabolically dormant population while SIR to the metabolically active population [43]. Hence, increase in SIR value would indicate higher concentration of metabolically active microflora *vis-à-vis* efficient microbial dynamics.

Microbial metabolic quotient (qCO_2) is the ratio of BR rate to Cmic, and hence reflects the efficiency of heterotrophic microorganisms to convert organic carbon into microbial biomass [44]. High values of qCO_2 usually indicate stressful condition in disturbed systems [45] and, in general, conventional agrosystems present higher values as compared to organic cultivation or natural ecosystems [46]. qCO_2 value decreased under organic and integrated management plots; just opposite trend was recorded under conventional soil management (Figure 16). Lower value of qCO_2 might reflect lower soil chemical stress to microorganisms, higher C utilization efficiency, less energy demand for microbial biomass maintenance and better soil quality; as also observed by other workers [47, 48].

Fluorescein diacetate hydrolyzing activity (FDAH) and specific hydrolytic activity (qFDA)

Fluorescein diacetate **(**FDA) hydrolysis rate is widely accepted as an accurate and simple method for measurement of total microbial activity in soil [49] because FDA hydrolysis is mediated simultaneously by lipase, protease and esterase and it can reflect the activities of these enzymes in soil [50]. FDA hydrolysis has been found to be significantly correlated with microbial biomass in both pasture and cultivated soils [51]; and therefore could be used as alternative estimate for microflora content in soil. Since Vekemans *et al*. [51] have reported that FDA hydrolysis and microbial biomass content are closely correlated, negative pollutant effects on FDA hydrolysis activity can generally be explained in terms of reduced biomass due to the toxicity of pollutant. Figure 17 reveals increase in soil FDAH value under all treatments post experimentation; however, the increase was significantly higher in case of plots receiving compost.

Perucci *et al*. [52] introduced the concept of specific hydrolytic activity (qFDA), where the percent FDA hydrolyzed is expressed per unit of microbial biomass carbon. qFDA is sensitive to the toxic effect of chemicals, always showing responses falling into the high or low toxicity and never into the nontoxic cases [53]. There was no significant change in qFDA value, which might be due to sustainable management approach (Figures 18 to 20) with almost 70% reduction of pesticide in these chemical plots.

Microbial Respiration Quotient (QR)

Microbial respiration quotient (QR) is the ratio of BR to SIR. The index is also used to assess the effects of various perturbations in soil ecosystems [54] towards assessment of the stability of soil microbial communities [55]. Most common under natural conditions are the QR values 0.1–0.2 revealing the contribution of active and potentially active microorganisms to soil respiration [56].

QR value was found to decrease post compost application under organic and integrated soil management (Fig. 21), considering that increase of SIR value is comparatively higher than BR value. QR value near 0.2 indicated predominance of active and potentially active microorganisms under these treatments.

Enhancement of active and potentially active microorganisms in soil will help to enhance soil dynamism as these are metabolically active microflora, which are responsible for maintenance of soil–plant–nutrient equilibrium.

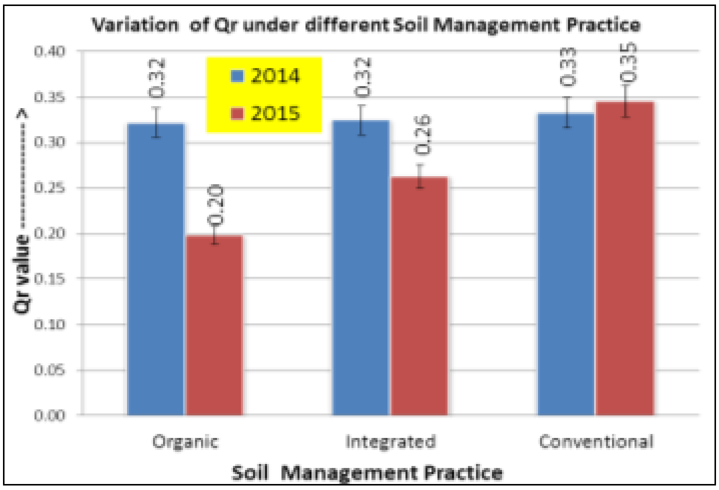

Fig. 21: *Variation of Soil Microbial Respiration Quotient (QR) Under Different Soil Management.*

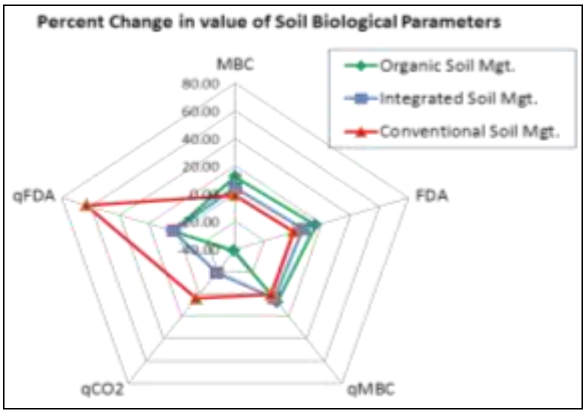

Fig. 22: *Percent Increase in Value of Soil Biological Parameters Under Different Soil Management.*

Fig. 23: *Analysis of Soil Biological Parameters in the Laboratory of Inhana Organic Research Foundation, Kolkata.*

Increase of FDAH activity per unit organic carbon indicates the enhancement of enigmatic microbial activity in soil, which might be due to increase of metabolically activated microbial population. Figure 16 showed that variation of FDAH per unit organic carbon was comparatively more in compost applied plots.

This might be due to application of compost, which acted as a source for inoculation of self-generated microflora in soil and provided ready food for microbial proliferation as well (Figure 22).

Soil Development Index (SDI)

Soil development index (SDI) is a concept to express the overall soil development by quantifying the variation in different soil quality parameters (Fig. 23) for easy understanding of the end-users [14].

In case of tea plantations, where there may be significant heterogeneity in the soil character of individual sections, quantifying soil quality through soil quality index (SQI) can help in the identification of priority areas, which if attended effectively might bring about significant soil development, which would positively influence the productivity of the entire garden (Figure 24).

Fig. 24: *Rain Water Harvesting—Bringing the Sustainability Within the Farm.*

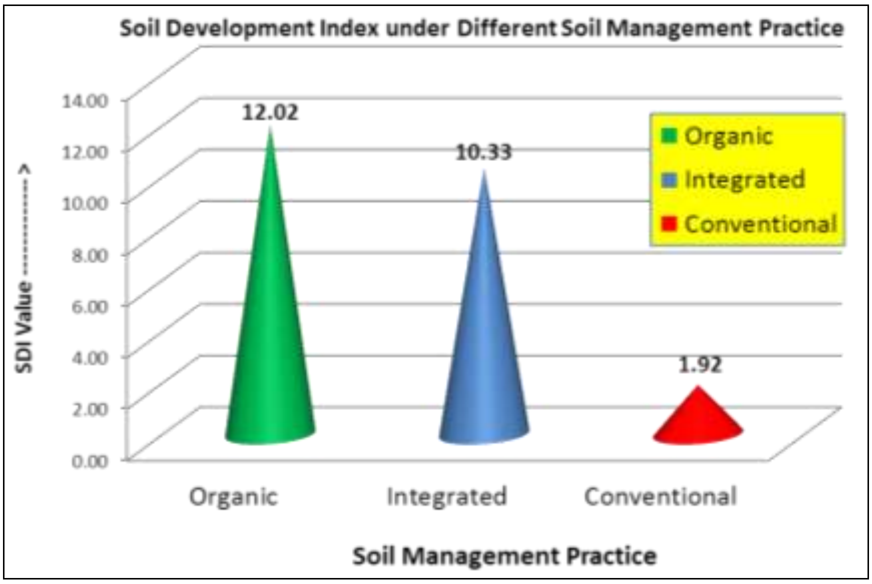

Fig. 25: *Soil Development Index (SDI) Under Different Soil Management.*

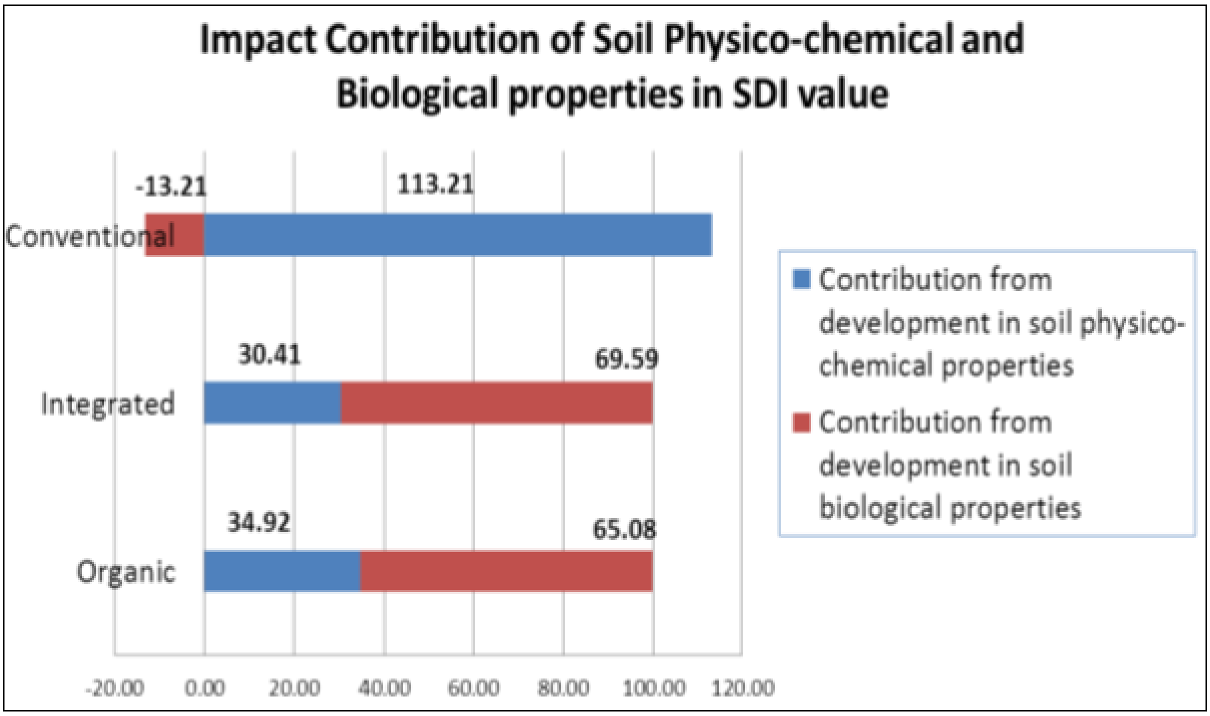

Fig. 26: *Impact Contribution of Soil Physicochemical and Biological Properties in Soil Quality Development.*

SDI was developed using soil physicochemical, fertility and biological parameters, *viz.* pH, organic carbon, available N, P, K and S, soil microbial biomass carbon, FDAH, qMBC, qCO_2 and qFDA.

Figure 25 indicates that SDI value was highest in case of organic soil management (12.02) followed by integrated management plots (10.33), while only marginal development (SDI value 1.92) was noted under conventional soil management.

In depth analysis of contributory factors behind SDI revealed 65–70% contribution from soil biological properties under organic and integrated soil management (Fig. 26). Whereas in case of conventional soil management, soil biological properties were found to negative influence SDI value, reflecting the detrimental impact of conventional soil management on soil biological properties *vis-à-vis* limited soil quality development.

CONCLUSION

In the pretext of climate change impact on crop sustainability, Goodricke Group's, initiative towards introduction of sustainable programme in tea will be a leading example for Indian tea industry. In this respect, initiation of the culture of on-farm composting or recycling of garden resources has been the primary step towards sustainability. The process 'Novcom composting method' deployed for the purpose was found to be a convenient and easily adoptable method, which could provide support for large scale composting.

The quality end product (as described by laboratory analysis), especially the rich inherent population of self-generated microflora could play a crucial role towards rejuvenation of the native soil microbial population in an effective and speediest manner. This was corroborated by the significant improvement of soil biological properties, the most important factor towards soil quality development; under compost application and intensive of soil management programme.

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