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Evaluation of Different On-farm Compost Quality & their Role in Made Tea Productivity and Development of Acid Tea Soils

A.K. Dolui[1], P. Goura[1], R Bera[2], and A Seal[2]

[1]Department of Agricultural Chemistry and Soil Science, Institute of Agricultural Science, Calcutta University, 35 Ballygunge Circular Road, Kolkata – 700019, West Bengal, India

[2]Inhana Organic Research Foundation (IORF), 168 Jodhpur Park, Kolkata – 700068, West Bengal, India

ABSTRACT: A study was conducted at Maud T.E., Assam, India as part of FAO-CFC-TBI Project (2008-09 to 2012-13) to evaluate the quality of on-farm compost produced under different composting method and its effectivity on soil quality development. Comparative nutrient content in terms of N + P_20_5 + K_20 was highest in Novcom compost (3.98 %) followed by Biodynamic (3.56 %), Vermi (3.16 %) and Indigenous (2.96 %) compost. But comparative evaluation of microbial population (total bacteria, fungi, actinomycetes, ammonifiers, nitrifiers and phosphate solubilizing bacteria) in all the compost samples revealed distinctly different status of Novcom compost as compared to the rest. In case of vermi, Biodynamic and Indigenous compost, microbial population varied between 10^7 to 10^{12} c.f.u. where as that of Novcom compost varied from 10^{12} to 10^{16} c.f.u. The comparatively high microflora population in Novcom compost could be due to its intense biodegradation process, which led to their natural generation within compost heaps. Post compost application effectivity assessment revealed that Soil Development Index (SDI) was highest in case of Novcom compost treated plots (SDI : 57.83) followed by plots receiving Biodynamic (SDI : 28.22), Indigenous (SDI : 27.82) and Vermi (SDI : 23.36) compost respectively. Positive and significant (r = 0.54**) correlation of SDI with crop yield indicated that it can used as an effective tool to judge the soil quality in relation to crop performance as well as to assess the competence of soil management programme.

KEYWORDS: Novcom , Biodynamic, Vermi, Compost Quality Index, Soil Development Index.

1 INTRODUCTION

Emerging threat in crop sustenance is the basic concern of present day agriculture, primarily due to degradation of soil quality leading to lower crop yield and quality and the resultant depressed input– output ratio. To restore soil quality, application of organic soil amendment has become obligatory; The primary role of organic amendments is to rejuvenate the soil by creating a favourable soil–plant–microbial environment, in addition to improving the physical properties of the soil. In other words, to make the soil system live for healthy plant growth [1]. But most of the organic manures have poor nutrient content as a result crop yield is unsatisfactory. Moreover, poor microbial status and lack of stability/ maturity/ phytotoxicity evaluation fails to assure soil regeneration deemed necessary for restoration of the desired crop sustainability [2]. At the same time, high cost of compost (considering its N content) renders application of organic soil amendment economically unviable (even if recommended quantity is not considered). Moreover, there is no clear perception among the agricultural community regarding the quality parameters that are ultimate regulators of compost effectivity [3].

However, to enable affordability at farmers level on a large scale, the quantitative requirement and unit cost has to be mitigated, which can be well attended only through application of good quality, stable and mature compost [4]. Such compost in turn can be derived only from an effective composting/ biodegradation process. Good quality compost manufactured through an accurate aerobic digestion process acts as food source and shelter for beneficial microbes that produce antibiotics along with antagonistic microorganisms that compete with plant pathogens, prey on and parasitize pathogens. Quality of compost becomes all the more important in the context of problematic soils like acid tea soils. In acid tea soils, availability of nutrients in soil solution is hindered as well as mono crop toxicity creates a hostile soil environment restricting the natural proliferation of soil micro flora [5]. So, to maintain equilibrium soil environment as well as ensure sustained crop production quality of compost is the most component for consideration [6]. Hence, the present study aims at the quality evaluation of on-farm compost prepared from different biodegradation process as well as their post application effectivity on soil quality development.

2 MATERIALS AND METHODS

2.1 STUDY AREA

The study was done as M.Sc. Project work, using data support from FAO-CFC-TBI project entitled 'Development, Production and Trade of Organic Tea', which was conducted at Maud tea estate (Assam) from 2008-09 to 2012-13. Analytical work was done partly in the Dept. of Agricultural Chemistry and Soil Science (Calcutta University) and at Inhana Biosciences laboratory, Kolkata. Young tea plantation (3 years) was taken for the study and the treatments were placed as per randomized block design with three replications and individual plot size of 0.01 ha. Different compost *viz.* Vermicompost (VC), Biodynamic (BD), Indigenous (FYM) and Novcom (NOV) compost were prepared with garden weeds and cow dung and applied (incorporated in soil) at a rate to supply 75 kg Nitrogen per hectare for plant uptake for 3 consecutive years.

2.2 PREPARATION OF DIFFERENT COMPOST

On-farm available green matter comprising common garden weeds *viz. Mikania micrantha*, *Ageratum houstonianum*, *Axonopus compressus, Digitaria setigera Roth*, *Clerodendrum viscosum Vent*., *Scoparia dulcis Linn.*, *Paspalum longifolium Roxb* etc. were used for making four different types of compost *viz*. vermi compost, Indigenous compost or Farm Yard Manure (FYM), Biodynamic compost and Novcom compost; as per their standard processes (described below) at Maud tea estate in Dibrugarh, Assam (India). Vermicompost was produced within a period of 75 days, the biodegradation period for Indigenous and Biodynamic compost was 90 days while that for Novcom compost was 21 days. Twelve heaps were made for each type of compost.

2.2.1 VERMI COMPOST PREPARATION AT MAUD TEA ESTATE

Raw materials used: Common garden weeds *viz. Mikaniamicrantha*, *Ageratum houstonianum*, *Axonopus compressus,Digitaria setigera Roth* etc. and cow dung at 60 : 40 ratio was used for making compost.

Earth worm: 4000 4500 earth worms (*Esenia foetida*) were required for each layer comprising about 600 to 650 kg of raw materials.

Vermi shed and Vermi compost pit : A plastic shed with bamboo structure was made for protecting the vermi pit from direct sunlight as well as rainfall. A vermi compost pit was prepared measuring 15 ft. in length, 4 ft. in breadth and 4 ft. in height. Base of the pit was soled with bricks followed by a sand layer. At the top of sand bed, thick cow dung slurry was sprayed.

Preparation of Vermi Compost:

At a selected upland chopped green matter and cow dung was stacked in a heap measuring 10 ft. in length, 6 ft. in breadth and 4 ft. in height. Proper watering was done, so that decomposition was initiated. This was kept for about 20 to 25 days and frequent watering was done till the materials were semi decomposed and temperature of the heap came down. Then the materials were ready for using in the vermi pit. The semi decomposed raw materials were transferred into the vermi pit and vermi was added layer wise in the specific quantity. Watering on regular basis was done to keep the vermi pit moist. The vermi compost was ready in 40 to 50 days time.

2.2.2 BIODYNAMIC COMPOST PREPARATION AT MAUD TEA ESTATE

Raw materials used: Common garden weeds *viz. Mikania micrantha*, *Ageratum houstonianum*, *Axonopus compressus, Digitaria setigera Roth* etc. and cow dung at 70 : 30 ratio was used for making compost.

Preparation of Biodynamic Compost: At first 2 kg Cow Pat Pit (CPP) was mixed with some water and kept for 4-6 hours. After that at least 30 ltr. of water was added to it and stirred well. A plain land facing east- west direction was chosen for better effectivity. After cleaning the land, the soil was moistened by spraying water on the surface. A 15 ft. long bamboo strip was placed in the middle of the land with the help of two bricks. Two 2 ft. long bamboo strips (lying across) were placed at every 2ft. interval on the main strip. Dry grasses were spread over the bamboo structure (up to 6 inches height) and watered to make it wet. A layer of cow dung (about 3 inches thick) was made next and water was sprayed on it. 2 ltr. CPP mixture was sprayed on the layer. The processes of layering with grasses and cow dung were repeated until the height was raised up to 2 ft. Then a layer of fresh green matter was made over it (about 4 inches height) and 15 kg CaO was broadcasted on top of the layer. The process of layering with grass and cowdung was again repeated until the height of the heap reached to about 4 ft. The top layer of the heap was made of cow dung. 3 holes were made on the heap and some CPP mixture was poured in those holes. After that CPP mixture was used to moisten the heap. Concentrated cow dung slurry was prepared by mixing a certain amount of soil with cow dung and the entire heap was plastered by it.

Method for preparation of CPP : A structure 1.5 ft. in length x 1.5 ft. in breadth x 1 ft. in height was made using bricks and the inner wall was pasted with fresh cow dung. The bottom of the structure was not lined with bricks. The pit was filled with fresh firm cow dung, eggshells and basalt dust was inserted into the dung (for 20kg of manure 65gms crushed eggshells and 166gm basalt dust was used) and spaded for an hour, next jaggery solution (100gm jaggery and one liter water) was sprinkled over it. After gently patting the cow dung six holes, 2 inches deep were made in it, followed by incorporation of Biodynamic preparations (1gm each of 503- 506 and 1ml of 507). Fresh jute sack was placed over the pit to maintain moisture and to avoid excessive drying. The mixture was aerated once during a month with a garden fork. CPP gets ready in 60 days.

2.2.3 INDIGENOUS COMPOST (FYM) PREPARATION AT MAUD TEA ESTATE

Raw materials used: Common garden weeds *viz. Mikania micrantha*, *Ageratum houstonianum*, *Axonopus compressus,Digitaria setigera Roth* etc. and cow dung at 70 : 30 ratio was used for making compost.

Preparation of Indigenous compost: At a selected upland and flat area chopped green matter was spread to make a base layer measuring 15 ft. in length and 4 ft. wide. Green matter was chopped down to 1/2'' Size and placed evenly till 1 ft. followed by a layer of cow dung. The process was repeated till the heap reached a height of about 5 ft. The heap was covered with clay mud. The heap was demolished and upturned once the height reduced below 4 ft. and reconstructed to a height of about 5 ft. Compost was ready in 3 months time.

2.2.4 NOVCOM COMPOST PREPARATION AT MAUD TEA ESTATE.

Novcom compost was prepared through Novcom composting method (Developed by an Indian Scientist, Dr. P. Das Biswas, Founder Director of Inhana Biosciences. Novcom composting method is a part of Inhana Rational Farming (IRF) Technology developed by Dr. P. Das Biswas is a complete package of practice for organic cultivation primarily conceptualized from Indian Mythology and Vedic Philosophy) using Novcom solution. The compost under this process is prepared within 21 days using green matter and cow dung as a raw materials.

Raw materials used: Common garden weeds *viz. Mikaniamicrantha*, *Ageratum houstonianum*, *Axonopus compressus,Digitaria setigera Roth* etc. and cow dung at 80 : 20 ratio was used for making compost.

Novcom solution: Biologically activated and potentized extract of Doob grass (*Cynodon dactylon*), Bel (*Sida cordifolia L*) and common Basil (*Ocimum bascilicum*).

Total requirement of Novcom solution: Total 250 ml Novcom solution is required for 1 ton of raw materials (100 ml on day 1 followed by 75 ml each, on day 7 and day 14).

Preparation of Novcom compost:

Day 1 : 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 was continued till the total height reached to about 6 ft. After construction of each layer of green matter it was compressed downward from the top and inward from the sides for compactness.

Day 7 : On the 7th day compost heap was demolished and churned properly. The material was next laid layer wise and after making each layer diluted Novcom solution (5 ml/ ltr.) was sprinkled thoroughly as done on 1st day. After seven days the volume of the composting material decreased due to progress in decomposition process. Hence, to once again maintain the heap height to about 6 ft.; the length and breadth of the heap was maintained at 6 ft. x 6 ft. respectively. The heap was once again made compact as described earlier.

Day 14 : The same process was repeated as on day 7 and to maintain heap height to about 6 ft., the length and breadth of the heap was further reduced to 6 ft. x 4 ft. respectively.

Day 21 : The composting process was complete and compost was ready for use.

2.3 ANALYSIS OF COMPOST SAMPLES

12 Compost samples (3 samples from 3 compost heaps of individual type) Physicochemical properties of compost *viz.* moisture content, pH, electrical conductivity and organic carbon were analyzed according to the procedure of Trautmann and Krasny [7]. The total N, P and K in compost were determined using the acid digestion method [8]. Estimation of bacteria, fungi and actinomycetes was performed using Thornton's media, Martin's media and Jensen's media respectively, according to standard procedure [9]. Stability tests for the compost (CO_2 evolution rate, phytotoxicity bioassay test/germination index) were performed according to the procedure suggested by Trautmann and Krasny [7]. Cress (Lepidiun sativum L.) seeds were used for the phytotoxicity bioassay test.

Fig 1 : Erection of Novcom Compost Heap with green matter and cow dung, monitoring of heap temperature and final measurement of compost heap size at Maud Tea Estate under FAO-CFC-TBI Project.

Fig 2 : Large scale Novcom compost preparation at Maud T.E. under FAO-CFC-TBI Project.

Fig 3 : Transportation and application of Novcom compost at Maud T.E. under FAO-CFC-TBI Project.

Fig 4 : Corresponding Author along with Ms Joelle Kato, Programe Manager, IFOAM, Germany inspecting Novcom compost heaps produced at Maud Tea Estate under FAO-CFC-TBI Project.

Fig 5 : Dr. P. Das Biswas, developer of IRF Organic Package of Practice with Ms Joelle Kato, Programe Manager, IFOAM, Germany discussed about young tea management under FAO-CFC-TBI Project.

Compost Quality Index (CQI) was calculated as per the methodology [10], which is represented by the following equation:

$$\text{Compost Quality Index (CQI)} : \frac{\text{Log}_{10}\,\{NV_{NPK} \times MP \times GI\}}{\text{C/N ratio}}$$

Where NV_{NPK} = Total nutrient value in terms of total ($N+P_20_5+K_20$) percent.

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

2.4 ANALYSIS OF SOIL SAMPLES

Samples from 0 to 50 cm soil depth were collected from all the experimental plots before compost application in 2011-12 and one year after in 2012-13. The soil samples were divided into two parts, one part was kept in the refrigerator at 4^0C for doing microbial analysis; the other part was air dried, ground in a wooden mortar and pestle and passed through 2 mm sieve. The sieved samples were stored separately in clean plastic containers. Soil physico-chemical, fertility and microbial properties were analyzed as per standard methodology [9]. Estimation of bacteria, fungi and actinomycetes was done as per plate counting method using Thornton's media, Martin's media and Jensen's media respectively according to the procedure outlined by [9]. Total phosphate solubilizing bacteria (PSB) count was also done as per plate counting method using Pikovskays's media [9].

The analytical values of the selected parameters before initiation of study in 2011 and one year after compost application (i.e. in 2012) were then used as per the following formula [11] to calculate soil quality index for different treatments.

$$\text{Soil Development Index (SDI)} = \frac{a}{n^2}\left\{\sum_{n=1}^{n} \frac{100(X_1 - C_1)}{C_1} + \frac{100(X_2 - C_2)}{C_2} + \cdots + \frac{100(X_n - C_n)}{C_n}\right\}$$

Where X = Soil Quality parameters after Experimentation; C = Value of individual Soil Quality Parameter before Experimentation ; a = no. of Soil Quality Parameters showing increased over initial value.

3. RESULTS AND DISCUSSION

3.1 ANALYSIS OF COMPOST QUALITY

To evaluate the comparative end product quality under different composting process viz. Vermi (VC), Biodynamic (BD), Indigenous (IC) and Novcom (NOV) composting method, final compost samples were evaluated for 35 different quality parameters. Under this study compost samples collected from Maud tea estate, Assam and analyzed for physicochemical properties, microbial population, stability, maturity and phytotoxicity parameters.

3.1.1 PHYSICAL PARAMETERS OF THE COMPOST SAMPLES

All the compost samples appeared dark brown in colour with an earthy smell, deemed necessary for mature compost [12]. Average moisture in compost samples were varied from 45.23 to 58.78 percent, which may be placed in the high value range (40 to 50) [13]. Bulk density of the compost samples (0.55 to 0.71 g/cc,) were almost within the standard range (0.4 to 0.7 g/cc) [14]. Porosity of the compost samples ranged from 49.21 to 60.22 percent (Table 1A). Water holding capacity values were 215.15, 212.04, 231.21 and 197.24 percent respectively in case of VC, BD, IC and NOV compost samples may be placed in the high value range (standard range of 100 to 200 with preferred value of >100) as [13]. The water holding capacity may be attributed to the abundance of humus particles in the compost [7] and higher water holding capacity may indicate presence of higher humus type materials in the samples. Application of compost with higher water holding capacity helped in retaining soil moisture during the dry months [15].

3.1.2 PHYSICOCHEMICAL PARAMETERS OF THE COMPOST SAMPLES

The predominant use of compost is to mix it with soil to form a good growing medium for plants, for which pH forms an important criteria of consideration . pH value were 6.81, 7.42, 7.14 and 7.52 respectively in case of VC, BD, IC and NOV compost indicate that Biodynamic and Novcom compost samples were well within the stipulated range (7.2 to 8.5) for good quality and mature compost [16]. The soluble salt concentration (reflected by the electrical conductivity values) is an important parameter, which indicates the nutrient status of compost. Very high concentration of soluble salts in the plant growth medium is detrimental to germinating seeds and to plant growth, whereas very low electrical conductivity value indicates low nutrient status / poor quality compost. Electrical conductivity value of all the compost samples were ranged between 1.47 and 2.02 dSm^{-1}, indicating its high nutrient status at the same time being safely below (< 4.0 dSm^{-1}) the stipulated range for saline toxicity as per USCC, 2002 [13]. However comparatively higher EC value in case of Novcom compost may indicate comparatively higher nutritional status within the compost (table 1A).

Table 1A : Quality parameters of different compost (Pooled data of 3 samples from each type of compost).

Sl. No.	Parameter	Analytical Value			
		Vermi compost	Biodynamic compost	Indigenous compost	Novcom compost
Physical Parameters					
1.	Moisture percent (%)	51.42	54.2	45.23	58.78
2.	Bulk density (g/cc)	0.71	0.62	0.58	0.55
3.	Porosity (%)	51.08	49.21	51.46	60.22
4.	WHC[1] (%)	215.15	212.04	231.21	197.24
Physicochemical Parameters					
5.	pH_{water} (1 : 5)	6.81	7.42	7.14	7.52
6.	EC (1 :5) dS/m	1.51	1.62	1.47	2.02
7.	Total Ash Content (%)	52.14	49.05	50.26	52.32
8.	Total Volatile Solids (%)	47.86	50.95	49.74	47.68
9.	Organic carbon (%)	26.59	28.31	27.63	26.49
10.	CEC (cmol(p+)kg^{-1})	146.87	187.65	168.98	198.45
11.	CMI[2]	1.96	1.73	1.82	1.98
12.	Sorption capacity index	5.52	6.63	6.12	7.49
Fertility Parameters					
13.	Total nitrogen (%)	1.71	1.84	1.68	2.16
14.	Total phosphorus (%)	0.67	0.70	0.59	0.81
15.	Total potassium (%)	0.78	1.02	0.69	1.01
16.	C/N ratio	15.55	15.38	16.45	12.26

[1]WHC : Water holding capacity; [2]CMI : Compost mineralization index

The organic matter in compost is a necessary parameter for determining the compost application rate, to obtain sustainable agricultural production. Organic carbon content in all the compost samples ranged between 26.49 and 28.31 percent, qualifying not only the criteria for field application (16 to 38) as per the range suggested by USCC (2002) [13] but also the standard suggested value of >19.4 percent [17] for nursery application. Ash content of the compost samples varied from 49.05 to 52.32 percent while volatile solids ranged from 47.68 to 50.95 percent. CEC is one of the most important properties of compost and is usually closely related to fertility. The CEC of compost indicates the relative presence of organic colloids, having high exchange capacity in the range of 100 to 200 meq/100g of compost. Cation exchange capacity of different compost samples ranged between 146.87 and 198.45 cmol (p+)kg^{-1}, where the higher value obtained in case of Novcom compost followed by biodynamic and indigenous compost. Compost mineralization index (CMI) expressed as ash content/ oxidizable carbon indicated the ready nutrient supplying potential of compost for plant uptake [11]. The CMI values of the compost samples were varied from 1.73 to 1.98 indicate that all the values obtained complied the standard range (0.79 to 4.38) [18]. Sorption capacity index, reflected the degree of maturity of specific humic compounds [19] and in compost samples varied within 5.524 and 7.492 once again qualifying the criteria(>1.7) for well humified compost as described [20].

3.1.3 NUTRIENT CONTENT IN THE COMPOST SAMPLES

Although 36 different nutrients are required for plant growth, but the macronutrient (N, P, and K) contribution of compost is usually of major interest [21]. Among the different macronutrients, availability of nitrogen to the plants is most complex. Nitrogen may be present in two significant inorganic forms NO_3^--N and NH_4^+-N. Immature compost will contain more ammonium-nitrogen than mature compost. The inorganic nitrogen forms are immediately available source for absorption by plants while the availability of the organic form depends on how rapidly the microorganisms break down the compost [22]. The total nitrogen content in the compost samples ranged between 1.71 and 2.16 percent, which was well above the reference range (1.0 to 2.0 percent) suggested by [23, 24]. The highest content of Nitrogen (2.16 percent) obtained in case of Novcom compost might indicate higher fixation of atmospheric N within compost heap during Novcom composting process [1]. Total Phosphate (0.59 to 0.81 percent) and total potash content (0.69 to 1.02 percent) were also higher than the minimum suggested standard (0.6 to 0.9 percent and 0.2 to 0.5 percent respectively) by [23, 24]. Total phosphate content was found to be highest in Novcom compost (0.81 percent) followed by Biodynamic compost (table 1B).

Table 1B : Quality parameters of different compost (Pooled data of 3 samples from each type of compost).

Sl. No.	Parameter	Value			
		Vermi compost	Biodynamic compost	Indigenous compost	Novcom compost
Ready Nutrient Supplying Potential					
17.	Water soluble carbon (%)	0.201	0.158	0.301	0.342
18.	Water soluble inorganic N (%)	0.067	0.093	0.064	0.137
19.	Water soluble organic N (%)	0.042	0.036	0.057	0.071
20.	Organic C/N ratio	4.79	4.39	5.28	4.82
21.	Humification ratio	0.008	0.006	0.011	0.013
Microbial Parameters (per gm moist soil)					
22.	Total bacterial count[3]	57×10^{12}	69×10^{12}	53×10^{12}	67×10^{16}
23.	Total fungal count[3]	29×10^{10}	34×10^{12}	54×10^{11}	34×10^{16}
24.	Total actinomycetes[3] count	18×10^{10}	23×10^{11}	23×10^{11}	17×10^{14}
25.	Total ammonifiers[4]	5.4×10^{7}	5.9×10^{8}	2.42×10^{8}	2.2×10^{12}
26.	Total nitrifiers[4]	23×10^{7}	31×10^{7}	13×10^{7}	3.1×10^{12}
27.	Total PSB[4]	17×10^{8}	22×10^{10}	19×10^{10}	11×10^{12}
28.	MBC[4] (%)	0.48	0.87	0.56	1.01
Stability Parameters					
29.	CO_2 evolution rate (mgCO_2–C/g OM/day)	1.98	2.31	2.56	3.92
Maturity & Phytotoxicity Parameters					
30.	NH_4^+ - Nitrogen (%)	0.024	0.032	0.015	0.027
31.	NO_3^- - Nitrogen (%)	0.043	0.061	0.049	0.11
32.	Nitrification Index	0.56	0.52	0.31	0.25
33.	Seedling emergence (% of control)	94.34	96.44	90.14	106.52
34.	Root elongation (% of control)	92.84	98.72	94.37	102.31
35.	Germination index (phytotoxicity bioassay)	0.88	0.95	0.85	1.09

[3]Count in MPN method.;[4]MBC : Microbial biomass carbon

(0.70 percent). However total potash content was highest in case of Biodynamic compost (1.02 percent) closely followed by Novcom compost (1.01 percent). Hence, the analytical value obtained may indicate intense biodegradation in case of Novcom compost resulting in minimum loss and appreciation of initial value (in case of N) contribute to the comparatively higher nutrient in the final compost samples (Fig 6) as also observed by [10, 3, 25, 26].

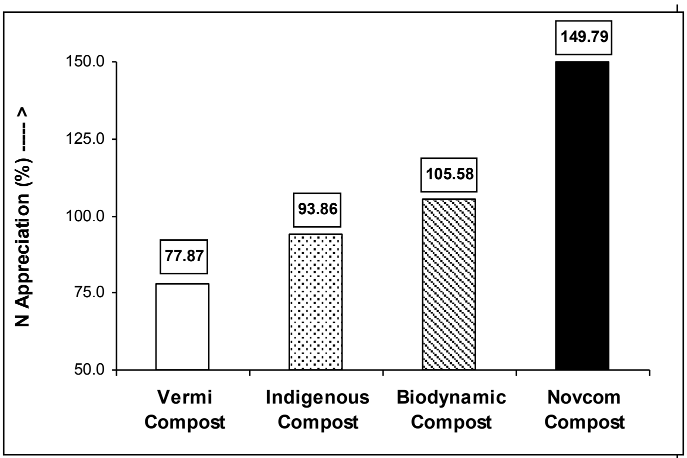

Fig 6 : Appreciation of total N value in final compost under different composting methods at Maud T.E.

The finding might provide an indirect indication of the fixation of atmospheric N within the compost heap by the autotrophic micro organisms generated during the composting process [1]. According to de de Bertoldi *et al* [27,28], an increase in the population of N-fixing bacteria in the later phase of composting, can be attributed to the increase in the value of total N in compost, despite volatilization (primarily) losses from compost heap during biodegradation.

The ideal C/ N ratio of any mature compost should be about 10, as in humus; but it can be hardly achieved in composting [29]. However, of greater importance is its critical value (C/N ratio 20), below which further decomposition of compost in soil did not require soil nitrogen, but released mineral nitrogen into the soil [30]. C/N ratio varied from 12 : 1 in case of Novcom compost and 17 : 1 in case of Indigenous compost indicate all the compost samples were mature and suitable for soil application.

3.1.4 Ready nutrient supplying potential of the compost samples.

The water soluble forms of carbon and nitrogen representing the plant available forms, increased during compost maturation phase [31, 32]. In the different compost samples water soluble carbon, varied from 0.158 to 0.342 percent, water soluble inorganic nitrogen ranged from 0.064 to 0.137 percent while water soluble organic nitrogen varied between 0.036 and 0.071, percent. Organic C/N ratio in compost water extract is considered to be one of the important index for compost maturity [16, 33, 15]. The values (4.39 : 1 to 5.28 : 1) obtained for compost samples were almost within the stipulated range of 5:1 to 6:1 as proposed by [34, 33].

3.1.5 MICROBIAL PARAMETERS OF COMPOST SAMPLES

Most organic substrates draw an indigenous population of microbes from the environment [25]. In case of open-air composting processes, further colonization occurs naturally within compost material during heap construction as well as urning of heap [35]. The microbial population (in order of 10^{16} cfu in case of total bacteria, total fungi and total actinomycetes count) in Novcom compost samples was significantly higher (at least 10^4 to 10^6 cfu times) than the population obtained in case of compost samples (Table 1B). The population of ammonifiers, nitrifiers and phosphate solubilizing bacteria (PSB) was also evaluated and varied between $5.4x10^7$ & $2.2x10^{12}$, $13x10^7$ & $3.1\ x10^{12}$ and $17x10^8$ & $11x10^{12}$ respectively. The population of ammonifiers, nitrifiers and phosphate solubilizing bacteria (PSB) was also distinctly higher in the Novcom compost as compared to the other compost as also obserbed by Bera *et al*, [11]. Such high microbial status of Novcom compost was also of special significance considering that they were not exogenous inoculation but self-generated during Novcom composting process. In this context, of special significance is the high population of nitrifiers within Novcom compost, which might indicate that nitrites have been transformed into nitrates, an indicator of a high degree of compost stabilization [36]. At the same time comparatively higher nitrogen converters in the compost samples may influences in the comparative higher appreciation of the nitrogen value within Novcom compost sample. Measurement of the microbial biomass is considered as an indicator of bio-maturity [30]. The values obtained for the different compost samples (0.48 to 1.01) were well within the critical limit of < 1.7 percent for compost maturity/ stability [37].

3.1.6 STABILITY, MATURITY AND PHYTOTOXICITY PARAMETERS OF COMPOST SAMPLES

Stability of compost sample indicated the status of organic matter decomposition and is a function of biological activity. Hence, microbial respiration formed an important parameter for determination of compost stability [**38**]. Mean respiration or

CO_2 evolution rate of all composts (1.98 to 3.92 mg/day) was more or less within the stipulated range (2.0 - 5.0) for stable compost [7, 39]. The value obtained was also in close conformity to the respirometry stability class rating of U.S Composting Council (2002) for compost stability [40]. Free ammonia released from decaying organic matter inhibited seed germination [41, 42, 43] delayed shoot growth [44] and root elongation processes. Analytical interpretation of all the compost samples revealed that it satisfied the critical limit (< 0.04 %) for NH_4^+- N [45] and (> 0.03 %) for NO_3^-- N [46]. The nitrification index (ratio of NH_4^+- N/ NO_3^-N) ranged between 0.25 and 0.56, which was in optimum conformity with the standard reference range (0.03 to 18.9) for compost maturity [34, 13]. Most importantly the ratio was even much below the stipulated safety limits (< 7.14) for application in Nursery beds [17].

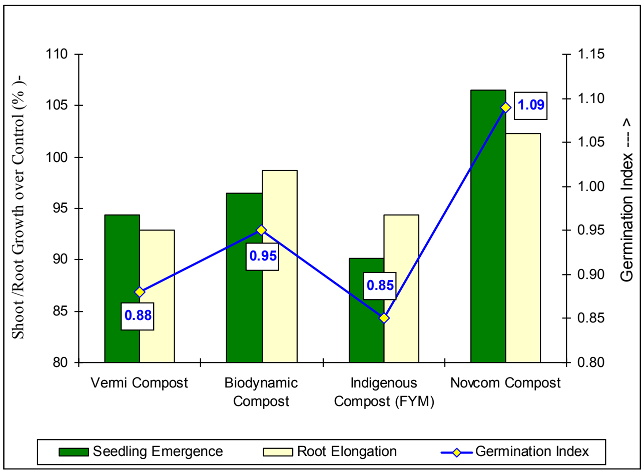

Fig 7 : Comparative study of Seedliing Emergence, Root Elongation and Germination Index in different compost prepared at Maud T.E.

The phytotoxicity bioassay test, as represented by germination index provided a means of measuring the combined toxicity of whatever contaminants may be present [47]. The test value indicated that total absence of any phytotoxic effect in Vermi compost, Biodynamic compost, Indigenous compost and Novcom compost (fig 7) as per the standard value of 0.8 to 1.0 [7]. At the same time germination index value of >1.0 as obtained in case of Novcom compost indicated not only the absence of phytotoxicity [48] in the compost but moreover, it confirmed that the compost enhanced rather than impaired germination and radical growth [7].

3.1.7 FORMULATION OF COMPOST QUALITY INDEX (CQI)

In order to classify the different types of compost, four specific quality parameters (which were combination of one or more properties that regulate the nutrient mineralization from compost as well as its post soil application effectivity) were taken up to formulate Compost Quality Index (CQI) as per the formula [10]

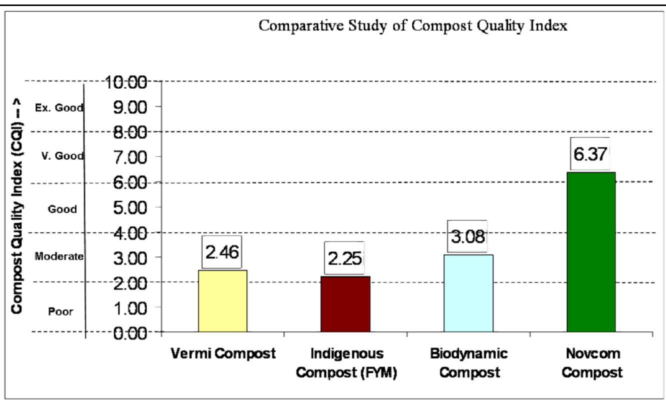

Fig 8 : Quality ratting of different compost as per Compost Quality Index.

Average CQI values obtained for different types of compost (Fig 4) revealed highest rating of Novcom compost (average CQI: 6.37) followed by Biodynamic compost (average CQI: 3.08), vermicompost (average CQI: 2.46) and Indigenous compost (average CQI: 2.25) (fig 8). Evaluation of end product quality indicated that though all the compost samples attained the desired stability and maturity Novcom compost was found to exhibit relatively higher potential as compared to the other composts especially in terms of it's high content of self- generated microbial population.

3.1.8 ECONOMICS OF COMPOST PREPARATION UNDER DIFFERENT COMPOSTING PROCESS

Economics of the compost preparation under different composting method has been calculated with the data provided by the Garden authority, Maud T.E. As per the calculation unit cost of compost preparation is lowest in case of Novcom compost (Rs 0.96/- per kg) followed by Indigenous compost (Rs. 1.15/- per kg), Biodynamic compost (Rs. 1.24/- per kg). The cost of Vermi compost preparation was highest among the composting method and the unit cost was Rs. 2.09/- per kg (Table 2). Variation in unit cost of total NPK in the end product under different composting methods was given in fig 9

Table 2 : Comparative evaluation of cost component under different composting method.

Parameters	Vermi compost	Biodynamic Compost	Indigenous Compost	Novcom compost
Size of heap	300 cft	240 cft	480 cft	360 cft
Time of composting	60-75 days	80 – 90 days	80 – 90 days	21 - 30 days
Recovery percent	49.23	57.73	51.11	69.11
Mandays required/heap	6.5	6.5	9.0	13.2
Raw materials for heap construction.	2600 kg	2200 kg	2700 kg	4500 kg
Cost of raw materials/heap	Rs 800/-	Rs. 655/-	Rs. 780/-	Rs. 1275/-
Cost of other component /heap	Rs. 1290/-	Rs 435/-	-	Rs. 525/-
Cost of mandays/heap	Rs. 579/-	Rs. 579/-	Rs. 801/-	Rs. 1175/-
Total cost/kg	Rs. 2.09/-	Rs. 1.24/-	Rs. 1.15	Rs. 0.96/-

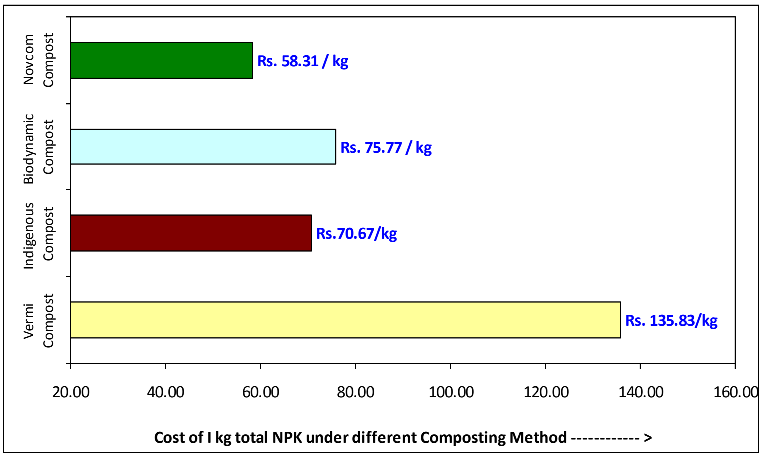

Fig 9 : Variation in unit cost of macro nutrients in the end product under different composting methods at Maud T.E., Assam.

Along with compost quality, cost of compost is the most important criteria for its adoption by the tea planters, considering that cost of soil input comprises 60 to 80 percent of the total expense made on inputs. Cost of 1 kg NPK was lowest in case of Novcom compost (Rs. 58.31/kg) followed by Indigenous compost (Rs. 70.67 /kg), Biodynamic compost (Rs. 75.77/kg made tea) and vermi compost (Rs. 135.83/ kg made tea). The comparatively higher cost of vermi compost is perhaps the most limiting factor towards its large scale application.

3.2 ANALYSIS OF SOIL QUALITY DEVELOPMENT

3.2.1 VARIATION IN PHYSICO-CHEMICAL AND FERTILITY PARAMETERS OF SOILS

Variation in physico-chemical and fertility parameters of soils in terms of pH, electrical conductivity, organic carbon, cation exchange capacity and available NPKS were studied before and one year post application of compost (Table 4). The soils of all the experimental plots were moderately acidic in reaction pH varying from 4.60 to 4.82 which was within the recommended soil pH (5.0-5.6) for tea cultivation [49]. After application of compost, pH of the soil samples was found to increase as compared to their control counterpart. Though the increase in pH value with application of compost is not so much significant (percent increase varied within 0.29 to 0.57 percent except in control plots), but it will be important with respect to the conventional garden, where increase of soil acidity was often noticed after application of chemical fertilizers which needs corrective management in regular basis. According to the observation of Oh et. al. [50] application of heavy nitrogen (N) caused serious soil acidification (77% of 70 tea fields having pH below 4.0) Thus, increase in soil pH after application of compost is important, as very low pH is often harmful for the tea plants. Low pH led to the increased uptake of nutrient elements like Fe, Mn, Al etc., which could prove toxic to tea in the long run [51]. Besides this low pH of soils is known to reduce the population of earthworms, which are essential for biological activities in tea soils, especially where soil rejuvenation is sometimes not possible for even as long 100 years.

Fig 10: Different compost prepared using garden weeds as raw material in Maud Tea Estate, Dibrugarh, Assam under FAO-CFC-TBI Project.

Fig 11 : Prof. A. K. Dolui and Prof. R. K. Sarkar of Calcutta University inspecting the tea plantation at Maud T.E., Assam under FAO-CFC-TBI Project.

Electrical conductivity (EC) of the soil (except in salt effected problematic soil) reflects the fertility of the soil. EC value of the experimental plots increases with the application of compost might be the indication of release of nutrient from compost sources in soil. The CEC of the soil samples were of low to medium range (according to the range suggested by Ilaco, [52] varying between 10.59 and 12.01 cmol $(p^{+})kg^{-1}$. Increase in the CEC value was noticed with the application of compost and the percent increase was highest with Novcom compost applied experimental plots followed by Indigenous, Vermi and Biodynamic compost applied experimental plots. Increasing trend of CEC value in the different experimental plots over control post compost application indicated the upliftment of soil fertility with application of compost (table 3).

Table 3: Variation of Soil Physico-chemical and Fertility Parameters in Acid Tea Soils under different Compost Application at Maud Tea Estate, Assam.

Soil Quality Parameters	< ---------------------------------- Treatment Plots -->				
	Control Plots	Vermi Compost Applied Plots	Biodynamic Compost Applied Plots	Indigenous Compost Applied Plots	Novcom Compost Applied Plots
pH (H_2O)	4.61 (4.60)	4.57 (4.60)	4.66 (4.67)	4.75 (4.78)	4.67 (4.70)
EC (dSm^{-1})	0.024 (0.024)	0.022 (0.023)	0.033 (0.034)	0.045 (0.046)	0.046 (0.047)
CEC cmol(p+)kg^{-1}	10.63 (10.67)	11.98 (12.14)	10.86 (10.98)	11.69 (11.87)	11.83 (12.02)
Org. C (%)	0.74 (0.74)	1.00 (1.07)	1.09 (1.11)	1.21 (1.23)	1.22 (1.25)
Av. N ($kgha^{-1}$)	299.8 (296.3)	401.8 (405.1)	399.4 (408.0)	410.3 (414.7)	413.2 (427.3)
Av. P_2O_5 ($kgha^{-1}$)	29.9 (28.0)	47.7 (50.6)	52.4 (55.8)	42.2 (46.1)	60.6 (66.4)
Av. K_2O ($kgha^{-1}$)	143.0 (139.8)	176.5 (177.3)	177.7 (180.0)	190.4 (194.1)	183.5 (193.4)
Av. SO_4^{2-} ($kgha^{-1}$)	18.3 (19.5)	36.1 (38.2)	39.0 (40.2)	41.2 (41.8)	43.8 (47.8)

The organic carbon content in the experimental plots ranged from 0.73 to 1.26 percent and except control in all the cases, increase in soil organic carbon is noticed with application of compost. The percent increase in the organic carbon varied within 1.52 to 2.56 except in control plots and there is not too much variation in percent organic carbon increase among the compost treated experiment plots .Available- N status in soils of the experimental plots were medium [53] and ranged between 286.7 and 412.3 $kgha^{-1}$. Except in control plots, the available- N status was found to increase in the different experimental plots after application of compost and the percent increase was highest (3.42 percent) in case of Novcom compost applied plots in comparison to others. The availability of phosphorous is one of the most limiting factors in acid tea soils as the available phosphate gets fixed with Fe^{3+} and Al^{3+} ion in acid atmosphere, thereby remaining unavailable for plant uptake [54]. Therefore, increase in the availability of phosphate in acid tea soil is the most challenging task. Available phosphate in the experimental plots were of medium status [53] and ranged between 28.3 and 61.2 $kgha^{-1}$. After one year of compost application, available phosphate status increased in the different experimental plots (except in control plots), which might indicate the positive influence of the compost towards higher availability of phosphate in acid tea soils. The effect might be due to the application of compost in soil, which reduced the capacity of soil minerals to fix P and increased its availability through release of organic acids [55, 56]. Available potash varied within 140.2 and 194.3 $kgha^{-1}$ in the experimental plots. After compost application slight increase in potash status was observed in almost all the experimental plots (with few exceptions). Similar post compost application effects were also obtained by several workers [56, 57].

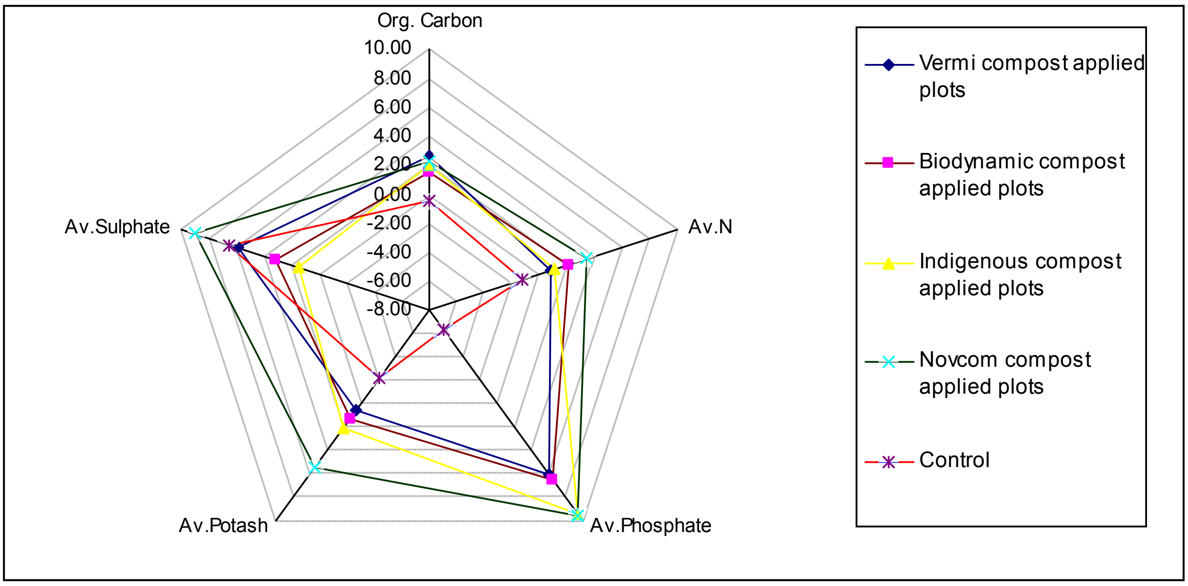

Fig 12 : Cobweb Polygons (Spider Diagrams) for displaying comparative change in soil fertility post application of different compost at Maud Tea Estate, Assam.

Available sulphate varied between 16.5 and 47.6 $kgha^{-1}$ in the experimental plots. After one year of compost application, available sulphate status increased slightly in all the experimental plots, which indicated the favourable influence of compost towards higher sulphate availability in acid tea soils. Trend of availability of major soil nutrients (NPKS) after compost application indicated that maximum increase was noticed in totality in case of Novcom compost applied experimental plots (4.81 percent) followed by Biodynamic and Indigenous compost applied experimental plots (2.32 and 1.85 percent respectively). These developments might be due to the high quality as well as very high self generated microbial status of Novcom compost resulting positive influence in activating soil nutrient dynamics in comparatively speediest way.

3.2.2 VARIATION IN SOIL MICROBIOLOGICAL PARAMETERS

Microbial activity is probably the most important factor that controls nutrient re-cycling in soil. Microorganisms participate in disintegration and decomposition processes leading to the release of nutrients trapped in plant and animal debris, rock and minerals as well as synthesize and release hormones that are essential for plant growth [58]. Soil microbial population in terms of total bacteria, fungi, actinomycetes and phosphate solubilizing bacteria (PSB) were studied for the different treatment plots in order to assess changes in their population before and one year post compost application (table4). The results obtained are given (log_{10} values) in table 6. In general, soil microbial population (irrespective of any specific type) was found to increase

Table 4: Variation of Soil Microbial Population in Acid Tea Soils under different Compost Application at Maud Tea Estate, Assam.

Soil Quality Parameters	< ---------------------------- Treatment Plots ------------------------------->				
	Control Plots	Vermi Compost Applied Plots	Biodynamic Compost Applied Plots	Indigenous Compost Applied Plots	Novcom Compost Applied Plots
Total Bacterial Count	6.324 (6.409)	8.242 (8.472)	8.111 (8.440)	8.071 (8.301)	8.071 (8.595)
Total Fungal Count	4.448 (4.483)	4.898 (5.013)	4.687 (4.967)	4.813 (5.027)	4.882 (5.039)
Total Actenomycetes Count	4.464 (4.399)	5.010 (5.056)	4.760 (4.914)	4.669 (4.773)	4.808 (5.270)
Total Phosphate Solubilizing bacterial Count	4.418 (4.326)	4.966 (5.119)	4.943 (5.029)	4.919 (5.050)	5.013 (5.384)

in post application (one year) of organic soil inputs in all the treatment plots, with few exceptions. Similar observation was made by other workers [59] in their study, post application of organic soil amendments in soil. However increase in microbial pollution with application was found to be highest in case of Novcom compost applied plots with respect to other compost applied plots which might be due to the very high self generated microbial population in the Novcom compost. It was significant in terms of regeneration of soil microflora in acid tea soils. Development of soil microbial population with application of Novcom compost was also observed by several workers [3, 60, 61, 62]

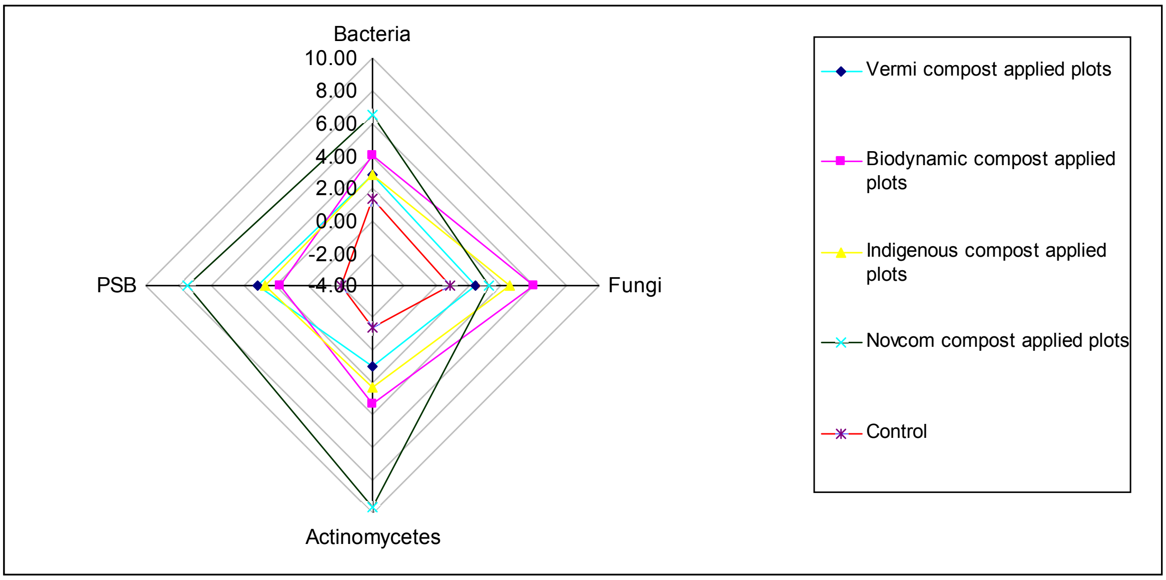

Fig 13 : Cobweb Polygons (Spider Diagrams) for displaying comparative change in soil microbial population post application of different compost at Maud Tea Estate, Assam.

3.3 CROP RESPONSE UNDER DIFFERENT COMPOST APPLICATION

Crop response in terms of green leaf production (Fig 8) in different experimental plots with the application of different compost was recorded (during 2011-12) and it was highest in case of Novcom compost applied experimental plots (9627 kg/ha) followed by Vermi (9208 kg/ha), Indigenous (8474 kg/ha) and Biodynamic (8356 kg/ha) compost applied Plots (fig. 14). Crop yield in the Novcom compost applied plots were 31.45 % higher than that of Control plots followed by others.

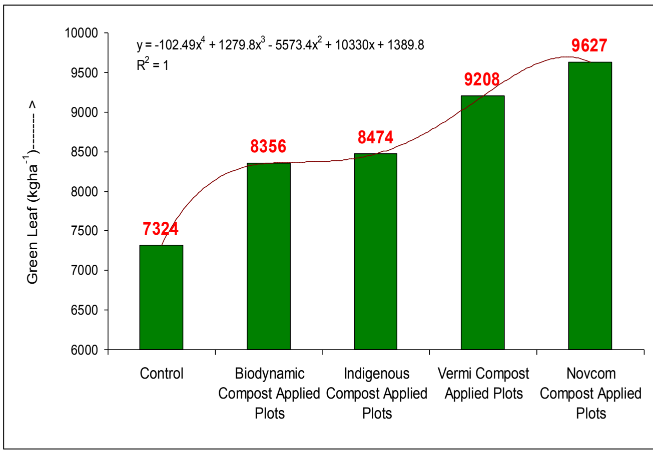

Fig 14 : Crop yield of new tea plantation (2+ year age) in terms of green leaf under application of different compost at Maud T.E.

Fig 15 : Young Tea Plantation in the Novcom compost applied plots at Maud T. E.

Information on relative agronomic effectiveness (RAE) of tea plantation under various available organic soil inputs could assist in selection of proper input thereby leading to economic crop production. Relative Agronomic Effectiveness (RAE) i.e. comparative effectivity of different treatments with respect to the best performer (Novcom compost in this case) [63], indicated that only one treatments i.e. vermin compost applied plots scored highly (RAE: 81.78 %) while rest all others obtained values lower than 50 percent.

3.4 INTERRELATION BETWEEN CROP YIELD AND SOIL QUALITY PARAMETERS.

To evaluate the interrelationship between crop response and soil quality parameters, total 12 soil parameters (analyzed during this study) were correlated with crop yield and 10 soil quality parameters were found to be positively and significantly correlated crop yield. As per the data revealed from table 7, crop yield was positively and significantly correlated with organic carbon (0.648***), CEC (0.501*), available N (0.536*), available P_2O_5 (0.590**), available potash K_2O (0.469*), available SO_4 (0.585**), total bacterial count (0.607**), total fungi count (0.615*), total actinomycetes count (0.694***) and PSB (0.646**). The study indicated that improvement of these soil quality parameters might influence the crop performance and regular application of quality compost helped to improve soil quality (table 5).

Table 5 : Correlation coefficient between Yield and soil quality parameters.

		pH	0.050			Av. K_2O	0.469*
		EC	0.356			Av. SO_4^{2-}	0.585**
Crop	**Yield**	Org. C	0.648**	**Crop**	**Yield**	Bacteria Count	0.607**
Vs		CEC	0.501*	**Vs**		Fungi Count	0.615**
		Av. N	0.536*			Actinomycetes count	0.694***
		Av. P_2O_5	0.590**			PSB	0.646**

*** Significant at 1% level; ** Significant at 5 % level; *Significant at 10 % level

3.5 RELATIONSHIP AMONG DIFFERENT SOIL QUALITY PARAMETERS

Relationship among soil quality parameters are given in table 8. Soil pH is one of the important components of soil quality. Especially in acid soil, minor change in soil pH affects nutrient availability. Soil pH was positively and significantly correlated with electrical conductivity (0.745***), organic carbon (0.645***), available potash (0.623**) and available-sulphate (0.486*). Soil CEC was also highly and positively correlated with available nutrient and microbial population.

Significant and positive correlation among soil available nutrient and soil microbial population (table 6) indicated their role in the availability of soil macro nutrients and the phenomenon in acid tea soil has a significant impact on crop productivity.

Table 6 : Correlation coefficient among different soil quality parameters.

Soil Quality Parameters	pH	CEC	Org. C	Av. N	Av. P_2O_5	Av. K_2O	Av. SO_4^{2-}	Bacteria	Fungi	Actino
CEC	0.285									
Org. C	0.645**	0.725***								
Av. N	0.464	0.734***	0.944***							
Av. P_2O_5	0.280	0.592**	0.830***	0.857***						
Av. K_2O	0.623**	0.709***	0.970***	0.956***	0.792***					
Av. SO_4^{2-}	0.486*	0.693***	0.930***	0.939***	0.865***	0.938***				
Bacteria	0.372	0.732***	0.905***	0.977***	0.869***	0.906***	0.914***			
Fungi	0.397	0.743***	0.857***	0.945***	0.792***	0.901***	0.862***	0.931***		
Actino[1]	0.078	0.704***	0.720***	0.842***	0.882***	0.751***	0.831***	0.846***	0.831***	
PSB[2]	0.307	0.715***	0.828***	0.907***	0.855***	0.894***	0.925***	0.887***	0.919***	0.931***

*** Significant at 1% level; ** Significant at 5 % level; *Significant at 10 % level; [1]Actino : Actenomycetes, [2]PSB : Phosphate solubilizing bacteria.

Hoorman and Islam [64] in their study indicated role of microbes in the availability of soil nutrients. Higher inter-relationship among different soil quality parameters indicates all these function in a harmonized mananer and a comprehensive approach towards soil development can bring the desire effectivity in a short time frame.

3.6 DEVELOPMENT OF SOIL QUALITY INDEX

Soil quality is the capacity of a soil to maintain key ecological functions in order to sustain yield and improve plant health. A fertile soil provides essential nutrients for plant growth and supports a diverse and active biotic community [65]. Soil quality index is a concept to express the overall soil development by quantifying the extent of development of different soil quality indices for easy understanding of the end-users [66]. The soil quality index should be easy to formulate, understandable and must reflect the extent of soil management undertaken and at the same time correlate with crop response.

In case of tea plantations, where there may be significant heterogeneity in the soil character of individual sections, assessment of Soil Quality Index (SQI) can help in the identification of priority areas, which if attended effectively might significantly influence the productivity of entire garden. The SQI was developed using soil physicochemical, fertility and biological parameters. Total 12 soil quality parameters *viz.* soil pH, EC, organic carbon, C.E.C, Available NPKS, total bacteria, fungi and actinomycetes were analyzed and only those parameters were selected which were significantly correlated with crop yield. The selected 10 quality parameters were organic carbon, available NPKS, total bacteria, fungi and actinomycetes.The analytical values of the selected parameters before initiation of study in 2011 and one year after compost application (i.e. in 2012) were then used as per the following formula [66] to calculate soil quality index for different treatments.

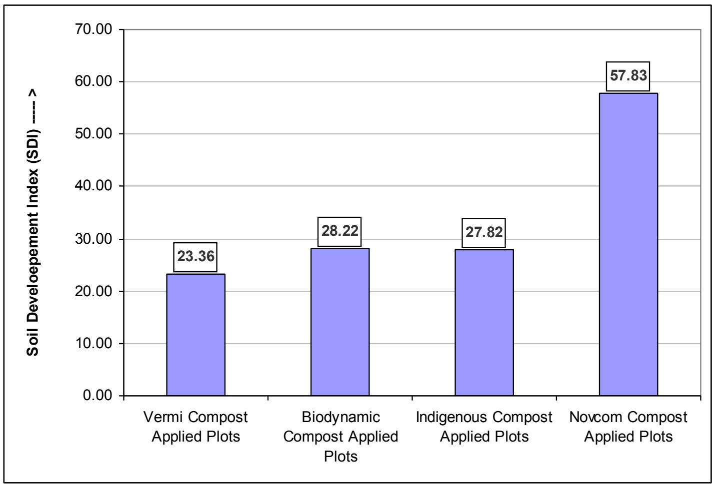

Fig 16: Development of soil quality as indicated by Soil Development Index (SDI) under application of different types of compost.

Soil quality index was highest in case of Novcom compost treated plots (SQI : 57.83) followed by plots receiving Biodynamic (SQI : 28.22), Indigenous (SQI : 27.82) and Vermi (SQI : 23.36) compost (Fig. 9). Soil quality index of Novcom compost applied plots was significantly higher than that of next best performer, which indicated higher potential of Novcom compost over other compost in terms of effcetive organic soil management in a speedy manner. The finding was further corroborated with crop performance data which showed highest crop yield in the Novcom compost applied plots.

3.7 CORRELATION OF SOIL DEVELOPEMENT INDEX WITH CROP PERFORMANCE

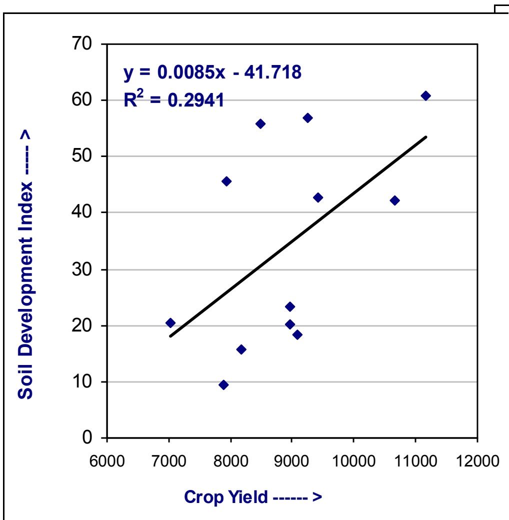

Fig 17 : Relationship between Soil Development Index (SDI) and Crop Yield.

Fig 18 : Microbial Analysis in the Laboratory of Inhana Biosciences as a part of MSc. Project.

Soil development index (SDI) will be representative only if it correlates with respective crop performance. The positive and significant (r = 0.542**) correlation of soil quality index with crop performance as obtained in the study, indicated that it can used as a effective tool to judge the soil quality in relation to crop performance as well as to assess the competence of the soil management programme undertaken for achieving the desired soil development, especially in acid tea soils. The trend line in the figure 10 also showed a close relationship between soil quality index and crop response.

4. CONCLUSION

Organic soil management is slowly becoming a necessary compulsion not only for organic conversion but also to restrict productivity depletion under chemical farming practice. Organic soil management will be successful only if the focus is shifted from quantitative to qualitative approach. The qualitative approach starts with the selection of good quality organic inputs through laboratory assessment of quality using standard protocol. At the same time development of soil quality index to measure the effectivity of organic management can help in practical assessment and justification of the qualitative approach. In the present study the result indicated that compost helps to improve soil quality and quality of compost played an important role in soil quality development leading to higher crop response.

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