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Differential Effects of Organic Inputs on Soil Fertility and Growth of Tea Plants

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Abstract

The objective of the experiment was to evaluate how newly planted biclonal Tocklai stock tea varieties (TS 462, TS 463, TS 520, and TS 589) respond to compost in a series of treatment including control (without application), cow dung, vermicompost, municipal solid waste compost, and homemade kitchen waste compost applications. A total of 20 tea plants (5 plants of each tea variety) were planted in plastic buckets of equal size (16 litres). 300 gm. of compost was applied to each plant continuously at an interval of 25 to 30 days for the initial six months, and then compost application was discontinued for the next six months. Data were collected before, during, and after compost application. The highest growth in plant height (11cm to 51 cm), number of leaves (33 to 95), and number of branches (8 to 15) were recorded in the tea plants of the TS 463 variety. The pH of soil samples was found in the range of 4.72 to 6.61. The pH level of the acidic soil was slightly increased by the compost application. The average SOM% ranged from 6.88% to 11.94%, and it was found that a good SOM% was supportive of the good growth of the tea crop. N% was found between 0.85% and 0.217%, and P levels were found between 18 ppm and 50 ppm. The suitable N% and P levels affect plant growth most significantly in terms of the number of leaves and the number of stems. SOM% was found to be highest in vermicompost-treated soil, N% and P levels were optimal in home-made kitchen waste compost, and K levels were highest in cow dung-treated soil. Therefore, it can be concluded that an integrated compost application can be recommended for ideal growth and good plant health status for sustainable tea production.

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Introduction

The tea plant, scientifically known as *Camellia sinensis (L.) Kuntze*, belongs to the family Theaceae. It is an evergreen shrub that is indigenous to China, India, and Southeast Asia. Tea is a significant beverage due to its flavour, aroma, and therapeutic benefits (Kosińska and Andlauer, 2014[1]). Tea plants require a balanced supply of essential nutrients such as nitrogen, phosphorus, and potassium to produce high-quality tea leaves (Souri and Hatamian, 2019). Tea can't grow at its best without fertiliser application and external nutrient supply (Ma *et al*., 2022[3]). Nevertheless, extensive use of chemical fertilisers and pesticides for high tea production have lots of negative impacts on soil fertility and environmental quality (Zargar Shooshtari *et al*., 2020[4]; Ebrahimi *et al*., 2021[5]). One of the major causes of pollution on a global scale is the overuse of chemical fertilisers and pesticides in agriculture (Vasco *et al*.,2021[6]).Using organic manure, compost, and biopesticides in tea cultivation is not only good for the environment and soil fertility but also helps generate revenue through exports. The authors (Ji *et al*.,2020[7]; Hajiboland,2017[8]) reported that organic tea production improves soil nutrient contents and can reduce the environmental impact of tea production. Various researchers (Das *et al*., 2020[9]; Altenbuchner*et al*.,2018[10]; Qiao *et al*.,2018[11]) also observed that organic farming practices had not only a positive environmental impact but also improved the socio-economic conditions of local farmers and workers.

Using agricultural waste compost on tea plantations reduces soil acidification and improves soil health and productivity.[12] Irrespective of the effects of different seasons on soil microbial populations, cow dung manure application is more convenient for improving soil microbial diversity in tea plantations.[13] Though prolonged research is required to assess the risk of aluminium, nickel, and chromium on tea plantations, it is observed that municipal solid waste compost-treated soil promotes healthy and well-grown tea plants.[14,15,16] There is not such research on the application of kitchen waste compost on tea plantations; however, strawberries and lettuce grow quite well in kitchen waste compost-treated soil.[17,18] Vermicompost is the most suitable and sustainable organic component for overall plant nutrition, promoting plant health and soil fertility.[19] The studies (Joshi *et al*., 2015[20]; Goswami *et al*.,2017[21]; Stewart.,2020[22]) have shown that compost application, especially vermicompost, can improve the growth, yield, and quality of tea plants. The present study focused on the effects of different types of compost application on tea plant growth and soil fertility.

The primary objective of the experiment was to evaluate the effect of cow dung, vermicompost, municipal solid waste compost, and kitchen waste compost on the growth of four biclonal tea varieties: TS 589, TS 463, TS 462, and TS 520. The present research was also conducted to promote the application of compost for organic tea production and to implement sustainable agriculture with the aim of conserving the ecosystem and soil without degrading the environment.

Materials and Methods

In the experiment, cow dung, vermicompost, municipal solid waste compost, and kitchen waste compost were individually applied to each tea plant. Four types of biclonal seed varieties of tea plants were selected for the experiment. These four biclonal seed varieties—TS 589, TS 463, TS 462, and TS 520—of tea plants were developed by the Tocklai Tea Research Association, Assam. These are the recommended varieties for plantation in Assam and the Dooars-Terai region of West Bengal.

Location of the Experimental Setup

The experimental design was set up in Siliguri, in the Darjeeling district of West Bengal. Siliguri is situated in the Terai region of West Bengal. The Terai region is characterised by a subtropical climate with hot summers, cool winters, and moderate rainfall. The average maximum temperature of Siliguri is 35° C, the annual average rainfall ranges between 2600 mm and 4000 mm, and the relative humidity of Siliguri ranges from 80% to 83%.[23] A moderately hot and humid climate is suitable for tea cultivation; hence, the mentioned site was chosen for the experimental purpose.[24]

Collection of Tea Plant Varieties for Experiment

TS 589, TS 463, TS 462 and TS 520varieties of tea plants (*Camellia sinensis*) were considered for the experiment. These are biclonal seed stocks released by the Tocklai Tea Research Association (TRA), Assam. These varieties are suitable for growth in the plains and are of above average quality.[25] The following table represents the parental combination of these biclonal seed tea varieties.[25]

Table 1: Biclonal seed varieties and their parental combination

Biclonal Tocklai Stock (TS)	Parental Combination
TS 589	TV 20 x TRA Heeleakah 22/14
TS 463	TV 1 x TV 19
TS 462	TV 1 x 124.48.8
TS 520	TV 19 x TV 20

TV (Tocklai vegetative clones for plains), TRA Heeleakah 22/14 (TRA certified garden clones for plains in Assam)

5 plants of each tea variety, i.e., 20 tea plants were collected from Gaya Ganga Tea Estate, situated in the Terai region of Darjeeling district in West Bengal.

These tea varieties were planted in pots and nurtured without the application of synthetic chemicals like fertilisers, pesticides, fungicides, herbicides, and growth regulators. 20 plastic buckets of equal size (16 litres) were selected for the experimental purpose. Five holes were made in the bottom of the bucket to ensure adequate drainage and prevent waterlogging.

Fig.1: Plastic buckets filled with soil

Left to Right – 1st bucket prepared for Control, 2nd bucket prepared for cow dung treatment, 3rd bucket prepared for Vermicompost treatment, 4th bucket prepared for solid waste compost, 5th bucket prepared for Kitchen waste compost

Collection of Soil for Plantation

The untreated sandy loam soil was collected from an abandoned fertile area for tea plantations. A 6-inch-deep dig was made, and then soil was collected by using a shovel. Soil samples were mixed thoroughly, the clumps were broken, and debris was removed. Plastic buckets were filled with the mixed soil, and tea plants were planted. The soil test was conducted at a Tea Board-approved laboratory (NITM) at Shiv Mandir, Siliguri, in the Darjeeling district of West Bengal. The pH value of the collected sandy loam soil was 4.72. According to the Tea Research Association, Tocklai24, the pH in the range of 4.5 to 5.5 is optimal for tea plant growth.

Source of Compost for the Experiment

Partially dried cow dung was collected from the nearby domestic cow shed. Vermicompost was commercially manufactured and purchased online. The vermicompost was 100% virgin, unadulterated, and had an earthy smell. It was made from cow dung only, without soil or cocopeat. It was fully composted by *Eisenia foetida* (red earthworms). Compost from municipal solid waste was prepared by the windrow composting method. The municipal solid waste compost was purchased from the Conservancy Environment Department of the Siliguri Municipal Corporation, Siliguri. Kitchen waste compost was made from vegetable and fruit scraps following the method described in the research paper by Baul Das and Gurung,2021.[26]

Experimental Design

A total of 20 tea plants (5 of each variety) were planted in 20 plastic buckets for the experiment. A single bucket was used for the plantation of each plant. Among the 5 tea plants, 1 plant of each variety was not treated with compost and was marked as control. The rest of the four buckets were labelled according to the treatment type and the name of the tea variety. Table II represents the compost treatment strategy for 20 tea plants of each variety.

Table 2: Compost treatment strategy

Treatment type	Soil treatment with compost	Applied compost amount	Duration of compost application	Period of No Compost application
No treatment	Control	_______	_________	________
Treatment 1	Cow dung	300 grams	6 months (February to July 2022)	6 months (August 2022 to January 2023
Treatment 2	Vermi compost	300 grams	6 months (February to July 2022)	6 months (August 2022 to January 2023
Treatment 3	Municipal solid waste compost	300 grams	6 months (February to July 2022)	6 months (August 2022 to January 2023
Treatment 4	Kitchen waste compost	300 grams	6 months (February to July 2022)	6 months (August 2022 to January 2023

The following figure 2 represents that each plant of the TS 520 variety was planted in a plastic bucket, and each treatment was applied to it.

Data Collection on Plant Growth (Height), Leaf, and Stem Count

From January 2022 to March 2023, data were collected on the plant's development in terms of height and the quantity of leaves and stems. The height of the 20 plants was measured using a measuring tape, and the number of leaves and stems was manually counted. The data collection schedule was based on the composting strategy. Prior to spreading compost, the first data was collected on January 24, 2022. During compost application, five data sets were collected, one for each month, beginning on February 15, 2022, then on March 24, 2022, after that on April 24, 2022, then on May 18, 2022, and finally on June 15, 2022. Three sets of data were collected when the application of compost was discontinued. The first set of data was collected on September 24, 2022; the second on December 23, 2022; and the third on March 12, 2022.

Fig. 2: Five planted tea plants of TS 520 variety

Left to Right – 1st bucket (Control, without treatment), 2nd bucket (cow dung), 3rd bucket (Vermicompost), 4th bucket (Solid waste compost), 5th bucket (Kitchen waste compost)

Compost - Treated Soil Sample Collection And Analysis Methods

6-inch-deep, four V-shaped pits were dug in the soil of a plastic bucket by using a trowel. Samples were collected from the top, middle, and bottom layers of soil and collected in plastic-sealed pouch packets. 17 soil samples were collected from 17 plastic buckets for analysis. Out of 17 soil samples, 16 were compost-treated soil samples and were labelled according to the compost treatment type and the name of the tea variety. The single untreated soil sample was marked as a control soil sample.

17 soil samples were analysed at a Tea Board-approved laboratory (NITM). The following methodologies were adopted at the laboratory for soil pH testing and analysis of soil organic carbon (SOC)%, nitrogen (N)%, available potassium (K)%, and available phosphorus (P)%.

Table 3: Soil Testing Methods

Parameters	Methodologies
pH	pH meter. Reference: Jackson's soil chemical analysis
SOC%	Chromic acid method. Reference: Jackson's soil chemical analysis Jackson's soil chemical analysis
N%	2% Boric acid method by Micro Kjeldahl Apparatus.
K_2O %	Ammonium acetate method
P_2O_5%	Modified Molybdenum blue method

SOM (%) = Total SOC (%) x 1.72[20]

Where 1.72, a conversion factor derived from 100/58, was taken since carbon constitutes 58% of the mass of organic matter.[27]

Statistical Analysis Method

Statistical analysis was done through 1-way Anova test and Tukey's HSD Test and Duncan test

Results and Analysis

Analysis of Soil pH

The pH affects various soil related processes like ammonia volatilization, nitrification and denitrification, mineralization of organic matter, precipitation and dissolution of organic matter and heavy metals, biodegradation of organic pollutants, soil enzyme activities, rhizosphere processes, (Najarian and Souri, 202028; Aghaye Noroozlo *et al*., 2019 [29])

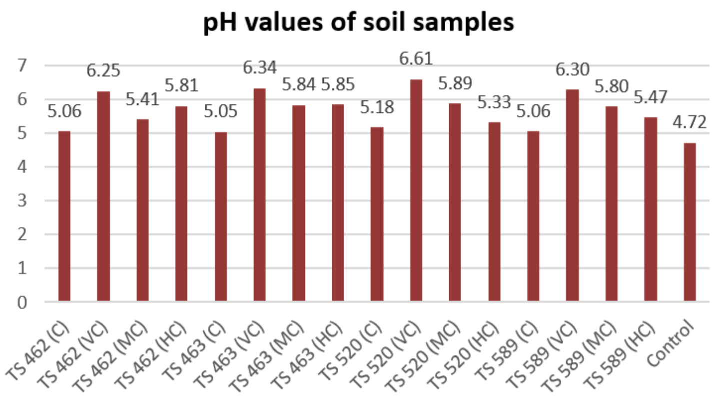

Fig. 3: pH values of soil samples

[Soil samples of Cow dung treated soil (C), Vermicompost treated soil (VC), Municipal Compost treated soil (MC), Home-made kitchen compost treated soil (HC)]

Tea grows well in slightly acidic soil with pH in the range 4.5 to5.5.[15] It has been observed that overall soil pH ranged between 4.72 to 6.61 (Figure 3). The optimal soil pH ranged from 4.72 to 5.47, which corresponds to 47.05% of total analyzed soil samples. Around 52.95%soil samples were found to have higher soil pH ranging between 5.80 to 6.61. No soil sample was found to exhibit lower soil pH value than the recommended value.

The control soil sample was found to be have an optimal pH of 4.72. However, the soil was already acidic in nature and in optimal range, the addition of any type of compost increased the pH of the soil. The study of (Neina ,2019[30]), found that organic manure application in acidic soil increased pH by 3.3%. It was reported by (Du *et al*.,2020[31]), that organic fertilizer increased soil pH. The authors (Lin *et al*.,2019[32]) found that continuously applying compost for three years increased soil pH in a soil – asparagus lettuce system. The authors (Chen *et al*.,2022[33]) explained that vermicompost had more or less neutral pH, and the lower pH was found in the final products due to the production of CO2, and microbial metabolism during decomposition.

Analysis of Soil Organic Matter (SOM)%

A variety of compounds contain carbon, hydrogen, and oxygen form soil organic matter (SOM), a substance that is an essential component of many processes that are vital to the health of the soil and the supply of nutrients to crops (Eugenae,2023[34]). According to TRA Tocklai, more than 2% of organic matter is required while cultivating tea.[24]

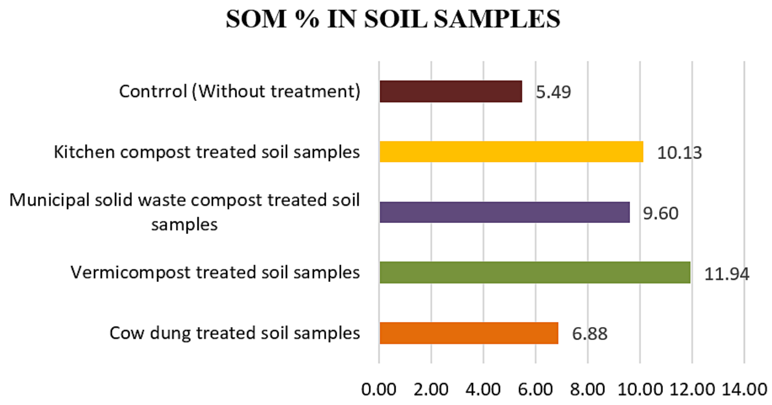

Fig. 4: SOM % in soil samples

It was found that all the soil samples contain more than 2 % of SOM. The control soil sample had 5.49% SOM. The average SOM% was ranging between 6.88 % to 11.94% after adding compost to the soil. According to 180 days of observation results of (Sullivan *et al*.,2023[35]; Mekki *et al*.,2019[36]), SOC and SOM levels significantly increased up to 120 days due to application of bio waste compost, but thereafter they started to decrease. The soil samples that had been treated with vermicompost had the highest average SOM% (11.94%), followed by the soil samples that had been treated with municipal waste compost (10.13%), kitchen waste compost (9.50%), and cow dung (6.88%). The results showed (Luck,2022[37]) that vermicompost did increase SOM compared to the control after 1 year application of soil amendments. According to the researchers (Fornes, *et al*.,2012[38]; Lim *et al*.,2015[39]) that earthworm digestion results in the production of more stable forms of organic matter, which contain higher carbon concentrations in vermicompost and greater increases in SOM compared to application of an equal amount of standard compost. Both the compost made from kitchen waste and the compost made from municipal solid waste are prepared using the aerobic process and almost have the same SOM content. The author reported (Pandit., *et al*.2020[40]) that aerobic composting process with manual pile rotation produced a good number of organic materials.

Analysis of Nitrogen (N)%, Phosphorus(P)% and Potassium (K)%

The tea plant, as a leaf-harvested crop, requires sufficient nutrients to meet the requirements for sprouting leaves and metabolite synthesis, especially macronutrients such as nitrogen (N), phosphorus (P), and potassium (K) (Tang *et al*.,2023[41]). TRA Tocklai recommended that available phosphorus (as P2O5) in soil should be more than 35 parts per million (ppm) and available Potassium (as K2O) should be more than 100 ppm. In Terai region total nitrogen content is within the range (0.1-2.0%) recommended by Tea Board of India (Mukherjee *et al.*,2020[42]).

Figure 5 shows that the N% of the control soil sample was 0.090%, while the N% for the soil treated with cow dung, vermicompost, municipal solid waste compost, and home-made kitchen waste compost ranged from 0.108–0.187, 0.110–0.217, and 0.85–1.148 respectively. Figure 5 indicates that, if compared to control soil sample, compost treated soil samples showed an increase in N% and homemade kitchen compost treated soil samples showed N% within the recommended range (0.1 to 2.0%). The findings of the study corroborate the report of Sanchez *et al.*,2017, which explained that repeated applications of stabilized and supplemented composts generally result in an increase in soil organic carbon and soil organic nitrogen.[43]

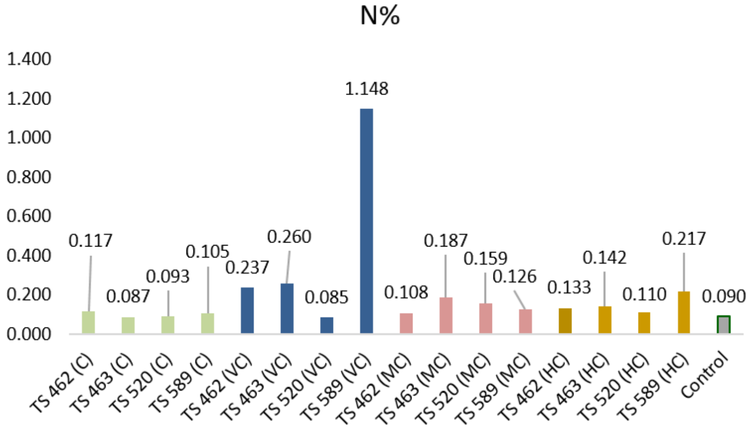

Fig. 5: N% in soil samples

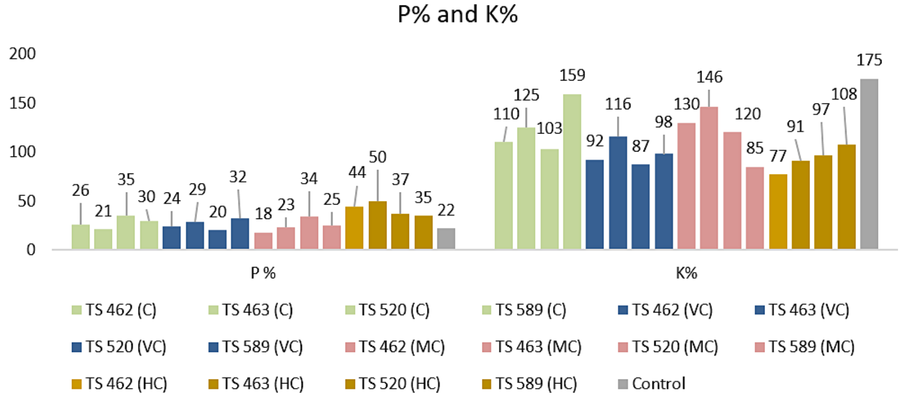

Fig. 6: P% and K % in soil samples

Figure 6 shows that the controlled soil sample had 22 ppm of phosphorus (P), which was below the recommended value of 35 ppm and the kitchen compost treated soil showed the optimum level of phosphorus. P level in other soil samples treated with compost was within the permissible range. P levels in soil samples treated with cow dung ranged from 21 to 35 ppm, those treated with vermicompost ranged from 20 to 32 ppm, those treated with municipal solid waste compost ranged from 18 to 34 ppm, and those treated with handmade kitchen compost ranged from 35 to 50 ppm. Other authors have also reported (Verma,2013[44]) that application of compost increases phosphorus availability in soils.

A high potassium (K) content (175 ppm) was found in the controlled soil sample; however, the K level was reduced in the compost-treated soil samples and the optimum level of K was observed in cow dung treated soil (Figure 6). Figure 6 represents that K levels ranged between 103-159 ppm, 87-116 ppm, 85-146 ppm, and 77-108 ppm in soil treated with cow dung, vermicompost, municipal solid waste compost, and kitchen waste compost. The authors (Taiwo*et al.*,2018[45]) found that potassium fixing capacity of soils were reduced after the application of organic manure. Therefore, it can be opinionated that N%, P and K level in soil after compost application were maintained within the permissible range recommended by TRA Tocklai, however the optimum level of N% and P was found in homemade kitchen waste compost. It was reported (Kelley., *et al*.2020[46]) that food-based compost has highest nitrate compared to cow manure and cow manure based vermicompost.

Plant Growth Evaluation

Each tea plant growth was evaluated in terms of plant height and number of leaves/stems.

One-Way ANOVA Test

A one-way ANOVA was performed with a significance level (alpha) set at 0.05 to assess the impact of different compost treatments on plant height and on leaf growth across four tea varieties across four tea varieties.

The ANOVA results revealed that the p-value (p = [insert p-value here]) was [greater than/less than] the alpha value. Since the p-value ([greater than/less than] 0.05), the one-way ANOVA is statistically [in]significant. This implies that there are no statistically significant differences in plant height growth among the compost treatments (Cow dung, Vermicompost, Municipal Compost, Home-made compost, and Control). Consequently, it may be inferred that, for this specific tea-growing context and set of varieties, the choice of compost treatment does not significantly influence plant height growth. This information can be valuable for tea farmers as it suggests that they can choose compost treatments based on other factors such as cost or availability without a substantial impact on plant height.

The one-way ANOVA results indicated that the p-value (p = [insert p-value here]) was [less than/greater than] the alpha value. Since the p-value ([less than/greater than] 0.05), the one-way ANOVA is statistically significant. This signifies that there are statistically significant differences in the increased number of leaves among the compost treatments (Cow dung, Vermicompost, Municipal Compost, Home-made compost, and Control). These differences imply that the choice of compost treatment has a significant impact on leaf growth in tea plants. Further post-hoc tests or pairwise comparisons can be conducted to determine which specific compost treatments differ significantly from each other in terms of their effects on leaf growth. This information can be valuable for tea growers, helping them make informed decisions about the most effective compost treatment for maximizing leaf growth and, consequently, tea plant yield.

Tukey's HSD Test

Table 4: Tukey’s HSD Test Results for Plant Height Growth

Multiple Comparison of Means - Tukey HSD, FWER=0.05

group1	group2	meandiff	p-adj	lower	upper	reject
TS 462	TS 463	35.0	nan	nan	nan	False
TS 462	TS 520	-1.0	nan	nan	nan	False
TS 462	TS 589	-8.0	nan	nan	nan	False
TS 463	TS 520	-36.0	nan	nan	nan	False
TS 463	TS 589	-43.0	nan	nan	nan	False
TS 520	TS 589	-7.0	nan	nan	nan	False

Table 5: Tukey’s HSD Test Results for Increased Number of Leaves and Stems

Multiple Comparison of Means - Tukey HSD, FWER=0.05

group1	group2	meandiff	p-adj	lower	upper	reject
TS 462	TS 463	-14.0	nan	nan	nan	False
TS 462	TS 520	-27.0	nan	nan	nan	False
TS 462	TS 589	-20.0	nan	nan	nan	False
TS 463	TS 520	-13.0	nan	nan	nan	False
TS 463	TS 589	-6.0	nan	nan	nan	False
TS 520	TS 589	7.0	nan	nan	nan	False

These results (Table 4 and 5) indicate whether there are statistically significant differences between the groups (treatments) within each dataset.

For the "Plant Height Growth" Dataset:
There are no statistically significant differences between any of the treatment groups (TS 462, TS 463, TS 520, TS 589) in terms of plant height growth. The "reject" column shows "False" for all group comparisons, meaning that none of the group comparisons resulted in a rejection of the null hypothesis.

For the "Increased Number of Leaves and Stems" dataset:
Similar to the first dataset, there are no statistically significant differences between any of the treatment groups (TS 462, TS 463, TS 520, TS 589) in terms of the increased number of leaves and stems. Again, all "reject" values are "False," indicating no significant differences.

In both cases, the Tukey's HSD tests did not find significant differences between the treatment groups.

This suggests that, based on the available data and a significance level of 0.05 (alpha), the various compost treatments did not lead to significantly different outcomes in terms of plant height growth or the number of leaves and stems.

However, a visible maximum height was observed in the plants of all varieties treated with vermicompost. (Figure 7). The study (Rekha *et al*.,2018[47]) revealed that the remarkable growth obtained in vermicompost-treated plants may be due to favourable and optimum temperatures, moisture, and a balance of organic and inorganic nutrients in the vermicompost, which greatly aid in the improved growth of the plants. These plants may have grown more quickly because the soil had better physical and chemical qualities, which increased microbial activity and macro and micronutrient levels, as vermicompost represents the most suitable form of a growing medium that is rich in minerals and growth bio stimulants (Serri *et al*., 2021[48] Najarian *et al*., 2021[49]).

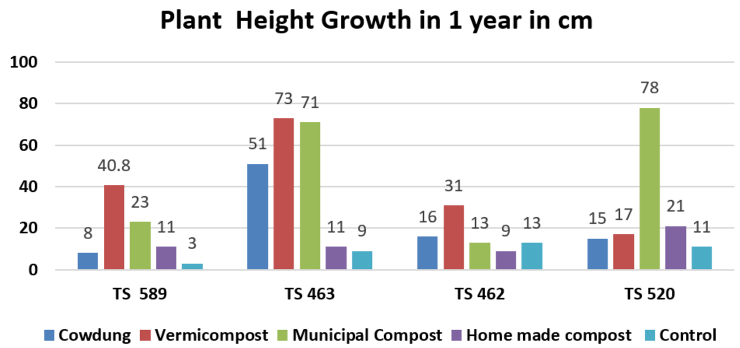

Fig. 7: Plant height growth in 1 year in cm

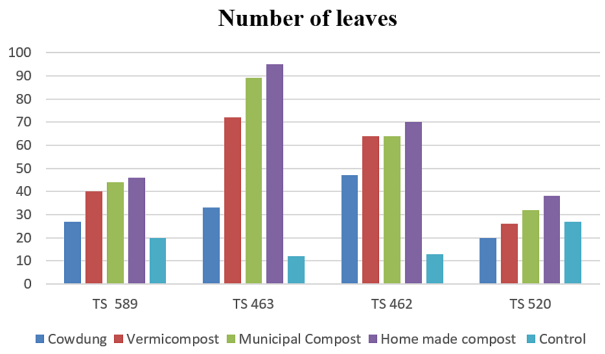

Fig. 8: Number of leaves in 1 year in cm

Fig. 9: Tea Plants of TS 463 varieties

It was visibly observed that homemade kitchen compost had a significant increase in the number of leaves in each variety of treated tea plants (Figure 8). Soil treated with homemade kitchen compost has optimum N% of0.11-0.21 % and 35-50 pm of Phosphorus (P). The ideal N% and P levels contained in home-made kitchen compost affects plant growth most significantly in terms of the number of leaves which is highly important for a foliar crop like tea. Phosphorous acts to strengthen the root system and increase the number of branches on a plant (Pandey and B.K. Sinha,2011[50]). The study results (Eedan *et al.*,2021[51]) indicated that an increase in nitrogen content resulted in considerable increase in number of leaves in all treated plants.

The figures (7 and 8) indicate how effectively TS 463 responded to the application of compost in terms of height and number of leaves. In TS 463 plant varieties, the average annual increase in height was 51 cm, increase in leaves 33, and branches 8 for the plant treated with cow dung; 73 cm in height, 72 leaves, and 9 branches for the plant treated with vermicompost; 71 cm in height, 89 leaves, and 10 branches for the plant treated with municipal solid waste compost; and 11 cm in height, 95 leaves, and 15 branches for the plant treated with homemade kitchen waste compost.

Conclusion

In West Bengal, tea cultivation in the Dooars and Tarai regions is almost entirely dependent on synthetic fertilisers, with the exception of the Darjeeling Hills region. In the present study, four types of composts, including cow dung, vermicompost, municipal solid waste compost, and home-made kitchen waste compost, were applied to four biclonal Tocklai tea plant varieties, TS 589, TS 520, TS 462, and TS 463, from the Terai region of West Bengal. The soil testing results showed that high pH and SOM were present in vermicompost-treated soil samples, whereas an optimal amount of phosphorus and N% were observed in home-made kitchen waste compost-treated soil samples, and a high potassium level was found in cow dung-treated soil samples. One-year visible observation revealed that due to high SOM, maximum height was achieved by vermicompost-treated plants. Due to the optimal phosphorus and nitrogen levels, the maximum number of leaves and stems were produced in home-made kitchen compost-treated plants. However, healthy leaves were observed mostly in cow dung-treated plants of each variety, probably because cow dung contains a suitable amount of potassium. The overall variability also found among the tea varieties and control group, as evidenced by the significant ANOVA results. However, Duncan's tests did not identify any specific pairs of varieties or groups with significantly different plant height growth or increased numbers of leaves and stems.

Therefore, it can be inferred that while there was variation among the groups, no distinct pairwise differences were detected. However, based on laboratory results and visible observation the authors recommend an integrated compost application strategy that should be implemented in conventional tea cultivation to enrich soil with SOM, nitrogen, phosphorus, and potassium and to achieve sustainable organic tea farming with high yields and healthy tea production.

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Conflict of Interest

There is no conflict of interest among the authors.

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