



Integrated Bioplant and Groundnut Husk Biochar Compost Application on Yield of Lettuce in a Rhodic Kandiuistalf

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OPEN ACCESS

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Specialty section:

This article was submitted to
Land, Livelihoods and Food Security,
a section of the journal
Frontiers in Sustainable Food Systems

Received: 06 March 2021

Accepted: 27 August 2021

Published: 01 October 2021

Citation:

Nartey EK, Darko DA and Sulemana N
(2021) Integrated Bioplant and
Groundnut Husk Biochar Compost
Application on Yield of Lettuce in a
Rhodic Kandiuistalf.
Front. Sustain. Food Syst. 5:676776.
doi: 10.3389/fsufs.2021.676776

Bioplant is a liquid soil conditioner that contains a consortium of beneficial fungi and bacteria manufactured by Artemis and Angel Company Limited in Bangkok. Bioplant is purported to stimulate beneficial microbial activity in soil and hence increase crop yield. However, the efficacy of Bioplant has not been evaluated on Ghanaian soils. A screen house trial was consequently conducted to evaluate the efficacy or otherwise of Bioplant on the yield of lettuce in a Rhodic Kandiuistalf amended with or without compost. The soil was mixed with compost at 20 parts soil to 80 parts compost and 60 parts soil to 40 parts compost (v/v) and potted in 1.7-L pots. There was another potted soil with no compost amendment. To each of these potted soils, Bioplant was applied at four rates, viz., zero, half the manufacturer's recommended rate, the manufacturer's recommended rate, and twice the manufacturer's recommended rate, and allowed to equilibrate for 2 weeks. Seedlings of lettuce of the variety Eden were transplanted into the pots, and the treatments kept at 80% field capacity. The treatments were replicated four times in a completely randomized design. At physiological maturity, the lettuce was harvested, and fresh and dry matter yields were taken. The C and N contents and N uptake in the harvested plants were also determined. Results indicate that conditioning the soil with Bioplant at half and the manufacturer's recommended rates increased N uptake, resulting in higher carbon accumulation with concomitant increases in both fresh and dry matter yields. The results also show that amending the Rhodic Kandiuistalf with Bioplant at twice the manufacturer's rate suppressed yield. Application of Bioplant at the manufacturer's recommended rate in combination with compost amended at 40 parts to 60 parts soil (v/v) saw a 47 and 90% respective significant yield increases in fresh weight and dry matter when only Bioplant was applied at the manufacturer's recommended rate. It is therefore recommended for Bioplant to be applied at the manufacturer's recommended rate of 825 mL/ha in combination with 40 parts of compost to 60 parts of soil (v/v).

Keywords: biochar, compost, nitrogen uptake, carbon, soil conditioner

INTRODUCTION

Soils of Ghana, except for the few variants of Vertisols in the Accra plains, are generally low in fertility. Their organic carbon contents are <1%, and the levels of N and P are very low (SRID MoFA, 2007; Obiri-Nyarko, 2012). The soils are also dominated by low-activity clays, mainly kaolinites and sesquioxides, with a cation exchange capacity (CEC) usually below 15 cmol(+)/kg.

To obtain appreciable crop yields, the application of nutrient from external sources has become imperative. Application of inorganic fertilizers through the soil for plant uptake has been the commonest way by which nutrients are made available to crops in Ghana. Thus, there is application of mainly inorganic fertilizers, of which the ammonium-based ones (urea and sulfate of ammonia) are the most popular. Application of these fertilizers has also aggravated the acidity problem as a result of nitrification under aerobic conditions (Chang et al., 2007; Gong et al., 2009). Thus, about 85% of soils have become acidic (Buri et al., 2005), making them prone to P fixation. Consequently, the soils are low in productivity. Fertilizers are also expensive and generally beyond the reach of small-scale farmers, who are in the majority. The government subsidy policy on fertilizer implemented in 2008 has also not helped much because of cross-border smuggling (Yawson et al., 2010). Additionally, the inorganic fertilizers are usually not in close proximity to the farmers. Consequently, fertilizer use in Ghana as of 2019 stood at a paltry 20 kg/ha (SRID MoFA, 2019).

Nutrient use efficiency of the already low rate of fertilizers applied to soils in Ghana is low because of the poor nutrient holding capacities of the soils as a result of the low organic matter content and the presence of the low-activity clays. Returns on fertilizer application are thus low, negatively affecting soil and crop productivity, and consequently food security. Improving nutrient use efficiency would demand increasing the organic matter content of soils in Ghana to improve on their nutrient holding capacity (Tandy et al., 2009), while making the nutrient more readily available. An intervention to improve nutrient storage and increase nutrient use efficiency is to apply compost. Compost, while supplying nutrients in the readily available form, increases the soil humus content to improve on the nutrient holding capacity (Dutta et al., 2003). Compost, being a buffer and alkaline can offset pH decreases arising from nitrification under aerobic soil conditions (Akumah et al., 2021; Sulemana et al., 2021). The amendment also improves on the general health or quality of the soil (Meena et al., 2016), by boosting the micro and macro flora and fauna population and activity (Ros et al., 2003) and organic carbon content (Sulemana et al., 2021) in the soil. Composting could also be a way of closing the nutrient loop in circular photosynthesis by returning nutrient to the soil, thus minimizing nutrient mining.

A drawback of the use of compost, especially, in short duration crops is the slow release of nutrients (Zhang et al., 2009; Chen et al., 2013), which is not in synchrony with plant uptake. Should the availability of nutrients from compost be improved, it could be the panacea to the low fertility and productivity problem of Ghanaian soils.

Any addition to compost that would accelerate the release of nutrients or make nutrients more readily available would be an impetus to improving the productivity of Ghanaian soils.

Bioplant is a soil conditioner manufactured by Artemis and Angel Company Limited in Bangkok, Thailand. Bioplant is a microbial liquid conditioner that contains bacteria and fungi and 7.00 g N/L, 4.00 g P₂O₅/L, and 5.10 g K₂O/L among other nutrients. It is purported to stimulate the activity of beneficial microbes in soil to improve nutrient uptake and hence increase crop yield. For Bioplant to be very effective, the soil must have high content of organic matter which would boost the proliferation of beneficial microbes and hence improve nutrient release¹ (Dutta et al., 2003).

Most soils in sub-Saharan Africa and particularly Ghana are low in organic carbon contents with levels lower than 10 g/kg (Jones et al., 2006). Bioplant may, therefore, not be very effective in such soils. As a means of increasing organic matter application to soils and managing organic waste, composting is being deployed in Ghana (Akumah et al., 2021). Many composting companies have thus sprung up in Ghana, and compost as a nutrient source has been included in the Ghanaian government's fertilizer subsidy program (SRID MoFA, 2019). Compost use, especially in northern Ghana where organic matter levels are exceptionally low, is expected to increase. Bioplant would be important to the Ghanaian farmer if it is applied in combination with compost to the soil. The efficacy of Bioplant would be ascertained better if it is applied with compost or decomposed organic matter under controlled conditions.

As a soil conditioner, Bioplant would be deemed efficacious if it aids in the release of nutrients rapidly to meet the demand of crops. This attribute could be evaluated best if Bioplant is assessed on short-duration crops. It is in the light of this that a screen house experiment was conducted using lettuce (*Lactuca sativa*), a leafy vegetable of short duration with a high N requirement as a test crop. Evaluation of the efficacy or otherwise of the conditioner was carried out on the Toje Series, a Rhodic Kandistalf and one of the most widely cultivated soils of the Coastal Savanna Zone of Ghana but of poor fertility. Should Bioplant promote N uptake and increase yield of lettuce from the Toje Series amended with both the conditioner and compost over the crop grown only on a compost amended soil, then the conditioner would be deemed to be efficacious enough in enhancing the availability of nutrient from soils amended with organic fertilizers.

A screen house experiment was conducted using Bioplant as a booster for N availability in a compost-amended Toje Series with the hypothesis that the biofertilizer would enhance N availability and uptake and, consequently, increase the yield of lettuce.

The objectives of the study were two-fold:

- i. to verify if the manufacturer's recommended application rate of the conditioner is effective in increasing N uptake and

¹<http://artemisthai.com/wp-content/uploads/2014/07/Regenerative-Agriculture> (accessed March 02, 2021).

hence yield of lettuce in a highly weathered Ghanaian Rhodic Kandistalf of low fertility and

ii. to ascertain the efficacy of Bioplant when applied in combination with compost on the yield of lettuce.

MATERIALS AND METHODS

Soil Sampling and Preparation

The Toje Series, a Rhodic Kandistalf, was used as the soil for the study. This soil is widely cultivated in the Coastal Savanna Zone of Ghana but is inherently low in fertility. The plow layer of the soil was sampled from an area that had had no known history of fertilizer and any soil conditioner application. The soil was air-dried and passed through a 2-mm sieve to obtain the fine earth fraction for some physicochemical analyses. Undisturbed soil samples were taken for the determination of bulk density and water holding capacity (WHC). The particle size distribution of the fine earth fraction was determined using the Bouyoucos hydrometer method (Day, 1965). Moisture content of the soil at maximum WHC was determined by covering the water-saturated sample of the undisturbed soil with polythene sheets and determining the moisture content after allowing gravitational water to drain for 48 h. Bulk density was determined using the core method by Blake and Hartge (1986). The pH and electrical conductivity (EC) of the fine earth were determined electrometrically in water using a 1:1 soil-water ratio (w/v) on an Oakton PC 2700 pH and EC meters. Organic carbon content of the fine earth was determined on a Leco TruMac CNS analyzer after destruction of carbonates in the soil with 6 M HCl. Total N in the fine earth fraction was analyzed using the Leco TruMac CNS analyzer with total P being extracted by wet digestion using perchloric and nitric acids. Available P in the fine earth fraction was extracted according to the method of Bray and Kurtz (1945). Total and available P concentrations in the extracts were determined on a UV spectrophotometer after color development using the Murphy and Riley (1962) method. The CEC of the soil was determined by the ammonium acetate method.

Screen House Experiment

Maize stubble was co-composted with groundnut husk biochar in the ratio of eight parts of the maize stubble to two parts of groundnut husk biochar on volume-to-volume basis.

An unprocessed Toje Series (unprocessed soil) was packed into 1.7-L plastic pots with drainage holes to attain the field bulk density of the soil. Subsequently, the soil was mixed with the compost in two soil-to-compost ratios of 20:80 (C80) and 60:40 (C40) on a volume basis and packed. To another pot, only soil was packed (C0), and this served as the control. Bioplant (BP) as a conditioner was applied to the potted soils at four rates of zero (BP0), half the manufacturer's rate (BP1), the manufacturer's recommended rate (825 mL/ha) (BP2), and twice the manufacturer's rate (BP3). All the soils were allowed to equilibrate for 2 weeks amidst watering to attain 80% WHC. While allowing the soils to equilibrate, lettuce seeds of the variety Eden were nursed. At the end of the 2 weeks, the seedlings were transplanted at two per pot. The moisture content of the media for growth (soil \pm compost \pm Bioplant) was maintained

at 80% WHC to avoid leaching. These were replicated four times. Thus, with three compost application rates of 0, 40, and 80 and four Bioplant application rates and four replications arranged in a completely randomized design, there were a total of 48 experimental units.

Agronomic Evaluation

At maturity, the lettuce was harvested, and the fresh weight determined. The lettuce was then dried in an oven at 65°C until a constant weight was attained and the dry matter content taken. The dried lettuce leaves were then milled, and the C and N contents determined on a TruMac C–N analyzer. The N uptake in the leaves per pot for each treatment was estimated by multiplying the leaf N content with the dry weight.

Residual Soils

After harvest, the soils from the various pots were poured out into plastic bowls, homogenized, and subsampled for air-drying. These were then sieved to obtain the fine earth fraction and analyzed for pH, organic carbon, total N, and available P as described earlier.

Data Analysis

The aforementioned measured parameters were subjected to analysis of variance (ANOVA) using Genstat 12th edition to establish, if any, significant treatment effects at $p < 0.05$. Mean separations were done using Tukey's least significant difference (LSD) (0.05).

RESULTS

Characterization of Soil

Some physical and chemical properties of the soil used for the study are presented in **Table 1**. The sand fraction of the soil at 74.4% was 12 times more than the clay fraction of 6.2%. The silt content was 19.4%, giving the soil a loamy sand texture. The bulk density of the soil was 1.3 Mg/m³. The soil had a moderately acidic pH of 5.7 with a low EC of 0.35 dS/m. Typical of Ghanaian soils, the organic carbon content (8.0 g/kg) was below 10 g/kg. Consequently, total N and available P were also low with values of 0.7 g/kg and 5.96 mg/kg, respectively. The total P concentration of 108.2 mg/kg was also low. The CEC of 5.62 cmol(+)/kg was low and characteristic of highly weathered tropical soil with low-activity clay.

Some chemical properties of the compost used in the study are presented in **Table 2**. The compost had an ideal neutral pH of 7.4 with an EC of 4.67 dS/m. The total carbon content was 326.0 g/kg with a total N content of 13.2 g/kg and a low available N concentration of 0.9 g/kg. Consequently, the compost had a C:N ratio of approximately 24.7, which was slightly above the critical value of 20. The compost had a very high total P content of 7,366.7 mg/kg, of which about 5% was in the available form (370.0 mg/kg). The total calcium content of the compost was 6.05 g/kg, with the magnesium content of about 5.41 g/kg being 10% lower. The compost had a low sodium content of 2.16 g/kg, with the total potassium content of 50.03 g/kg accounting for almost 79% of the total bases.

TABLE 1 | Some physicochemical properties of Toje Series*.

Sand	Silt	Clay	Bulk density	pH	EC	OC	TN	Av. P	CEC
	%		Mg/m ³	(H ₂ O)	dS/m	g/kg		(mg/kg)	cmol(+)/kg
74.4	19.4	6.2	1.3	5.7	0.35	8.0	0.7	5.96	5.62

*EC, electrical conductivity; OC, organic carbon; TN, total nitrogen; Av. P, available phosphorus; CEC, cation exchange capacity.

TABLE 2 | Some chemical properties of the compost used.

Parameters	Results
pH (1:1) _{water}	7.4
EC (dS/m)	4.67
Total carbon (g/kg)	326.4
Total nitrogen (g/kg)	13.2
Available nitrogen (g/kg)	0.9
Total P (mg/kg)	7,366.7
Available P (mg/kg)	370.0
Total Ca (g/kg)	6.05
Total Mg (g/kg)	5.41
Total Na (g/kg)	2.16
Total K (g/kg)	50.03

TABLE 3 | Effect of compost on yield, nutrient composition and N uptake in lettuce*.

Treatment	Fresh weight	Dry weight	C	N	N uptake
	(g)		(g/kg)		(g/pot)
C0	104.27a	3.98a	410.8a	36.7ab	0.15a
C40	220.7b	12.01b	473.2c	39.1b	0.49b
C80	107.3a	3.58a	432.8b	34.9a	0.13a
Cv (%)	18	17.8	4.5	8.8	18.5

*Means with the same alphabet are not significantly ($p < 0.05$) different. C0, no application of compost; C40, compost-to-soil application ratio of 40:60; C80, compost-to-soil application ratio of 80:20; Cv, coefficient of variation.

Compost Effect on Fresh and Dry Matter Yields and Nutrient Content of Lettuce

The effect of compost on lettuce yield, nutrient content, and uptake is presented in **Table 3**. The un-amended soil produced lettuce with fresh and dry matter weights of 104.3 g and almost 4 g, respectively. On amending the soil with 40 parts of compost (C40), the fresh and dry matter yields of the crop saw 2.1-fold and 3-fold significant increases, respectively ($p < 0.05$), to 220.7 and 12.01 g.

Increasing the volume of compost applied to 80 parts decreased yield by almost 51% from 220.7 g in the C40 amended soil to 107.3 g fresh weight ($p < 0.05$), statistically similar to the fresh weight of lettuce from the un-amended soil. The dry matter, which was 12 g in the C40 treatment, also decreased to 3.58 g, statistically similar ($p < 0.05$) to the dry matter yield of lettuce in the un-amended soil.

TABLE 4 | Effect of Bioplant on fresh and dry matter yields and N uptake of lettuce.

Treatment	Fresh weight	Dry weight	C	N	N uptake
	(g)	(g)	(g/kg)	(g/kg)	(g/pot)
BP0	94.73a	3.33a	397.0a	32.3a	0.11a
BP1	146.52b	7.09c	452.2b	38.9b	0.29c
BP2	200.28c	9.9d	458.9b	37.9b	0.41d
BP3	134.82b	5.77b	447.8b	38.5b	0.22b
Cv (%)	18	17.8	4.5	8.8	8.8

Means with the same alphabet are not significantly ($p < 0.05$) different.

BP0, no Bioplant application; BP1, Bioplant at half the manufacturer's rate; BP2, Bioplant at the manufacturer's recommended rate; BP3, Bioplant at twice the manufacturer's rate. Cv, coefficient of variation.

The carbon content of the lettuce in the un-amended soil was 410.8 g/kg. On application of 40 parts of the growing medium with compost (C40), the carbon content of the lettuce increased ($p < 0.05$) by 62.4 g/kg to 473.2 g/kg. A further 40-part increase in volume of compost added to the soil (C80), however, decreased carbon content in the lettuce to 432.8 g/kg, albeit 22 g/kg significantly higher ($p < 0.05$) than the carbon content in lettuce grown in the un-amended soil. The nitrogen content of lettuce from the un-amended soil was 36.7 g/kg, which was statistically similar ($p < 0.05$) to the 39.1 g/kg in lettuce grown in the soil amended with 40 parts of compost (C40). However, when 80 parts of compost were applied to the soil, the N content in the lettuce decreased significantly by 4.2 g N/kg from that in the C40 soils to 34.9 g/kg, albeit similar ($p < 0.05$) to the N contents in lettuce grown in the un-amended soil. Uptake of N by lettuce was in the order ($p < 0.05$) C40 > C0 = C80. It is worth noting that lettuce uptake of N in the soil amended with 40 parts of compost was over three times higher than that from the un-amended and amended soils with 80 parts of compost.

Effect of Bioplant on Fresh and Dry Matter Yields and Nutrient Content of Lettuce

The effect of Bioplant on fresh and dry matter yields of lettuce is presented in **Table 4**. The fresh weight of lettuce grown in the non-conditioned soil (BP0) was 94.73 g. On addition of the Bioplant at half the manufacturer's rate (BP1), there was an almost 55% increase ($p < 0.05$) in the fresh weight of lettuce to 146.52 g. Dry matter yield, which was 3.33 g in the non-conditioned soil, increased ($p < 0.05$), 2.13-fold to 7.09 g on addition of Bioplant.

Increasing further the Bioplant application rate to that of the manufacturer recommendation (BP2) saw a 2.1-fold and almost

1.4-fold increases in fresh weight of lettuce over those grown in BP0 and BP1 soils, respectively.

Carbon accumulations were generally statistically similar ($p < 0.05$) in lettuce grown in the Bioplant-amended soils, irrespective of application rate as the carbon contents were approximately between 450 and 460 g/kg.

Nitrogen levels in the lettuce followed a similar pattern as carbon, with the lettuce from the Bioplant-amended soils being similar in concentrations of the primary nutrient accumulated, albeit with significantly higher ($p < 0.05$) values than those accumulated in plants grown in the un-amended soils. The positive attribute of Bioplant was also evident in the 2.64-fold increase in N uptake of lettuce grown in soil conditioned with Bioplant at half the manufacturer's rate (BP1) over lettuce plants grown in the unconditioned soil (BP0). At the manufacturer's recommended rate (BP2), N uptake increased ($p < 0.05$) approximately 41% over uptake in lettuce grown in the soils amended with Bioplant at half the manufacturer's recommended rate (BP1).

Increasing the application rate to twice the manufacturer's recommended rate (BP3) saw a 33% reduction in fresh matter yield from that of lettuce plants grown in soils conditioned with Bioplant at the manufacturer's recommended rate. Uptake of N consequently decreased to almost half that in lettuce at the recommended rate. Uptake of N in lettuce induced by Bioplant application was in the order ($p < 0.05$) BP2 > BP1 > BP3 > BP0.

Interactive Effect of Bioplant and Compost on Yield and Nutrient Content

The interactive effect of both compost and Bioplant application on yield of lettuce is presented in **Table 5**. From the table, when the compost at 40 parts was applied in combination with Bioplant at half the manufacturer's recommended rate, the fresh and dry matter of lettuce harvested were almost 240 and 14.38 g, respectively. Carbon content in lettuce was 486.2 g/kg, much higher ($p < 0.05$) than when either compost or Bioplant only was applied at any of the rates. Nitrogen accumulation in the lettuce was 42.20 g/kg, which is 3.1 g N/kg higher ($p < 0.05$) than the highest accumulation in lettuce when either compost or Bioplant alone was amended to the soil. Uptake of N in lettuce, which was 0.61 g/pot, was far higher than when either of the two amendments only was applied to the soil.

On doubling the rate of Bioplant to the full recommended rate while maintaining the compost rate at 40 parts (C40), the fresh weight of the lettuce did not increase significantly from that at the half rate of Bioplant. However, the dry matter yield increased almost by 31% from 14.38 to 18.85 g. Carbon and N accumulations were similar to those in lettuce when the half Bioplant rate and C40 compost were applied to the soil. Nitrogen uptake increased significantly ($p < 0.05$) from that at the half Bioplant rate and C40 from 0.61 to 0.85 g/pot.

At twice the manufacturer's recommended rate of Bioplant application in combination with C40, both fresh and dry matter yields of lettuce declined significantly from those at the manufacturer's rate, corroborating the decline in yield when twice the recommended rate was applied with no compost

amendment. Combining Bioplant at the recommended rate with 40 parts of compost produced lettuce that is almost 95 g heavier in fresh weight and 9 g heavier in dry matter than the corresponding lettuce grown in only Bioplant-conditioned soil at the manufacturer's recommended rate (BP2). These increases represented 47 and 90% significant yield increases ($p < 0.05$) in fresh weight and dry matter, respectively, in the combined application over the application of only Bioplant. Similarly, application of Bioplant at the recommended rate in combination with 40 parts of compost gave lettuce that is almost 74 g heavier in fresh weight and 6.84 g heavier in dry matter weight than lettuce counterparts grown in soil amended with only 40 parts of compost. These significant increases in yield represented 34 and 57% increment over yield of lettuce grown in compost only at 40 parts application rate to soil.

It is noteworthy that combining C40 and Bioplant at half the recommended rate produced lettuce with fresh weight that was statistically similar to the fresh weight obtained when C40 was combined with Bioplant at the manufacturer's recommended application rate. However, when the former (C40 + BP1) is compared with only Bioplant at half the manufacturer's recommended rate (BP1), there was a 64% increase in fresh weight of lettuce compared with the C40 + BP1-amended soil.

Combining 40 parts of the compost with all the three rates of Bioplant did not show any changes in C and N accumulation in the lettuce leaves, with the levels of carbon ranging between 471.2 and 504.7 g/kg and those of N between 35 and 45 g/kg. Nitrogen uptake among the treatments, however, was significantly different. Amendment of Bioplant and 40 parts of compost to the Toje Series saw N uptake in the following order: manufacturer's recommended rate > half the manufacturer's rate > double the manufacturer's rate (**Table 5**). Combination of 40 parts of compost with Bioplant at both half and full manufacturer's recommended rates gave more than 1.5-fold increases in N uptake in lettuce over lettuce grown in Bioplant-amended soils only (**Tables 3, 5**). Nitrogen uptake of lettuce from the soil amended with C40 and twice the recommended Bioplant application rate (0.28 g/pot) was, however, similar to the uptake when lettuce was grown in the soil amended with only Bioplant at half and twice the manufacturer's recommended application rates.

When the compost was applied at 80 parts on a volume basis to 20 parts of the soil in combination with the three different rates of Bioplant, the yield of lettuce decreased with respect to those at similar rates of Bioplant and 40 parts compost amendment. At half the Bioplant recommended application rate with C40 compost amendment, fresh lettuce weight was 239.9 g, more than twice the weight when the same rate of Bioplant was amended with soils to which 80 parts of compost had been applied (**Table 5**). Similarly, when the full recommended rate of Bioplant was applied to C40 compost-amended soils, fresh lettuce weight was 1.88 times higher than the lettuce counterparts from the same rate of Bioplant application to a C80-amended soil. It is thus clear that compost application at 80 parts to 20 parts of soil is not conducive for cultivation of lettuce.

There was no difference in carbon contents of the leaves of lettuce among the three rates of Bioplant applied to 80 parts of

TABLE 5 | Interactive effect of compost and Bioplant on yield, nutrient composition, and N uptake of lettuce.

	Conditioner	Fresh weight	Dry matter	C	N	N uptake
		(g)	(g)	(g/kg)	(g/kg)	(g/pot)
C40	No application	172.53e	6.59de	430.6bc	34.6abc	0.23cd
	Half rate	239.99f	14.38f	486.2de	42.2cd	0.61e
	Full rate	295.33f	18.85g	504.7e	45.1cd	0.85f
	Double rate	174.96e	8.23e	471.2.cde	34.6abc	0.28d
C80	No application	39.36a	1.00a	380.8a	29.4a	0.03a
	Half rate	107.53bcd	3.27abc	436.7bc	35.7abc	0.12abc
	Full rate	156.74de	5.79cde	448.8bcd	32.1ab	0.19bcd
	Double rate	125.57bcde	4.25bcd	464.8cde	42.4d	0.18bcd
Cv (%)	18	17.8	4.5	8.8	18.5	

Means with the same alphabet are not significantly ($p < 0.05$) different. C40, compost-to-soil application ratio of 40:60; C80, compost-to-soil application ratio of 80:20; Cv, coefficient of variation.

TABLE 6 | Effect of compost application on some residual soil properties*.

Treatment	pH (H ₂ O)	EC (ds/m)	OC (g/kg)	TN (g/kg)	Avail. P (mg/kg)
C0	5.8	0.37	7.8a	0.528a	3.20a
C40	6.5	1.45	11.8b	0.757b	11.45b
C80	7.1	2.34	14.5c	0.905b	18.10c

Means with the same alphabet are not significantly ($p < 0.05$) different.

*EC, electrical conductivity; TC, total carbon; TN, total nitrogen; Avail. P, available phosphorus; C0, no application of compost; C40, compost-to-soil application ratio of 40:60; C80, compost-to-soil application ratio of 80:20.

compost-amended soil. However, doubling the manufacturer's recommended rate of Bioplant application reflected in the superior N accumulation to the other rates at 80 parts of compost amendment to the soil. This superior accumulation of N in lettuce grown in pots with double the manufacturer's recommended rate did not affect uptake of N as all the Bioplant treatments had statistically similar levels of N uptake under 80 parts of compost amended to the soil.

Effect of Compost on Residual Soil Characteristics

Some chemical properties of the residual soil after harvest are presented in **Table 6**. The pH of the residual soil which had had no amendment was 5.8, similar to that of the original soil before cultivation (5.7). There were, however, respective 0.7 and 1.3 pH increases to 6.5 and 7.1 in the residual soils which had been amended with compost at 40 and 80 parts compared with the soil before cultivation. It is worthy of note that the EC of the original soil, which was 0.35 dS/m, did not change in the residual non-conditioned soil after harvest. However, the EC increased over four-fold and six-fold in the residual C40 and C80 soils, respectively, after harvest. Organic carbon contents of the residual soil with no amendment (7.8 g/kg) was also similar to that of the original soil (7.8 g/kg). Total nitrogen and available P of the residual un-amended soil decreased marginally from the levels before

planting with respective concentrations of 0.53 g/kg and 3.2 mg/kg. Organic carbon and available P levels of the residual soil seemed to increase with increasing application of the compost. There were almost 1.5-fold and 1.8-fold respective increases in organic carbon contents of the C40 and C80 residual soils and corresponding two-fold and three-fold increases in available P contents. Total N of the compost-amended residual soils was statistically similar (0.76–0.91 g/kg). It is, however, noteworthy that the nitrogen levels in the residual soils were between 0.23 and 0.38 g/kg higher than the contents in the residual un-emended soil.

DISCUSSION

Soil Characteristics

The loamy sand texture of the soil coupled with the bulk density of 1.3 Mg/m³ gave a good indication of the soil's physical suitability for root growth and permeability, which are very important for the soil–plant–water relationship (McKenzie et al., 2004). The low organic carbon, total N, and available P contents are indications that the Rhodic Kandistalf (Toje Series), chosen for the study, is indeed inherently low in fertility. Additionally, the loamy sand texture, coupled with the low organic carbon content, is likely to contribute to a low WHC of the soil and promote leaching of nutrients. These soil types should therefore not be irrigated above field capacity. They should rather be irrigated to a fraction of moisture content at field capacity and more regularly for optimum moisture availability to crops. The low clay content of the soil, which has been found to be dominated by low-activity clays like kaolinite (Eze, 2008), may, in part, explain the low CEC of 5.62 cmol(+)/kg. The moderately acidic pH of the soil in water coupled with the low organic carbon contents and the kaolinitic nature of the clay would promote low P availability (Nartey et al., 1997; Sulemana et al., 2021) as corroborated by the 5.96 mg/kg concentration. The poor fertility status of the soil justifies its choice and use as a medium for testing the efficacy of Bioplant. Lettuce grown on this Toje Series should respond positively to external inputs of fertilization and conditioning to improve soil and lettuce productivity.

Effect of Soil Amendments on Fresh and Dry Matter Yields and Nutrient Content of Lettuce

The addition of compost to soil generally helps to improve the structure and fertility status of the soil. Additionally, amendment of the soil with the biochar-compost should increase the pH of the moderately acidic soils to near neutral to enhance P availability and dry matter yield (Latifah et al., 2018; Sulemana et al., 2021) as evident in the pH and available P content, especially of the residual C40 soils. The respective 2.1-fold and 3-fold increases in fresh and dry matter yields over the lettuce grown in the un-amended soil following the application of 40 parts of compost (C40) may be due to higher availability of N and P from the compost. The increase in lettuce biomass indicates an improvement in nutrient availability in the soils after the amendment of (C40) as found elsewhere by Sulemana et al. (2021). This assertion is corroborated by the neutral pH, elevated total N, and available P contents in the residual levels of C40 treatments (**Table 6**). Increasing the volume of compost to 80 parts (C80), however, led to a 51% yield decline in fresh weight compared to amending the soil with only 40 parts of compost. This decline in yield was due to the 73% decrease in N uptake in the plants grown on soil with C80 amendments compared to those that had application of 40 parts compost as indicated in **Table 3**. The biochar compost used was in a ratio of two-part groundnut husk biochar to eight parts maize stover. The high Ca and K in the biochar certainly elevated the level of the two basic cations in the compost product. Addition of 80 parts of the biochar-compost to 20 parts of the soil must have elevated the Ca and K levels in the growing medium. This must have induced an osmotic stress on the lettuce roots, thus limiting N uptake with a concomitant lower leaf expansion, carbon accumulation, and hence fresh and dry matter yields. The EC of the residual C40 soil being lower than that of the C80 (**Table 6**) gives credence to the fact that absorption of nitrogen by lettuce would be hindered more from the C80 pots. The higher total N and available P levels in the residual C80 soil compared to the residual C40, albeit with a lower uptake in lettuce grown in the former, are an indication of the fact that even though the nutrients may be available, uptake was hindered.

As indicated in **Table 4**, addition of the soil conditioner (Bioplant) at half the recommended rate and the manufacturer's recommended rate resulted in 1.55-fold and 2.11-fold increases, respectively, in fresh weight of lettuce compared to those grown in the soil without any conditioner. These yield increases also translated into increases in dry matter yield of lettuce. The significant increases in both fresh and dry matter yields following the application of the soil conditioner could be a reflection of increased availability and higher uptake of N by the lettuce as a result of higher mineralization of native organic matter in the Toje Series used for the work. This assertion is corroborated by the 41.4% significant increase in N uptake from the lettuce grown in the soil amended with Bioplant at the manufacturer's recommended rate (BP2) over

those grown in soils amended with half the manufacturer's rate (BP1) (**Table 4**).

The higher nitrogen uptake of lettuce in the BP1 and BP2 soils than their BP0 counterparts also reflected in their respective significantly superior carbon contents of about 450 g/kg relative to the 400 g/kg of BP0. A higher N uptake would promote better leaf expansion as a result of higher chlorophyll formation and hence higher assimilation of carbon (Gastal and Saugier, 2006). It is clear from the results that conditioning the soil with Bioplant at both manufacturer's recommended rate and half the rate significantly increased both fresh and dry matter yields. Considering the fact that lettuce is eaten fresh and the increase in fresh weight of lettuce is almost 37% higher at the manufacturer's recommended application rate relative to half the application rate, the former rate should be the preferred choice. However, for resource-poor farmers and clients interested in N content at cheaper cost, half the recommended rate could be used as there is no significant difference in the N composition of lettuce grown at the two rates.

A reduction in fresh matter yield following a 100% increase in the manufacturer's recommended Bioplant application rate to BP3 may have resulted in a lower N uptake, culminating in a lower dry matter yield of lettuce. It is evident that doubling the manufacturer's recommended application rate of Bioplant to the soil reduced the dry matter yield of lettuce significantly by 19 and 42% from the BP1- and BP2-conditioned soils, respectively. It thus appears that doubling the rate suppressed nutrient availability, leading to a decrease in leaf expansion and hence fresh and dry matter yields.

Interactive Effect of Bioplant and Compost on Yield and Nutrient Content

As indicated in **Table 5**, the superior interactive effect of compost and the soil conditioner was evident in the fresh and dry matter yields of lettuce when compared to those of either compost or the Bioplant alone. It is noteworthy that when C40 was combined with Bioplant application at half the recommended rate, lettuce fresh weight was statistically similar to that of C40 in combination with Bioplant at the manufacturer's recommended rate. However, C40 interacting with Bioplant at half the manufacturer's recommended rate yielded lettuce with a fresh weight that is 64% heavier than lettuce grown in soil amended with only Bioplant at half the manufacturer's recommended rate (BP1). The corresponding increase in dry matter of lettuce was two-fold. This increase in dry matter may be attributed to an increase in uptake of N over lettuce grown in either the BP1-conditioned soils or the C40 alone as seen in **Table 5** (Glaser et al., 2015; Kammann et al., 2015). The fact that combining compost at 40 parts to the soil and further amending it with Bioplant at the manufacturer's recommended rate produced lettuce that is 55.34 and 4.47 g, respectively, heavier in fresh and dry matter than their counterparts grown in C40 soils amended at half the manufacturer's recommended rate of Bioplant, and the former combination gave the highest N uptake of 0.85 g

N/pot, which shows that C40 and Bioplant at the manufacturer's recommended rate are a suitable mixture for growth of lettuce in the Toje Series. Thus, the combination of the conditioner at the manufacturer's recommended rate with 40 parts of compost to 60 parts of soil on (v/v) seems to be the ideal condition for lettuce production.

CONCLUSIONS

Results from the work have shown that Bioplant as a conditioner when applied to the Rhodic Kandistalf at the manufacturer's recommended rate during land preparation boosts N uptake and increases yield of lettuce. For better and more efficient utilization of Bioplant, it is ideal to apply it in combination with some amount of compost.

It is recommended for Bioplant to be used in combination with compost or decomposed organic manure for better yield if the organic matter content of the soil is low. Under conditions of high organic matter contents of soils, Bioplant could be used

without compost. Bioplant should be applied to the soil well-ahead of seeding or planting to boost microbial activity and mineralization to synchronize nutrient availability with uptake.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

All authors listed have made substantial intellectual contributions to the work and approved it for publication.

ACKNOWLEDGMENTS

The authors would like to thank the Plant Protection and Regulatory Services Directorate of the Ministry of Food and Agriculture, Ghana, for the provision of the Bioplant conditioner.

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