THESIS

EVALUATION OF THE EFFECTIVENESS OF COLORADO STATE UNIVERSITY'S COMPOST FOR LETTUCE PRODUCTION

Submitted by

Mohammed Abdullah Alfurayji

Department of Horticulture and Landscape Architecture

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Master's Committee:

Advisor: Harrison Hughes

Mohamed Shahba
Adriane Elliott

ABSTRACT

EVALUATION OF THE EFFECTIVENESS OF COLORADO STATE UNIVERSITY'S COMPOST FOR LETTUCE PRODUCTION

The impact of Colorado State University (CSU) compost application at high and low rate (36.48, HC, and 9.52, LC, kg/acre respectively) on red leaf lettuce (*Lactuca sativa*) production in a high hoop house was evaluated during spring of 2014. Measurements used to evaluate production was plant height, leaf number, fresh weight, leaf area, dry weight and relative photosynthesis. Leaf nutrient content of the red leaf lettuce was also compared among treatments. The experiment was conducted in a high tunnel at the Horticulture Field Research Center (HORT Farm) at Colorado State University in Fort Collins. CSU compost treatments at HC and at a LC were compared to Alaska fish fertilizer 5-1-1 (41.2ml/7.6 liters once a week) and no fertilizer as a control. The experiment was set up in a randomized complete block design with four treatments and three replications in the high tunnel (15.24 ×6.096 m) for a total of 12 treatment replication combinations. Samples were taken at 3 times (after 25, 35 and 45 days after transplanting, DAT). JMP software program was performed and statistical significance was determined using analysis of variance followed by Student's t test for mean comparison.

CSU compost analysis showed that the organic matter and C/N ratio (60.1%, 22.8 respectively) were high indicating that nitrogen may have been immobilized in the high carbon. Also, the salt level was high (3.5 mmhos/cm) which may have impacted production of the lettuce. The total nitrogen in the compost was at a moderate level (0.53%) which should have supplied sufficient nitrogen to the lettuce. Nitrate-N was high (92.7 ppm) while ammonium-N was low (19 ppm) indicating that this compost had matured. Results under low concentration of CSU's compost (LC, 9.52kg/acre) showed a significant increase in several perimeters as follow; leaf number of 18.06 after 45days, a fresh weight of (269.86 g) after 45days, a leaf area of (232.5 cm^2) after 25 days, and total dry weight of (12.5g) after 45 days when compared to the other treatments. The LC (9.52kg/acre) application had significantly greater total N at 4.28% at 25 days aafter transplanting. Also, LC, fish and control treatments contained similar levels of P (6.98, 6.87 and 6.64 mg/g respectively) after 45 days from transplanting but differ when compared to 25 and 35 days. There were no significant differences in potassium (K) levels among compost treatments and the control treatment of leaves of red leaf lettuce. On the other hand, at the LC and HC concentrations of CSU's compost there was a significant increase in K concentration from 25 and 45 DTA. The lettuce grown under HC (36.48 Kg/acre) had a significant increase in the Sodium (Na) level at 25 and 35 DTA (6.45 and 4.45 mg/g) when compared to the control (3.63 and3.24 mg/g) respectively. The HC (36.48Kg/acre) had a significant reduction in Mg, Fe, and Al concentration at 35 days DTA when compared to the control (C) (3.14, 0.05, 0.62 mg/g respectively). There were a few differences in the minor elements when treatments were compared as follows: calcium was significantly lower in the HC (8.81mg/g) after 35 days when compared to control treatment; there was a significant increase in zinc (0.05 mg/g) after 35 days of transplanting when compared to the control as well. There were no significant differences among the CSU compost treatments and control treatments for Nitrate concentration and manganese.

Colorado State University compost may be used as a nutrient source for red leaf lettuce production. However, high rates of application of the compost may be a problem as it contains high salt levels. Leaching of the salts is recommend when high levels of the compost is used.

ACKNOWLEDGMENTS

There are many people I would like to thanks for their support and encouragement. I would like to express my sincere appreciation and deep gratitude to my advisor Professor Harrison Hughes for his guidance, encouragement, suggestions, and continued interest in the completion of this research. I would also like to thank Adriane Elliott for many helpful suggestions and discussions which gave me great encouragement. She has also taught me many things about compost that cannot be learned in a classroom or a book. I would also like to thank Professor Mohamed Shahba for his excellent guidance and useful comments in this research. Thanks are also due to Gary Gross for his help in the initiation of the research and in the management of the high tunnels at the Horticulture Field Research Center.

I am also indebted to Mohammed Albaqami for his friendship, positive encouragement, unlimited assistance and immeasurable support.

Sincere appreciation and deep gratitude is due my parents, brothers and sisters for their love, patience and continuous support. Also, I would like to express my thankfulness and gratefulness to my close friends.

Finally, I would like sincerely to thank Al Qassim University in the Kingdom of Saudi Arabia for their financial support to finish my M.S degree at Colorado State University.

DEDICATION

This research is dedicated to the soul of my father (God's mercy upon him), who passed away in November 2012 while doing this research and didn't share me these moments.

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INTRODUCTION

Nutrient availability is critical in efficient agriculture production systems. Conventional agriculture uses chemical fertilizers which have several possible negative side effects. These are often associated with soil degradation and depletion as well as water and soil pollution. (Grubinger, 1999) noted that chemical fertilizers are made up of minerals which dissolve rapidly in damp soil resulting in rapid availability of large doses of minerals to the plants. Furthermore, excessive use of urea fertilizer which contains nitrogen (N) may lead to soil and groundwater contamination further affecting the environment. Inorganic fertilizers have been reported to lead to leaching and contamination of groundwater, crop reduction and imbalance of soil nutrients (Sridhar, 2003) (Ayoola & Adeniyan, 2006). Several chemical fertilizers also have high acid content such as hydrochloric acid and sulfuric acid which influence diazotroph destruction thereby affecting the nitrogen fixation processes (http://www.ecochem.com). Chemical fertilizers contain macro-nutrients such as nitrogen, phosphorus and potassium which may be released quickly in the soil resulting in excess supplementation for plant growth (Inckel, de Smet, Tersmette, & Veldkamp, 2005). The long term effects of chemical fertilizers exposes the soil to exhaustion and degradation if organic matter is not added and secondly the pH of the soil may be negatively influenced by the chemical composition of the fertilizer (Inckel et al., 2005). Chemical fertilizers have the ability to improve soil fertility in the short run but may not lead to soil building that encourages soil sustainability.

Modern research has identified alternative agricultural methods that lead to good yields and enhanced soil fertility without using chemical components. Organic agriculture is one of the agricultural forms that often depend on using green manure, compost, and biological pest management. In other words, organic agriculture is the right management of the ecosystem by eliminating the use of pesticides, chemical fertilizers, genetically modified seeds, and preservatives (FAO). Notably, the number of consumers of organic products has increased as a result of their awareness of side effects from using synthetic chemical components in agriculture (Thybo, Edelenbos, Christensen, Sørensen, & Thorup-Kristensen, 2006). Therefore, agricultural researchers have a need to improve organic agriculture methods in order to supply organic food for consumers.

Organic fertilizers are made from animal and plant materials, including manure, worm castings, peat, seaweed, and humic acid to name a few. Using organic fertilizers has been found to improve soil structure, microbial biomass and may lead to increased agriculture output (Sarker, Kashem, & Osman, 2012). In addition, some organic fertilizer have high nutritional elements that enhance plant growth and yields, while organic fertilizers may often be less expensive when compared to chemical fertilizers (Mantovi, Baldoni, & Toderi, 2005). According to (Pascual, Garcia, Hernandez, & Ayuso, 1997) and (Allen & Zink, 1998), soil organic matter is an essential source of nutrients in order to maintain high microbial populations and activities in the soil. This in turn increases biomass for efficient basal respiration as well as improves total organic ratio in the soil. Animal manures, yard wastes, food wastes and compost are organic resources that are used to provide nutrients for plant growth and yield as well as maintain the fertility of the soil (Arancon & Edwards, 2005). Furthermore, hay residue and animal manure applications may lead to high crop production rates (Johnston, Janzen, & Smith, 1995).

Organic soil amendments are an alternative way to improve soil fertility and increase crop yield. One of the common materials used for organic soil amending is compost. It’s a method that allows for organic matter recycling and reuse as a fertilizer and a soil amendment. Composting is one of the best solutions to reduce the huge piles of organic wastes and convert it to a soil amendment with nutrient value. The feed stocks for compost are often farm waste such as crops residues and animal manure, therefore, compost may have a very low cost. Since the compost has essential nutrients for plant growth and the main input is the farmer's labour, compost is an appropriate method for organic agriculture (Mantovi et al., 2005) (H. A. Hoitink, M.J. Boehm and Y. Hadar, 1993). In addition to its nutrient value, compost is a foundation of soil fertility in organic farms. The National Organic Program defines compost as *"The product of a managed process through which microorganisms break down plant and animal materials into more available forms suitable for application to the soil. Compost must be produced through a process that combines plant and animal materials with an initial Carbon: Nitrogen ratio of between 25:1 and 40:1. Producers using an in-vessel or static aerated pile system must maintain the composting materials at a temperature between 131 F^0 and 170 F^0 for 3 days. Producers using a windrow system must maintain the composting materials at a temperature between 131 F^0 and 170 F^0 for 15 days, during which time, the materials must be turned a minimum of five times"* (USDA, 2002). In other words, compost is a biological process that controls decomposition of organic materials by microorganisms. Any type of organic material can be used for compost such as kitchen waste, crop residues and animal manure.

Increasing the organic materials in the soil through the addition of compost results in several benefits in an agriculture system. Organic fertilizer improves soil fertility and increases tilth of the soil, which facilitates plant growth. This may increase crop yield and has a positive affect on soil structure. (Bevacqua & Mellano, 1993) studied the effects of soil amendments by adding compost. They found that organic material, major nutrients, and soluble salts were increased in the soil. Furthermore, they found that the treated soil had a lower pH than the untreated soil. In terms of production improvements; (Bryan & Lance, 1991) reported that under compost-amended conditions, the growth and yields of tomatoes improved, suggesting the positive role of organic fertilizer for plant growth and crop production. In addition, comparative studies on yield of compost-amended soil showed increasing fruit yields in response to addition of compost to the soil (Maynard, 1993). Moreover, growing plants with compost-amended soils result in an increase of fresh and dry plant matter along with oil percentage of marjoram plants as compared to plants that received chemical fertilizer (Edris, Shalaby, & Fadel, 2003). These studies are an indication of the importance of compost in organic agriculture, and demonstrate a benefit to crop yields without using synthetic fertilizers.

A report of USDA/ERS, 2008 (http://www.ers.usda.gov/Data/Organic/) mentioned that Colorado was the third largest organic producer in the US. Colorado State University (CSU) has a composting program that produces compost from resident hall dining center food waste. This program aims to minimize landfill inputs and keep appropriate nutrients in the landscape, gardens and flower beds around the campus. The compost bin is located at the Foothills Campus and every day is supplied with 2,000 pounds of material from the campus. CSU compost consists of food waste from CSU dining centers mixed with bulking material such as wood chips, straw and horse manure from the Foothills campus. The approximate food to manure/straw ratio is 1:2. CSU's composting system is the Earth Flow system developed by Green Mountain Technology which is fully enclosed to provide control over moisture, odor, varmin, and leachate (Fig1). The system has a 30 cubic yard volume capacity. The Earth Flow system is capable of composting materials in approximately 21 days. The composted material is piled on site in windrows to cure for at least 3-4 weeks before being used as a soil amendment. During the curing phase compost samples are taken and the temperature is recorded to make sure that the compost is mature and managed by the specifications and standards for use in organic systems. In 2011, CSU's composting program produced about 418 tons of compost. In 2013 the CSU compost program diverted around 191,011 pounds of food waste from the landfills which was more than what was diverted in 2012 (95,000 pounds (Housing and Dining Services at CSU, www.colostate.edu). The usage of CSU's compost is limited to campus applications. There have been no studies conducted to test the efficiency of CSU's compost on crop production. Therefore, this study was designed to investigate CSU compost for crop production. At the same time, it is of interest to examine the effect of CSU'S compost on the overall yield.

Figure 1: Earth Flow compost system at the Foothills Campus in Fort Collins which has diverted approximately191, 011 pounds of food waste from the landfill in 2013.

The goals of this study are as follow:

- Test if CSU's compost is suitable for organic crop production.
- Test if CSU's compost is efficient for high quality organic crop production or not.
- Evaluate the effect of CSU's compost on lettuce primary elements (NPK) as well as micronutrients in lettuce leaves.

MATERIAL AND METHOD

Experimental design:

The experiment was set up in a randomized complete block design with four treatments and three replications with 'New Red Fire' lettuce (*Lactuca sativa*). Four fertility levels were used during spring 2014 in high tunnels at the Horticulture Field Research Center (HORT Farm) at Colorado State University in Fort Collins, Colorado to investigate the efficiency of CSU's compost use as a source of nutrients for red leaf lettuce production. The high tunnel was 15.24× 6.096 m and was covered with a single layer of plastic. The top of the door was open on both sides for ventilation and side walls were rolled up throughout the summer. The high tunnels were tilled with a rototiller (Fig2 to a depth of 15 cm. The overall growing area was divided into 12 plots which consisted of four treatments with 3 replications (Fig3). There were 2 walkways between the plots which were 0.508 m and covered by plastic (Fig4). Each treatment contained 48 plants (total 576). Plots were 3.35 m long with 1.52 m width and contained 5 rows and were spaced 0.25 m in the row and 0.30 m between plants. The experiment was irrigated with a micro sprinkler system every two days (Fig5).

Figure 2: High Tunnel growing area was tilled to a depth of 15 cm.

Figure 3: Layout of the experiment with plots and walk ways identified by flags in the high tunnel.

Figure 4: Walkways covered with plastic which facilitated separation of plots and treatments.

Figure 5: The experiment was irrigated by a micro sprinkler system.

Organic Fertilization:

Soil samples were analyzed at the Soil, Water and Plant Testing Laboratory at Colorado State University for macronutrient and micronutrient and the results tabulated in Table(1). The soil was a sandy clay which served as the control (C) treatment which had no additional nutrients added. There was a high compost (HC) level applied which was tilled into the soil; each replication contained 36.48 kg/acre of Colorado State University's compost (CSUC). The low compost (LC) was applied at 9.52kg/acre of CSUC (Fig 6) per replication. The fourth treatment was a fish derived fertilizer (F) from Alaska Fish Fertilizer (5-1-1) applied at the rate of 41.2 ml/7.6 liters once per week for 4 weeks for each replication.

Planting and Sampling:

'New Red Fire' lettuce cultivar (*Lactuca sativa*) from (Johnny's Selected Seeds) was selected for this experiment. The seeding was done on 31 March 2014 in the greenhouses at the Plant Environmental Research Center (PERC), Fort Collins, CO. Seeds were sown singly in cell plug trays filled with organic seed starter media (Espoma) which were held at (70^0 F) 21.1^0C (Fig7) and watered by a micro sprinkler system. After 20 days, the seedlings were transplanted into the high tunnel on 21April, (Fig8). The lettuce seedlings were planted after 5 days post application of compost at the equivalent of 36.48 kg/acre of HC and 9.52kg/acre for LC (Fig9). Plant samples were taken 25 days after transplanting and repeated twice at 10 day intervals. Samples consisted of five plants randomly selected per treatment per replication. There was a total of 15 plants per treatment replication combination for a total of 60 plants.

Table 1: Soil chemical properties of the high tunnel soil as determined by the CSU Soil, Water and Plant testing laboratory.

Paste		**Lime Estemate**	**% OM**	**AB-DTPA (ppm)**						
PH	**EC mmhos/cm**			**NO3-N**	**P**	**K**	**Zn**	**Fe**	**Mn**	**Cu**
7.8	0.8	Very High	1.8	21.8	25	433	4.6	8.2	3.5	4.1

Figure 6: The high tunnel area was divided into 3 replications with each containing 4 treatments of High Compost (HC), Low Compost (LC), Fish (F) and Control (C) or no additional amendment.

Figure 7: The seeding of ‘Red Fire’ leaf lettuce was on 31 March 2014 at the Plant Environmental Research Center (PERC), Fort Collins, CO. Seeds were sown singly into cell plug trays filled with organic seed starter media (Espoma) and held at 70^0F (21.1^0C).

Figure 8: Seedlings as illustrated here were transplanted into the high tunnel after 20 days.

Figure 9: Relative amounts of compost applied at the high compost (HC) rate of 36.48kg/acre on the left and low compost (LC) rate at 9.52 kg/acre obtained from the Colorado State University compost system.

Measurements:

The leaf samples were taken after 25 days of growth in the high tunnel and every 10 days until termination of the experiment. Five plants were randomly chosen from each treatment in each rep to be measured and analyzed. The vegetative parameters were photosynthesis, number of leaves, and leaf area as described by (Arancon & Edwards, 2005). The number of leaves and plant height were measured in the high tunnel before harvesting the samples. After harvesting, the samples were packed in plastic bags and kept on ice for transport to PERC to complete other measurements. Fresh weight was determined after harvesting for all samples. Leaf area (LA cm^2) was determined by using the LI-3100C Portable Leaf Area Meter at harvest (Fig10). Dry weight was determined after drying in a forced air oven at 70^0 C for 2 days for all samples.

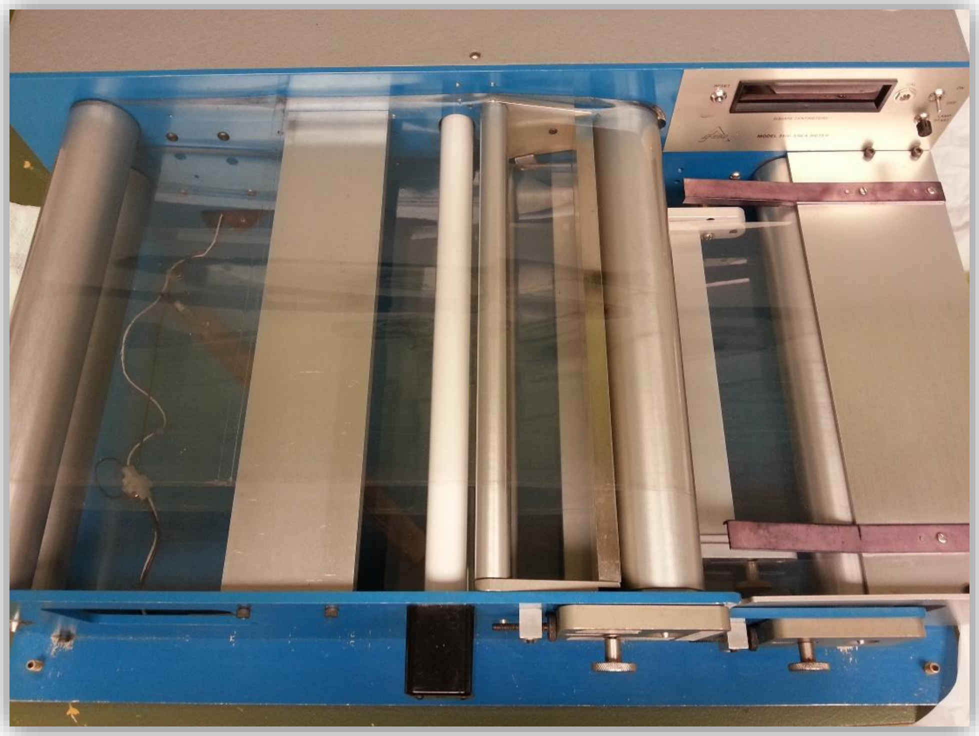

Figure 9: The LI-3100C Portable Leaf Area Meter used to measure lettuce leaf area of samples.

Statistical analysis:

The study was carried out with a randomized complete block design with four treatments and three replicates resulting in 12 experimental units. JMP software program (2014) (http://www.jmp.com) was executed and statistical significance was determined using analysis of variance followed by Student's t test for mean comparison $P<0.05$.

Chemical analyses of soil and plant samples:

Soil nitrate and ammonium were determined by using a 2N potassium chloride extract (Bremner & Keeney, 1966) while phosphorus was determined using Olsen's sodium bicarbonate test (R.Olsen, 1954). Potassium was extracted using NH4OAc-EDTA (Homer Dwight Chapman & Kelley, 1930). All results of the soil analysis are tabulated and appear in Table1. Also, the chemical properties of the CSUC were analyzed and are noted in Table2.

Plant tissue samples were packed in paper bags for drying in the forced air oven at 70^0 C for 48 h. The 5 samples for each treatment and replication combination were ground in a blender and mixed prior to storage in plastic bags for chemical analysis. For chemical analysis, the samples were digested by using the wet digestion method via 1 ml of concentrated nitric acid added to 100 mg of dried samples in a glass tube. All tubes were covered with small glass funnels to retard water evaporation. All glass tubes were placed in a block heater overnight. 10 ml of water was added to each sample and they were stored in a falcon tube at -4^0C. The samples were then subjected to ICP (Inductively Coupled Plasma) analysis as described by (Albaqami, 2013). Nitrogen, phosphorous and potassium in the acid digested solution were determined by using Kjeldahl method for N, a spectrophotometer for P (colorimetric method) and a flame photometer for K (Homer D Chapman & Pratt, 1962).

Table 2: Chemical properties of the Colorado State University Compost as determined by the CSU Soil, Water and Plant testing Laboratory. (Nutrients Level are as follows: Low. Medium.. High…Very High….).

Parameter	As Received Basis	lbs/ton	Dry Matter Basis	lbs/ton	method*	Level
Total Solids (%)	35.7		100		03.09-A	…
Moisture (%)	64.3		0		03.09-A	…
Organic Matter (%)	21.5		60.1		05.07-A	….
Ash (%)	14.2		39.9		05.07-A	…
Soluble Salts (1:5, mmhos/cm)	3.5				04-10-A	….
Soluble salts (paste, mmhos/cm)	6.8					….
pH 1:5	9.1				04-11-A	….
pH (paste)	8.3					…
Total Nitrogen (%)	0.5300	10.6	1.485	29.7	04.02-D	…
Organic Nitrogen (%)	0.5188	10.4	1.453	29.1	Calc	…
Ammonium-Nitrogen (%)	0.0019		0.0053		04.02-C	…
Ammonium-Nitrogen (ppm)	19.0		53.2		04.02-C	…
Nitrate-Nitrogen (%)	0.0093		0.0260		04.02-B	….
Nitrate-Nitrogen (ppm)	92.7		259.7		04.02-B	….
Total Phosphorus as P (%)	0.1784	3.6	0.500	10.0	04.03-A	….
Total Phosphorus as P2O5 (%)	0.4085	8.2	1.144	22.9	04.03-A	….
Total Potassium as K (%)	0.6885	13.8	1.9286	38.6	04.04-A	….
Total Potassium as K2O (%)	0.8262	16.5	2.3143	46.3	04.04-A	….
C/N ratio	22.8		22.8		Calc	….
Ammonium-N/Nitrate-N Ratio	0.20		0.20		Calc	.
Lime (% calcium carbonate)	4.73		13.25		6E1c**	….
Sodium Adsorption Ratio (SAR)	3.7		3.7		10-3.4***	..
Plant available phosphorus (ppm)	108		303		AB-DTPA	….
Plant available potassium (ppm)	4520		12661		AB-DTPA	….
Plant available zinc (ppm)	7.1		19.9		AB-DTPA	…
Plant available iron (ppm)	47.3		132.5		AB-DTPA	…
Plant available manganese (ppm)	6.4		17.9		AB-DTPA	…
Plant available copper (ppm)	2.1		5.9		AB-DTPA	…
total zinc (ppm)	31.7		88.8		3050/6010	…
total iron (ppm)	2548		7137		3050/6010	….
total manganese (ppm)	86.1		241		3050/6010	…
total copper (ppm)	13.0		36.4		3050/6010	…

RESULTS

Plant Height:

There was no significant differences observed when the control treatment was compared to both compost levels ($P \leq 0.05$) for mean plant height after 25, 35 and 45 DAT. Plant height (14.993 cm) was significantly higher with the fish fertilizer (F) when compared to the control (13.19 cm) and low compost (LC) (13.50 cm) treatment at only 35 DAT (Fig11).

Leaf Number:

The LC treatment and F treatments had significantly higher mean leaf number (18.06) and (17.86) respectively when compared to the control treatments (15.86) at only 45 DAT. There were no other significant difference among treatments at any other sampling time (Fig12).

Fresh Weight:

A significant difference in fresh weight was only observed in the LC treatment (269.86) at 45 DAT when compared to the other 3 treatments with 236.12, and 227.02 and 198.69g for HC, F and Control treatments (Fig13).

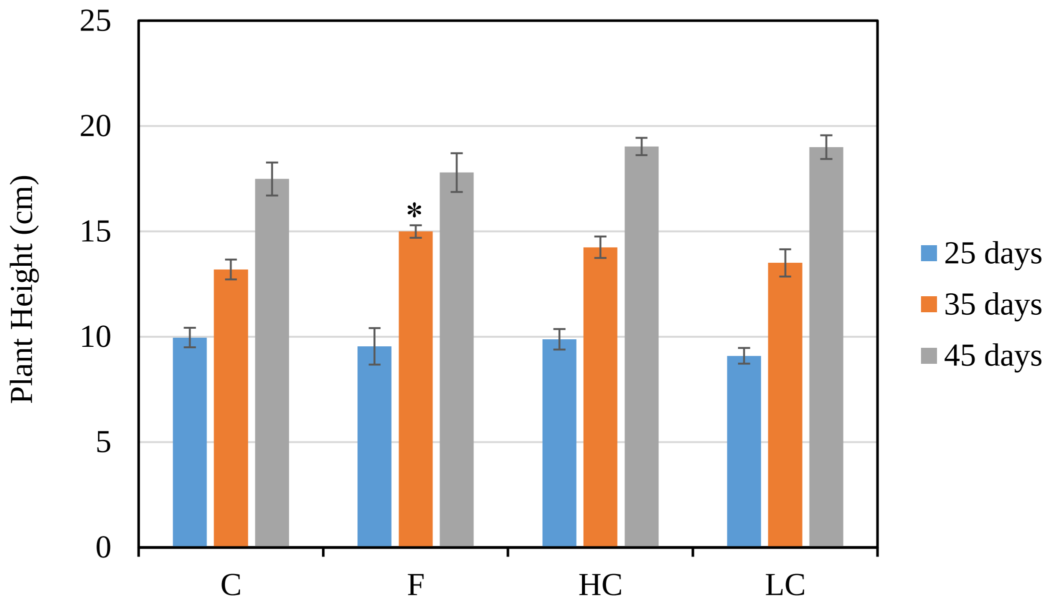

Figure 11*:* Relative plant height from 4 treatments (control, C, with no additional soil amendments; Alaska fish fertilizer at 5-1-1, F; high compost, HC; and low compost, LC), at 3 times after transplanting. Statistical analysis was conducted using JMP software, comparisons for each pair was made using Student's t with P-Value ≤ 0.05. (*) indicates the significant different.

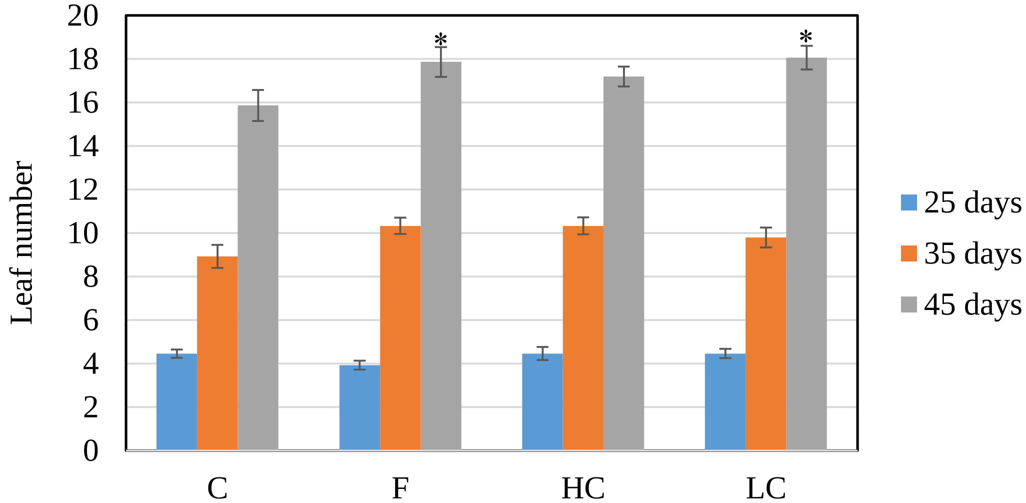

Figure 12: Average lettuce leaf number observed with treatments (control, C, with no additional soil amendments; Alaska fish fertilizer at 5-1-1, F; high compost, HC; and low compost, LC, at 3 times after transplanting. Statistical analysis was conducted using JMP software with comparisons for each pair using Student's t with P-Value ≤ 0.05, (*) indicates significant different.

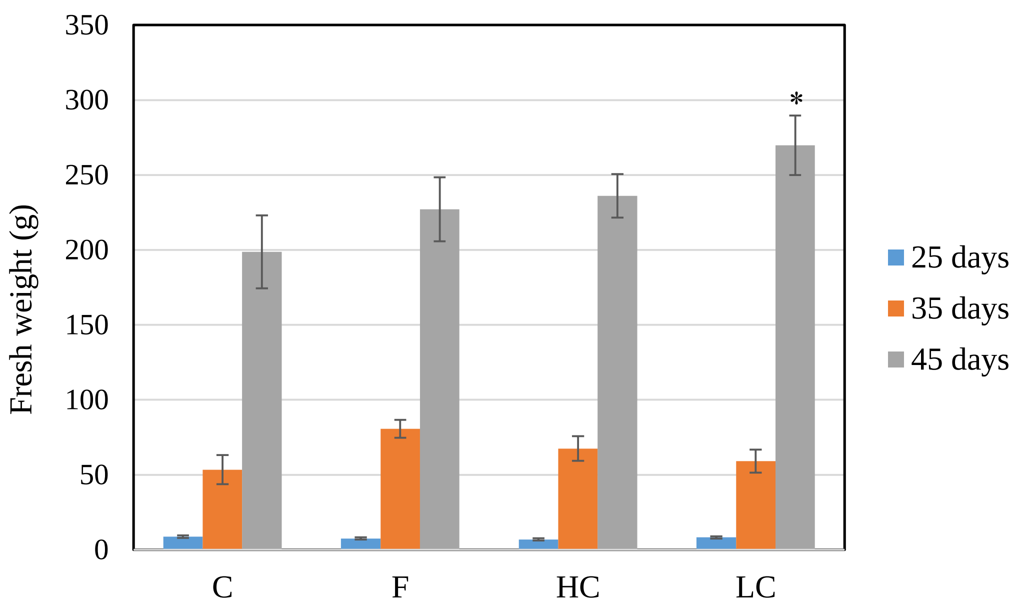

Figure 13: Average fresh weight of red leaf lettuce harvested at 3 times after transplanting from 4 treatments (control, C, with no additional soil amendments; Alaska fish fertilizer at 5-1-1, F; high compost, HC; and low compost, LC) at 3 times after transplanting. The measurement and statistical analysis was conducted using JMP software with comparisons of each pair using Student's t with P-Value ≤ 0.05 and (*) indicates significant different.

Dry Weight:

Differences in dry weight were observed at 35 DAT when dry weights with F was 4.85 g as compared to C with 3.1 g and LC with 3.4 g. HC showed no differences in dry weight with any of the other treatments. At 45 DAT the LC treatment with 12.5g was significantly greater than the control at 9.32g and the F at 10.2g. There were no significant differences between the LC and HC treatments (Fig14).

Leaf Area:

The only significant difference observed in mean leaf area was the LC with a leaf area of 232.5 cm^2 which was significantly greater than the HC which was 187.05 cm^2 at 25 DAT. There were no other significant differences among treatments at 35 and 45 DAT (Fig15).

Photosynthesis:

No significant differences were observed among the treatments for mean photosynthesis at 45 DAT (Fig16).

Nutrients:

Oven dried leaves were ground and analyzed for relative chemical elements. The LC had a significantly greater total Nitrogen (N) of 4.8% at 25 DAT when compared to the control with 3.89%. Also, F treatment was significantly greater at 35 DTA when compared to all others (Fig17).

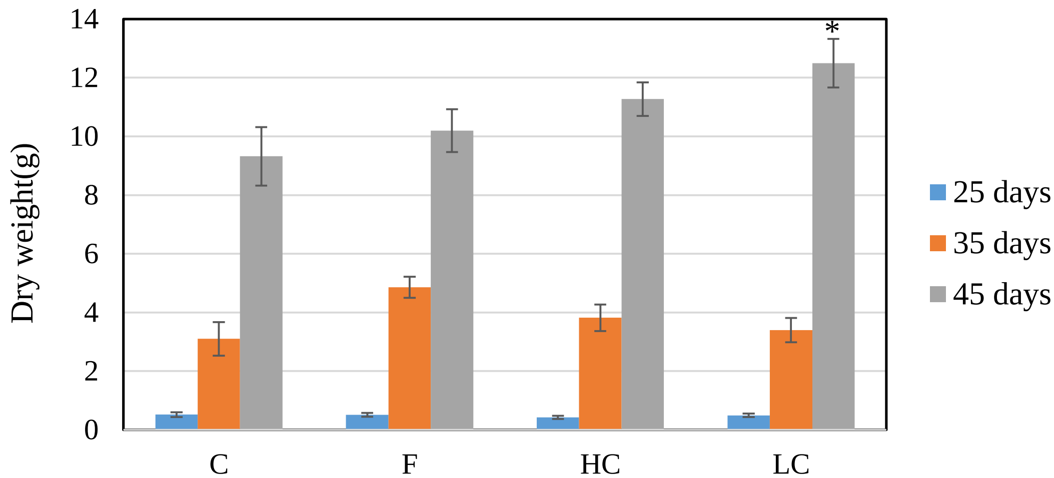

Figure 14: Average weighs of oven dried red leaf lettuce for 2 days at 70o C. Treatments were control, C, with no additional soil amendments; Alaska fish fertilizer at 5-1-1, F; high compost, HC; and low compost, LC, with samples taken at 3 times after transplanting Statistical analysis was conducted using JMP software with comparisons for each pair using Student's t with P-Value ≤ 0.05, (*) indicates significant different.

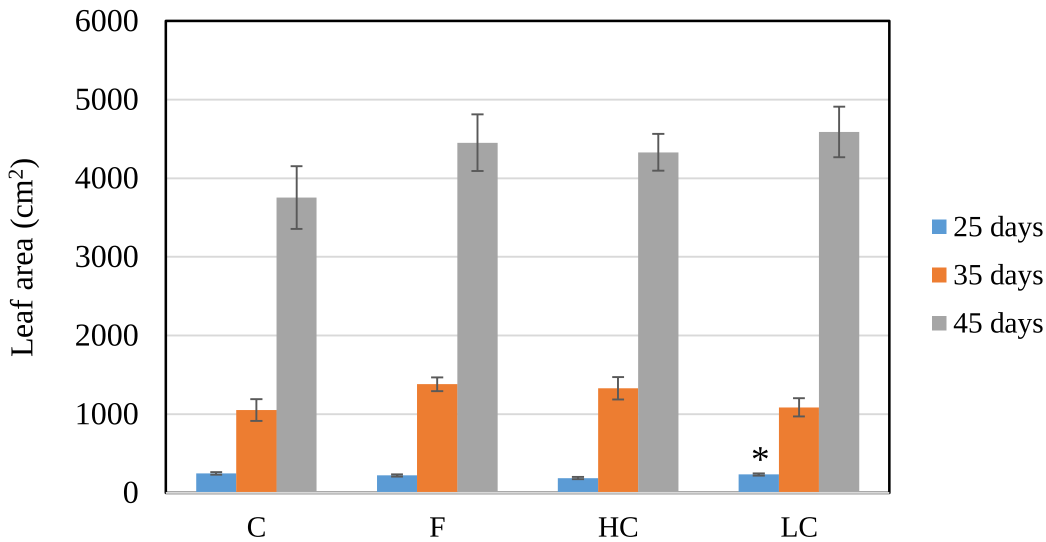

Figure 15: Average leaf area of red leaf lettuce harvested from 4 treatments (control, C, with no additional soil amendments; Alaska fish fertilizer at 5-1-1, F; high compost, HC; and low compost, LC) with samples taken at 3 times after transplanting The LI-3100C Portable Leaf Area Meter was used to measure leaf area. The low concentration of CSU's compost enhanced the leaves area of 25 days old plants. Statistical analysis was conducted using JMP software as before, comparisons for each pair using Student's t with P-Value ≤ 0.05, (*) indicates the significant different.

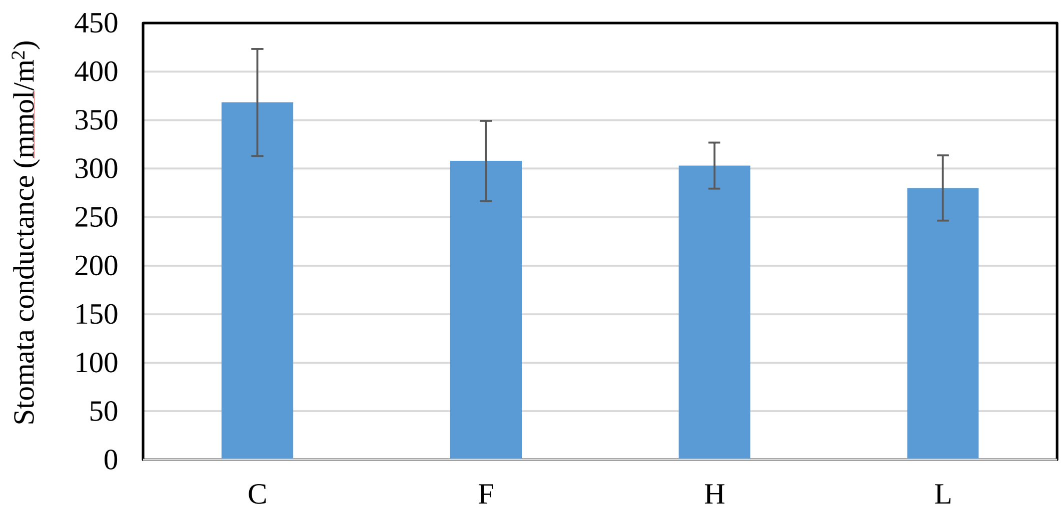

Figure 16: Average relative stomata conductance measured at 45 DAT of plants grown with 4 treatments of control, C, with no additional soil amendments; Alaska fish fertilizer at 5-1-1, F; high compost, HC; and low compost, LC, Statistical analysis was conducted using JMP software with comparisons for each pair using Student's t with P-Value ≤ 0.05.

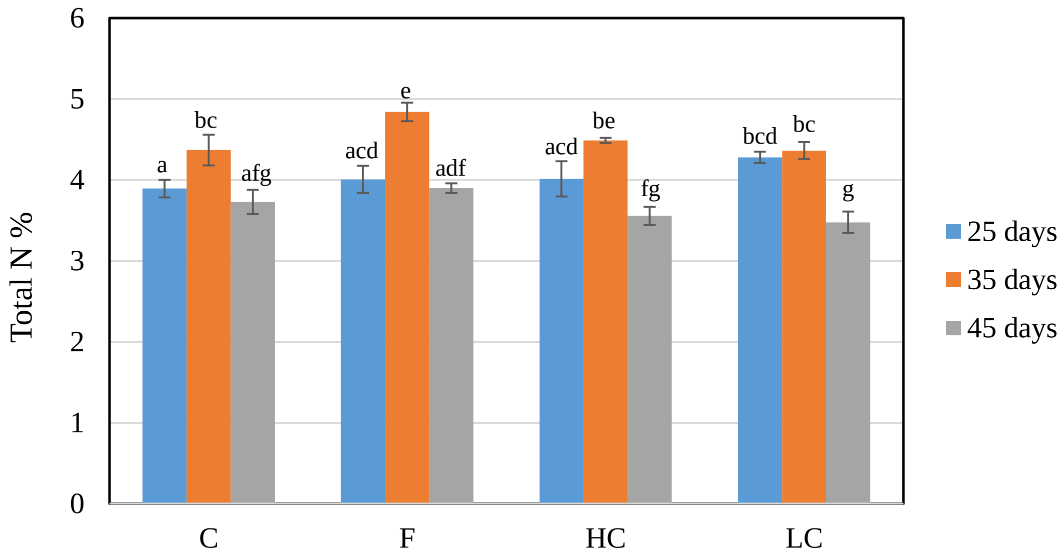

Figure 17: Relative total percent of Nitrogen (N) of red leaf lettuce grown under 4 treatments (control, C, with no additional soil amendments; Alaska fish fertilizer at 5-1-1, F; high compost, HC; and low compost, LC) and harvested at 3 times after transplanting. Plant tissue was harvested, oven dried at 70^{0}C for 48 hours then ground and analyzed for total N. Statistical analysis was conducted using JMP software and bars with different letters denote significant differences according to Student's t with p-value ≤ 0.05.

However, Phosphorus (P) rates significantly increased after 45 DAT in the LC, F and control (6.98, 6.87 and 6.64 mg/g) compared to a HC treatments (Fig 18). The level of Potassium (K) was not significantly different among all treatments during the 3 sampling times. On the other hand, LC, HC, and the control treatments resulted in significant increases in K from 25 to 45 days (Fig 19) when compared to F. Moreover, the Sodium (Na) rates under HC had significantly higher levels at 25 and 35 DAT (6.45, 4.45 mg/g) when compared to the control (3.63, 3.24 mg/g, Fig 20) but not at 45 days. Magnesium (Mg) levels among all treatment and sampling times were similar although under HC there was a significant reduction at 35 DAT (3.14 mg/g) when compared to the control at 3.84 mg/g (Fig 21). No differences were observed in Manganese (Mn) levels in red leaf lettuce (Fig 22). Differences in the level of Iron (Fe) in the lettuce was limited with only a significant decrease to 0.05 mg/g at 35 DAT under HC compost when compared to control 0.09 mg/g (Fig 23). Copper (Cu) levels differed more with HC, LC and F all having significantly lower levels of 0.021, 0.020 and 0.01 mg/g at 25 DAT when compared to the control of 0.43 mg/g (Fig 24). Differences in levels of Zinc (Zn) in lettuce was limited with significance at 35 days of HC with 0.05 mg/g compared to control with 0.04 mg/g. F was significantly lower with 0.03 mg/g compared to HC with 0.04 mg/g at 25 DAT (Fig25).

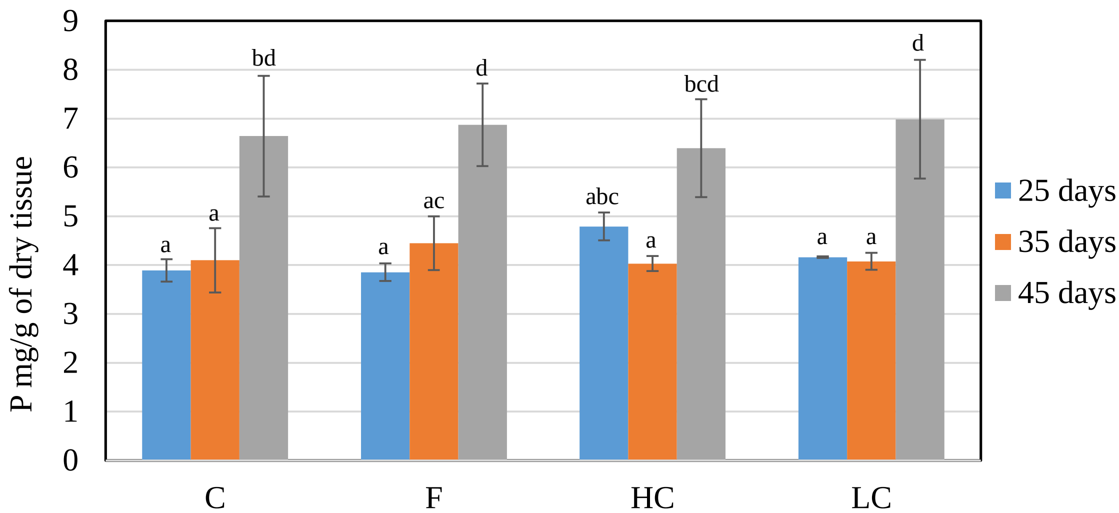

Figure 18: Relative average Phosphorus (P) levels of red leaf lettuce tissue harvested and dried at 3 times from 4 treatments (control, C, with no additional soil amendments; Alaska fish fertilizer at 5-1-1, F; high compost, HC; and low compost, LC). Tissue was oven dried at 70°C for 48 hours and then ground before analysis. Statistical analysis was conducted using JMP software, and bars with different letters denote significant differences according to Student's t with p-value ≤ 0.05.

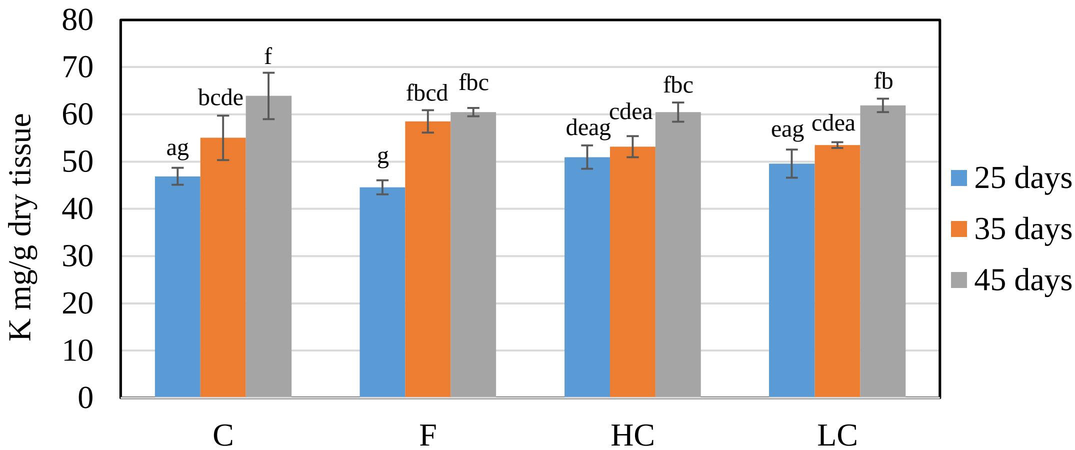

Figure 19: Relative average Potassium (K) concentration in leaf tissue harvested at 3 times from 4 treatments (control, C, with no additional soil amendments; Alaska fish fertilizer at 5-1-1, F; high compost, HC; and low compost, LC). Tissue was oven dried at 70^{o}C for 48 hours and then ground before analysis. Statistical analysis was conducted using JMP software, and bars with different letters denote significant differences according to Student's t with p-value ≤ 0.05.

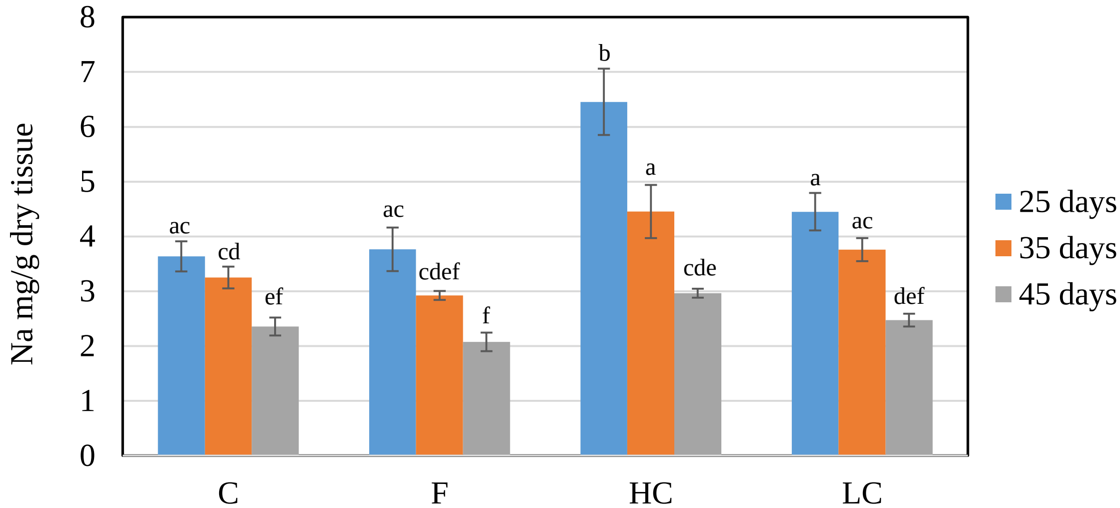

Figure 20: Relative average Sodium (Na) concentration in red leaf lettuce leaves harvested at 3 times from 4 treatments (control, C, with no additional soil amendments; Alaska fish fertilizer at 5-1-1, F; high compost, HC; and low compost, LC). Tissue was oven dried at 70^{o} C for 48 hours and then ground before analysis. Statistical analysis was conducted using JMP software and bars with different letters denote significant differences according to Student's t with p-value ≤ 0.05.

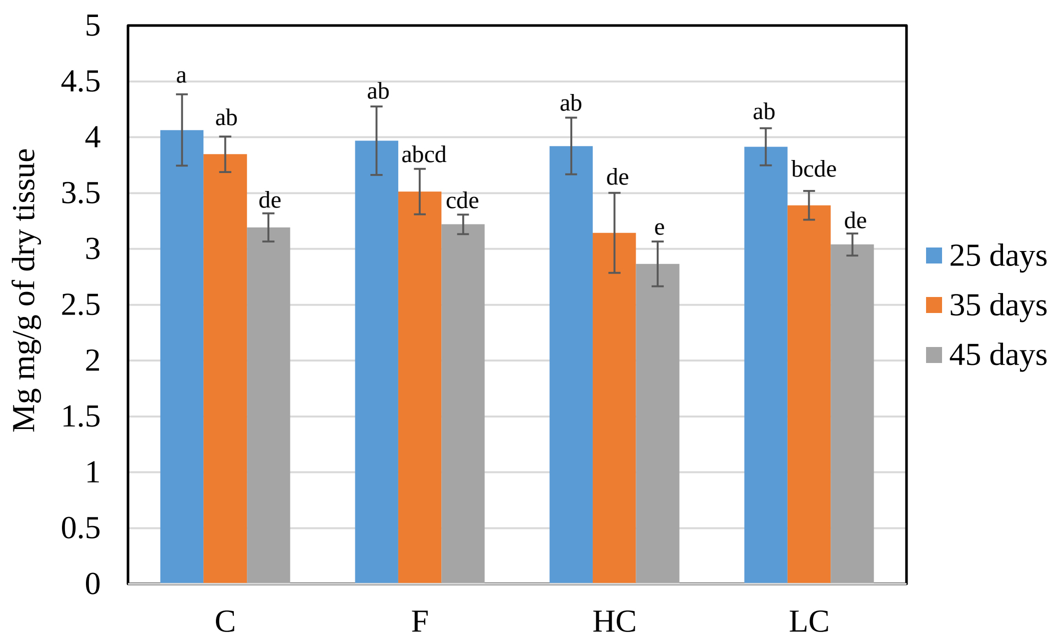

Figure 21: Relative average Magnesium (Mg) concentration of red leaf lettuce leaves harvested at 3 times from 4 treatments (control, C, with no additional soil amendments; Alaska fish fertilizer at 5-1-1, F; high compost, HC; and low compost, LC). Tissue was oven dried at 70^{o} C for 48 hours and then ground before analysis. Statistical analysis was conducted using JMP software, and bars with different letters denote significant differences according to Student's t with p-value ≤ 0.05.

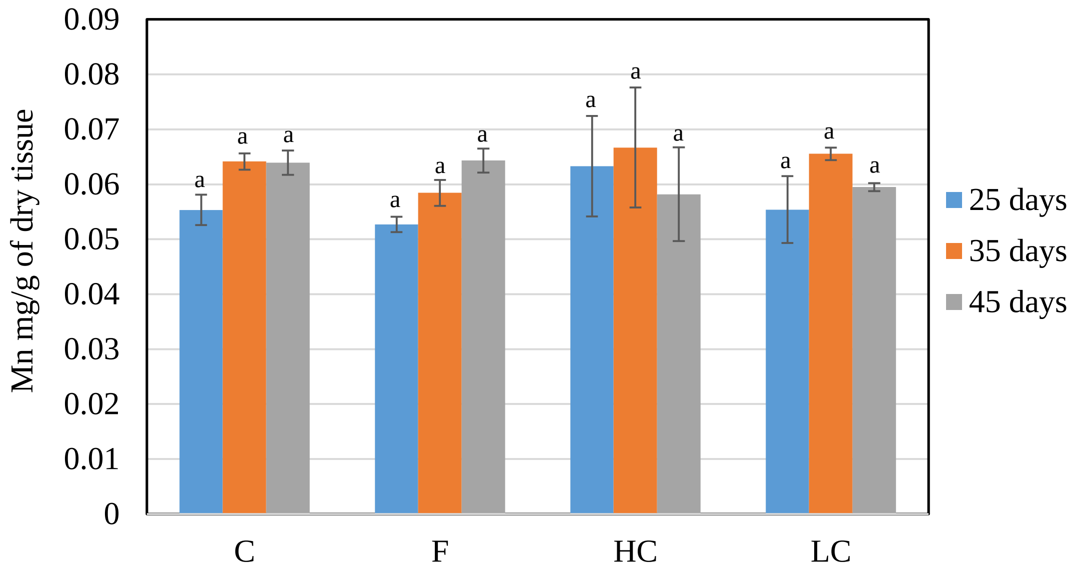

Figure 22: Relative levels of Manganese (Mn) concentration in leaves harvested at 3 times from 4 treatments (control, C, with no additional soil amendments; Alaska fish fertilizer at 5-1-1, F; high compost, HC; and low compost, LC). Tissue was oven dried at 70°C for 48 hours and then ground before analysis. Statistical analysis was conducted using JMP software with comparisons for each pair using Student's t with P-Value ≤ 0.05.

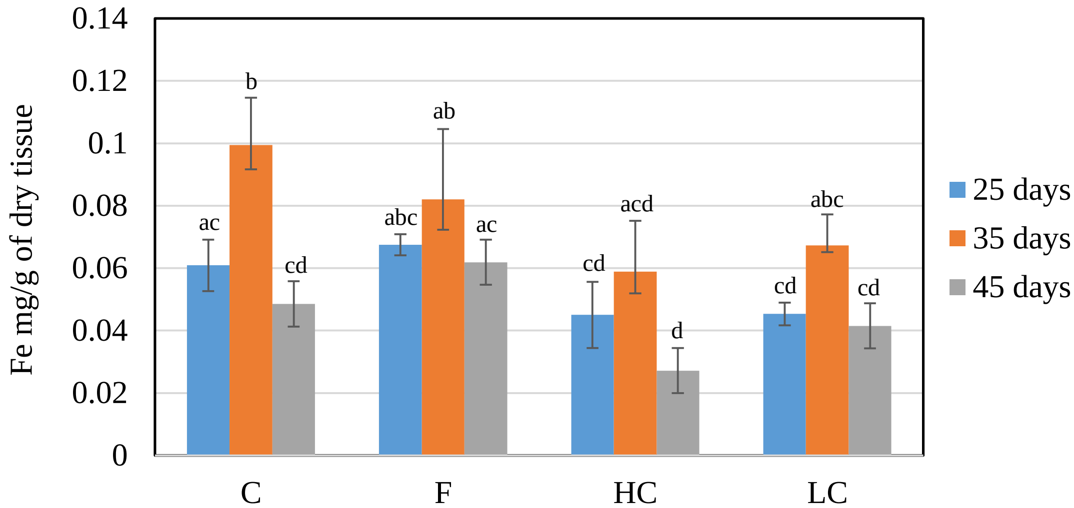

Figure 23: Relative average iron (Fe) concentration in red leaf lettuce leaves harvested at 3 times from 4 treatments (control, C, with no additional soil amendments; Alaska fish fertilizer at 5-1-1, F; high compost, HC; and low compost, LC). Tissue was oven dried at 70°C for 48 hours and then ground before analysis. Statistical analysis was conducted using JMP software, and bars with different letters denote significant differences according to Student's t with p-value ≤ 0.05.

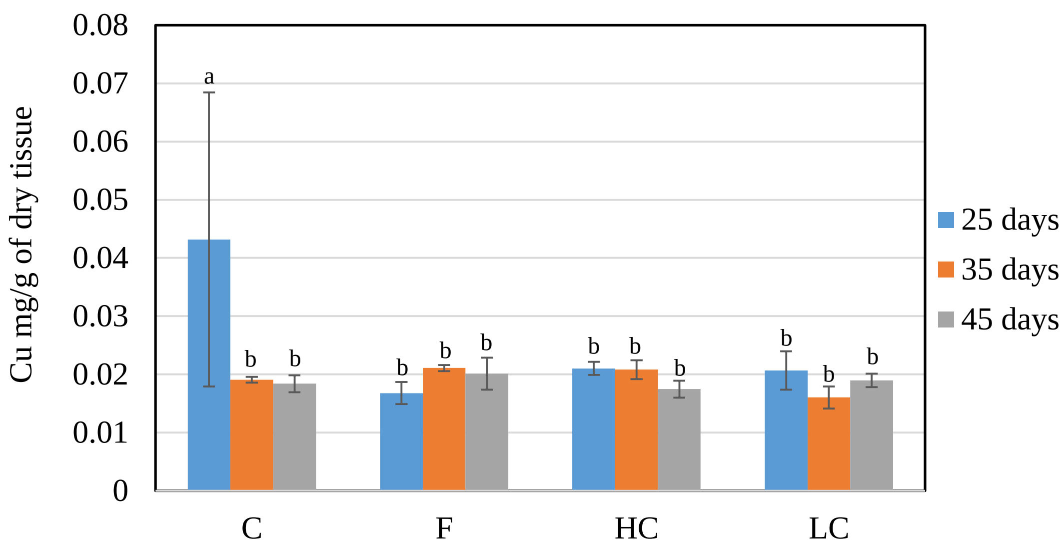

Figure 24: Relative average Copper (Cu) concentrations in red leaf lettuce leaves harvested at 3 times from 4 treatments (control, C, with no additional soil amendments; Alaska fish fertilizer at 5-1-1, F; high compost, HC; and low compost, LC). Tissue was oven dried at 70°C for 48 hours and then ground before analysis. Statistical analysis was conducted using JMP software, and bars with different letters denote significant differences according to Student's t with p-value ≤ 0.05.

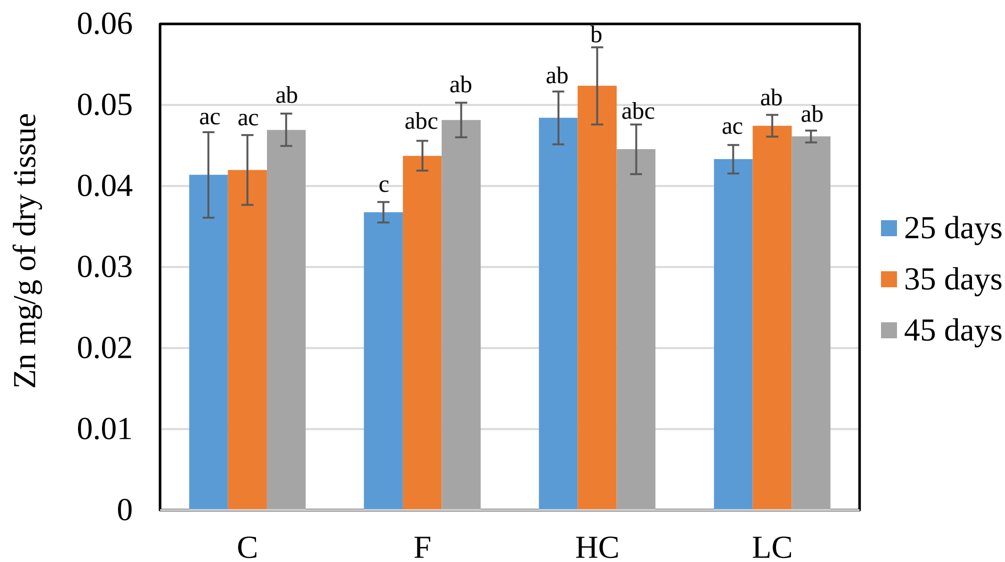

Figure 25: Relative average Zinc (Zn) concentration of red leaf lettuce leaves harvested at 3 times from 4 treatments (control, C, with no additional soil amendments; Alaska fish fertilizer at 5-1-1, F; high compost, HC; and low compost, LC). Tissue was oven dried at 70°C for 48 hours and then ground before analysis. Statistical analysis was conducted using JMP software, and bars with different letters denote significant differences according to Student's t with p-value ≤ 0.05.

The Calcium (Ca) concentration in red leaf lettuce was significantly less only when comparing the HC treatment (8.81mg/g) with the control (10.90mg/g) at 35 DAT (Fig26). Aluminum (Al) levels varied over sampling time but generally decreased although HC resulted in significantly lower levels of 0.62 mg/g when compared to the C (1.11 mg/g) at 35 DAT and with significantly less (0.29 mg/g) when compared to F (0.66 mg/g) at 45 DAT (Fig 27). In general, nitrate concentration was significantly higher at 35 days of sampling for all treatments when compared to the other sampling times with F having the greatest level at 35 days (6189.33 mg/kg) when compared to the control at 35 days and when compared to all other sampling times.

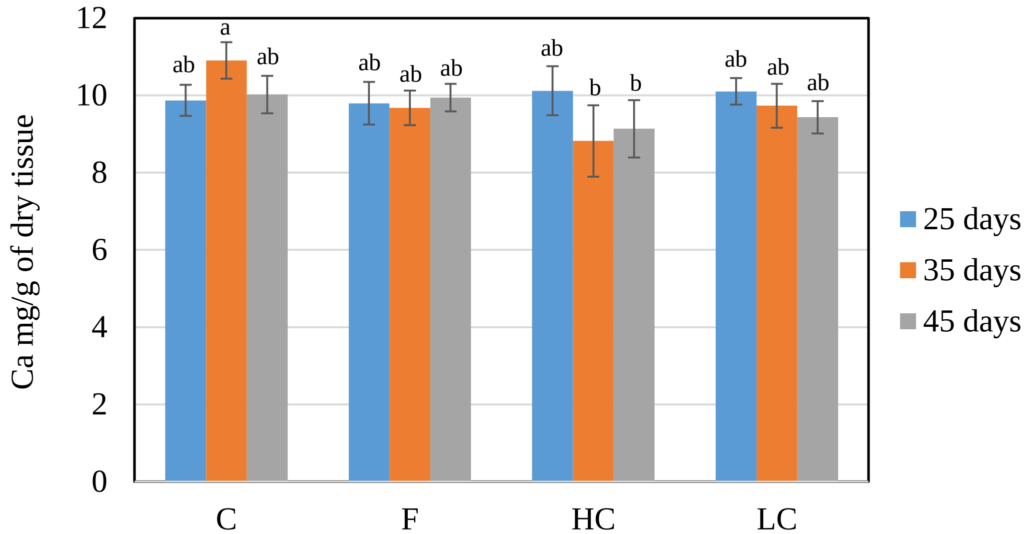

Figure 26: Relative average Calcium (Ca) concentration in red leaf lettuce leaves harvested at 3 times from 4 treatments (control, C, with no additional soil amendments; Alaska fish fertilizer at 5-1-1, F; high compost, HC; and low compost, LC). Tissue was oven dried at 70^{o} C for 48 hours and then ground before analysis. Statistical analysis was conducted using JMP software, and bars with different letters denote significant differences according to Student's t with p-value ≤ 0.05.

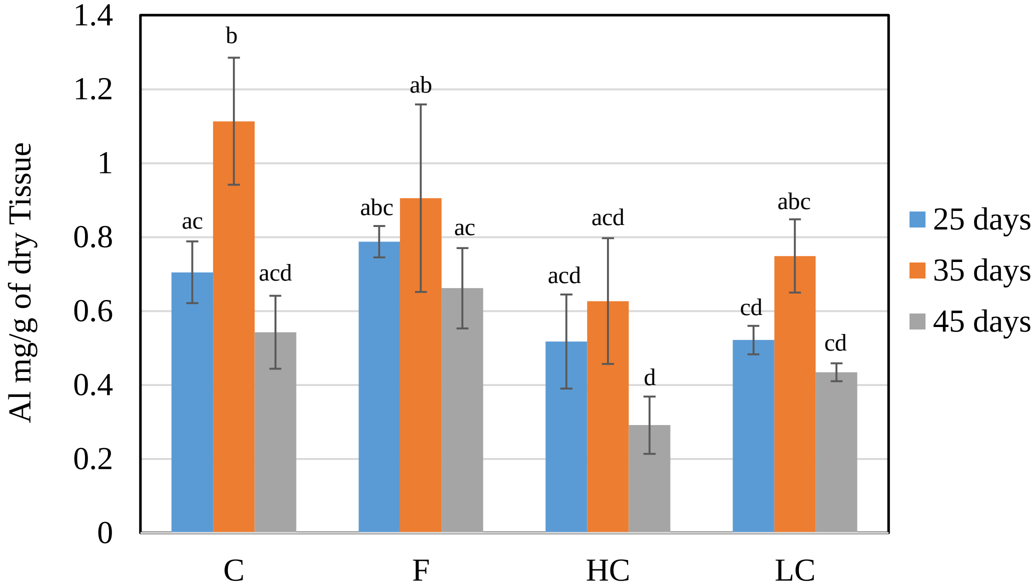

Figure 27: Relative average Aluminum (Al) concentration in red leaf lettuce leaves harvested at 3 times from 4 treatments (control, C, with no additional soil amendments; Alaska fish fertilizer at 5-1-1, F; high compost, HC; and low compost, LC). Tissue was oven dried at 70^{o} C for 48 hours and then ground before analysis. Statistical analysis was conducted using JMP software, and bars with different letters denote significant differences according to Student's t with p-value ≤ 0.05.

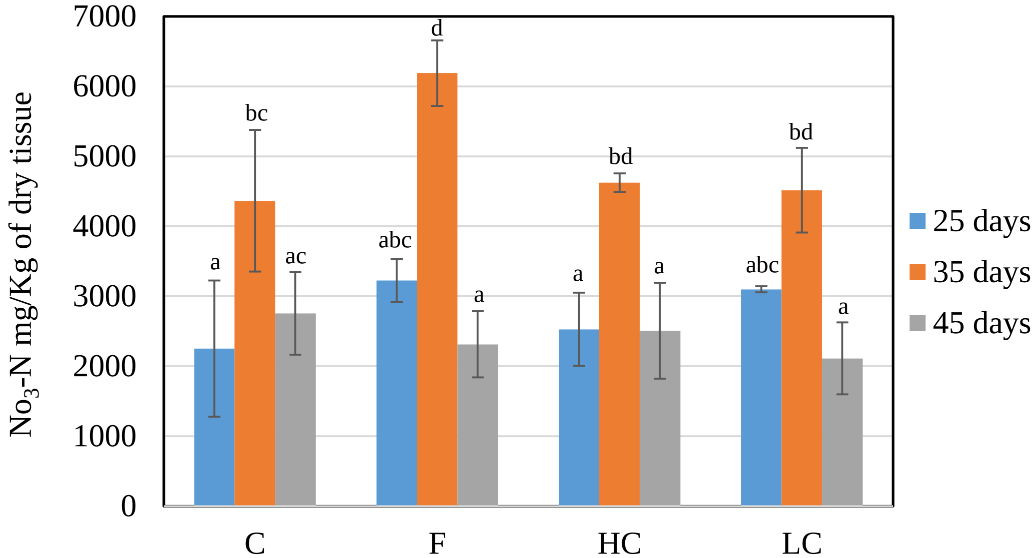

Figure 28: Relative average Nitrate concentration ($NO_3{-}N$) in red leaf lettuce leaves harvested at 3 times from 4 treatments (control, C, with no additional soil amendments; Alaska fish fertilizer at 5-1-1, F; high compost, HC; and low compost, LC). Tissue was oven dried at 70^o C for 48 hours and then ground before analysis. Statistical analysis was conducted using JMP software, and bars with different letters denote significant differences according to Student's t with p-value ≤ 0.05.

DISCUSSION

Adding compost to the soil is helpful to improve the soil structure, soil fertility and increase crop production. Compost is highly enriched with the most important nutrients that are critical for plant growth and development as compare to other growth media (Eghball, 2000). Moreover, compost increases soil organic matter and has less pathogens (H. Hoitink, Stone, & Han, 1997). The goal of this study was to investigate the efficacy of CSU compost as a soil amendment. CSU compost was compared to a positive control (fish emulsion) as well as no additional fertilizer (control). The results indicated that CSU compost is a suitable soil amendment for crop production. However, the CSU compost had some negative effects on some plant growth parameters. This is likely associated with the high soluble salt concentration. The carbon/ nitrogen ration was high as well while total nitrogen was moderate.

Compost is applied to plant growth medium as a source of nitrogen, phosphorus and potassium, as well as micronutrients. It is also used as an amendment to enhance aeration as well as water holding capacity (Brenda Platt, 2014). The CSU's compost analysis showed that the organic matter and the C/N ratio were greater than standard composts which has C/N ratios around 12. This indicated that N may be limited and partially immobilized as it may be found bound in microbial organisms. Total nitrogen was at a moderate level which would likely be a reasonable source of nitrogen when applied to the soil. The soil had moderate N concentration prior to adding any treatments. Nitrate was high and ammonium was low as compared to compost standards for the ratios which is generally less than 4. The ratio indicated that CSU's compost has not reached the end of the composting process where ammonium is converted to nitrate. There was no differences in the plants under either levels of CSU's compost media when compared to the control. However, the fish emulsion fertilizer had a significant increase in height. The fish emulsion does have many essential amino acids, lipids, vitamins, proteins, and a combination of bacteria and plant growth regulators according to (El-Tarabily, Nassar, Hardy, & Sivasithamparam, 2003).

Lettuce growth parameters (leave number, leave area, fresh and dry weight) were improved by the low concentration of CSU's compost which was consistent with earlier studies (Mastouri, Hassandokht, & Dehkaei, 2005) (Khalighi & Padasht-Dehkaee, 2000). However, higher concentration of CSU's compost had a negative effect on lettuce growth. This may be the result of the high level of organic components in which many nutrients are bound up and not available. It is also likely associated with high salt levels observed which would effect water uptake associated with osmotic stress or perhaps due to ion toxicity in plants. Also, the PH of the compost at 9.1 is excessive and with a C/N ratio of 22.8 the CSU compost likely had not matured. All of these factors likely had some influence on the lower growth parameter of leaf number, leaf area, fresh and dry weight as compared to the low concentration of CSU compost.

Applications of nitrogen (120 Kg N ha) to the soil has been shown to increase total leaf area which leads to increase in photosynthesis which in turn enhances biomass (Boroujerdnia & Ansari, 2007). In this study, photosynthesis did not show any differences among the treatments. However, photosynthesis was measured only at one growth stage at the end of the experiment after 45 days from planting. Differences may have occurred early in the growth period after initial transplanting. Further research should make more frequent readings during the early growth period.

Elemental analysis of lettuce leaves showed the Na was high during the leaf tissue analysis at 25 & 35 DAT in the HC treatment. This likely negatively impacted photosynthesis. Previous research has reported the negative effect of Na on tomato growth (Cuartero & Fernández-Muñoz, 1998). In addition, the HC clearly impacted lettuce growth as measured by several parameters.

One of the major concerns to improve crop production is the study of the interaction between salinity, nutrition and crop yield (Flores, Carvajal, Cerdá, & Martínez, 2001). Leaf N concentration was significantly higher in LC at 25 DAT which reached a total N level between 4 and 6 % (Laboratories, 1990). The high C/N ratio in the compost may have caused a competition between plants and soil microorganisms for soil N. To prevent the N competition between soil microorganisms and plants, the compost process should be monitored more closely and should only be used when there is a C/N ratio of 18 or less for optimum crop production (Fricke, 1993). Although there were significant differences in levels of P and K over sampling times there were no significant differences among treatments within the sampling times.

Calcium (Ca^{2+}) has a central role in plant signaling and stress responses. The Ca^{2+} was significantly reduced only under the HC at 35 DAT. This was the only significance among treatments noted and likely had only a minimal influence on overall productivity. Ca^{2+} and Mg^{2+} content are reduced under salt stress in plants (Albaqami, 2013). In the leaf tissue analysis, the HC showed a significant increase in Na level with an associated reduction in $Ca2^{+}$ and Mg^{2+}. These results suggested that CSU's compost has high salt which negatively effects lettuce growth. This was evident in that the LC which did not negatively effect lettuce growth. Although the salts were high in the low concentration of compost the overall amounts were insufficient to negatively effect growth. Therefore, continued use of the CSU's compost requires the leaching of the salts so that it would be an optimal plant growth medium. In the cases of Mg, Fe and Al ions, high concentration of CSU compost also led to significantly reduced amounts in the same growth stage (after 35 days) that showed high Na. This would indicate that there may be an interaction between Mg, Fe and Al with Na which needs further investigation.

In conclusion, the results indicate that CSU's compost is an appropriate source for important nutrients for crop growth and production. The CSU compost analysis suggested that all the nutrients are at sufficient level for plant growth. Moreover, the results indicate that with lettuce production the low level of CSU's compost is most suitable for crop production, perhaps related to the high salts. This was based on the significant increase in lettuce growth parameters including increase in leaf number, fresh weight, dry weight and leaf area. However, some parameters measured did not show any significant increase which included lettuce height and photosynthesis. This as well as the reduced growth of lettuce at HC would seem to indicate that high salt concentration in the CSU compost has a negative effect. Therefore, the salt concentration in the CSU compost must be reduced prior to use in crop production. Furthermore, it is important that compost be tested for salt levels but also for relative C/N ratios to insure that the compost has completed its process.

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