AIMS Environmental Science, 7(4): 350–365.
DOI: 10.3934/environsci.2020023
Received: 03 June 2020
Accepted: 01 September 2020
Published: 21 September 2020

http://www.aimspress.com/journal/environmental

Research article

Impacts on vegetable yields, nutrient contents and soil fertility in a community garden with different compost amendments

Dongyan Mu[1,*], John Hawks[2] and Andrew Diaz[1]

[1] School of Environmental and Sustainability Science, Kean University. 1000 Morris Ave, Union NJ 07083, USA
[2] Albert Dorman Honors College, New Jersey Institute of Technology. 323 Dr M.L.K. Jr. Blvd, Newark, NJ 07102, USA

* **Correspondence:** Email: dmu@kean.edu; Tel: +19087373689.

Abstract: This study aimed to test impacts on soil fertility, plant yield, and plant nutrient content when growing vegetables (Arugula and Radish) at different compost treatments rates (10%, 30%, 50% and 70% v/v) and with synthetic fertilizer. The compost used in this study was produced from food wastes in combination of wood chips. The results showed the impacts on vegetable growth and soil fertility varied exceptionally by the compost amendment rate. Specifically, the leafy crop experienced an increased yield with the incremented compost ratio and therefore the highest treatment (70%) generated a harvest several times larger to that of non-treated soil. For the root vegetable, the largest output was observed at a medium treatment rate (50%). Additionally, the applications revealed compost treatments at high percentages generally promoted elements N, P, K, Na, Mn, Zn and Mg within the vegetable contents. On the contrary, a low compost amount (10%) boosted Ca, Al, and Fe levels. In terms of soil fertility enrichment, the compost can improve C, N, K and Zn at medium to high treatment rates (30% to 70%). Particularly, at such amounts, the compost enhanced C and N contents within the ground soil more than the fertilizer application. Based on the gathered outcomes, root vegetables will thrive at 50% compost treatment allowing for the replacement of complete synthetic fertilizer use without significant reduction on yields and nutrients. As for leafy green vegetables, the 70 % compost concentration permits the replacement of more than half the total fertilizer usage.

Keywords: food waste compost; vegetable growing; soil fertility; vegetable nutrients; sustainability

1. Introduction

The rapid population surge among metropolitan areas, is one of the grand challenges faced by human beings within the twenty-first century. Currently, the urban community has outnumbered the rural sector. By the year 2050, approximately 68% of the total world's population is expected to live in cities [1], meaning two out of three people will be city dwellers [2]. This is bound to increase the cities' dependency on external food sources, and thus raise risks in proper food provisions as well as reduce access to fresh and nutritious food [3].

Today, the majority of urban centers primarily receive food from conventional agricultural lands, relying on massive use of resources. According to the United Nations Environmental Programme, agriculture consumes 70% of world's fresh water and 38% of the world's ice-free land [4]. Such intense use of resources has drove agriculture to be a major source of detrimental environmental impacts. As of 2018, more than 75% of Earth's total land area has been significantly degraded by the rapid expansion of agriculture alongside the unsustainable management of farming and grazing lands [5]. In addition, the production of crops contributes to 25% of greenhouse gas (GHG) emissions along with 60% of all water pollution worldwide [6].

To manage the many challenges in urban food provisioning, there is an urgent necessity to build a more resilient food supply system among cities across the world. Such a system will need to reduce resource consumption and shorten the food supply chains by promoting the regional or local agricultural capabilities. Also, the operations emplaced must minimize synthetic fertilizer use to mitigate soil degradation and to encourage waste reuse so as to mitigate harmful environmental impacts as well as emissions created throughout the food production and corresponding supply chains. Upon such demands, many community gardens have been initiated to address the matter. The locality and organic nutrients found in compost have spurred the movement to cultivate fresh and local vegetables, herbs, and fruits.

Compost is a product from the decomposition of organic materials under aerobic conditions. Over the past few years, food waste composting has been highly encouraged due to the abundant amount. Respectively, 40% of all food within the United States will directly be transformed to waste every year [7]. Consequently, concerns are raised when developing waste collection, transportation, and disposal infrastructure among densely populated regions. In addition, when food debris rots in landfills, it is degraded to methane (CH_4), a much stronger greenhouse gas than carbon dioxide (CO_2). Based on the USEPA report, sanitary landfills are the third largest source of CH_4 emissions in the United States, accounting for 18% of total U.S. methane emissions in 1990–2012 [8]. Hence, the generation of compost from food waste will divert a significant fraction of garbage from landfills while mitigating climate change [9]. More importantly, compost allows for materials and energy to be recycled and furthered to produce a valuable soil amendment to promote vegetation production and replace synthetic fertilizer use [10].

Many previous studies have been conducted to display the positive impacts of compost application to soil properties, yield enhancements, and nutrient contents of crops. Common claims stated the benefits of compost treatment, with results in higher yields, improved soil fertility and texture, higher carbon and nitrogen sequestration, and reduced nutrient losses to local waters [11–20]. Studies to specifically investigate vegetable response were pursued. For example, Bonanomi, D'Ascolib, Scottia et al. [21], examined vegetables grown under plastic tunnels with a combined application of compost and wood. The overall findings were: improved soil organic carbon recovery, heightened soil biological functions, and increased crop yields. Evanylo, Sherony, Spargo et al. [22], focused on the environmental effects of vegetable crops (pumpkins, corn, and peppers) onto soil and water. Data confirmed an increase of soil fertility and yields, from the application of compost. Furthermore, efforts to compare the lasting effects of compost and fertilizer amendments over a twelve-year period were overseen [11]. The experiment demonstrated with long-term use of compost, similar yields and nutrient contents will follow, like that of fertilizer applications, across multiple crops. However, the majority of the studies were directed towards the incorporation of compost among grain crops and animal husbandry. Still, a shortage of numerical documentation for root vegetables in compost treated soil was evident [23].

To fill the knowledge gap in this branch, the research team at Kean University (KU) operated a study on soil fertility, plant yield, and nutrient content of two vegetables. Both arugula and radish were nourished by compost in a community farm, Liberty Hall Farm, Kean University (40.6781 ° N, 74.2343 °W). The local climate registers with the USDA hardiness zone 7a. Arugula and radish belong to the family of *Brassicaceae.* Selection for the study was decided by the popularity of the two among the University dining halls. The leafy vegetable, arugula, is typically incorporated in salads within the U.S and European cuisine. Favorable conditions include cool to mild weather, and expected harvest is within 30 to 40 days. In contrast, the radish is a root vegetable highly prevalent among the diet of many across the globe. A summer variety of radish was grown; quick germination along with durability to warm temperatures was ideal. The time to harvest vary between 30 to 50 days depending on access to water and nutrients.

In this research, the compost was directly produced from a combination of both food wastes and wood chips in an in-vessel composter established at Kean campus. Two vegetables were grown in a raised bed located on Liberty Hall Farm for a total of 44 days during the summer. The nutrients present in the soil, the yields of vegetables, and the plant tissues, underwent tests and then further were compared based on various compost and fertilizer applications. The major goals of the study include: 1) assess how compost promotes vegetable growth under distinct compost application ratios, 2) identify which is the best compost treatment ratio in soil to promote vegetable growth, 3) analyze how soil fertility is changed with compost treatment, and 4) determine how compost can replace synthetic fertilizer application.

The expectation is to provide an in-depth understanding of how food waste compost is employed as a soil amendment in leafy and root vegetable production. This is to contest to the rising concern to reach a sustainable agricultural method. Data collected in this study is to enrich the current database on compost application for vegetable cultivation. Additionally, all discoveries will become part of a guide for farmers to effectively apply compost at the right rates, and also facilitate the environmental and economic analysis of compost application within city community gardens. This documentation is to advocate for farming in urban areas; the local production of goods will provide new sources of fresh and nutritious food to city dwellers, while at the same time, will reduce environmental impacts in the agriculture sector. Such encouragement will stimulate the diversion of food waste and thus reduce greenhouse gas emissions from landfills to combat climate change.

2. Methodology

2.1. Compost production

Kean University uninstalled an in-vessel, rotary drum composter in 2009 and continues to operate. The facility is designed to process 1000 lbs./day of food scraps, running through eight months per year due to the limited availability to obtain food waste during summer break. Both pre and post-consumer food remains are sourced and collected primarily from the student dining; the range of trash come from proteins, fruits, vegetables, grains, seafood, and bones [24]. A supplementary amount of wood chips are combined to the mix at a 1:4 ratio by weight, to maximize the decomposition speed, ensure the correct C:N proportion, and reduce undesired odor. The wood chips are obtained from the local woodworking business at no cost. In this way, the wood wastes are diverted from the landfills at the same time. Each day, the diverted food waste is first weighed, then added to the composter, awaiting to be shredded. Wood chips follow and join the composter at the calculated amount. Aeration occurs every 15 minutes, accompanied by rotation every 60 minutes to establish thorough mixing of all feedstocks. In just 5 days, once decayed food scraps are transformed to rich, organic compost. A 20 day wait period is observed before further application on soil within the farm. Components of compost were tested and are shown in Table 1.

Table 1. Components of compost, bed soil and fertilizer.

	Compost	Bed soil	Fertilizer*
C%	40.40	5.75	-
N%	2.26	0.34	5.25–14
P (P_2O_5) %	0.429	0.10	6.5–19.5
K (K_2O) %	0.79	0.026	8.1–21.6
Ca %	0.17	0.19	1.84–3.6
Mg %	0.05	0.024	-
S %	0.15	0.0019	-
Cu mg/kg	5.14	16.84	-
Zn mg/kg	21.58	67.67	-
pH	6.7		
Mn mg/kg	46.53		
Al mg/kg	98.54		
Fe mg/kg	149.72		
Na mg/kg	4383		
Ammonium mg/kg	2440.1		
Organic Matter %	81.3		
C:N Ratio	17.9		

Note*: Osmocote Classic 14-14-14.

2.2. Raised bed preparation

A set of trials with varying compost amendment rates (0%, 10%, 30%, 50% and 70%, v/v) were organized and set in the raised beds located at the six-acre plot. The intention to plant within explicit, varied compost concentrations, was to ascertain the best compost combination rate and to observe the effect of such soil practice. A comparison to common synthetic fertilizers was required to decipher an accurate estimation of fertilizer substitution by way of compost.

The raised bed was constructed from wood and extended 28 feet (8.5 meters). To properly begin, the bed was first cleared to remove all weeds and then divided into six equal blocks. Afterwards, the first seven inches of topsoil in the bed were removed per marked plot and mixed with appropriate amounts of compost. Calculations were derived by volume ratio of topsoil to compost. Weights of both soil and compost brought major inconveniences and therefore the lab chose volume percentages instead. Block #1 represented the control bed where no soil amendment was given (0% of compost); blocks #2 through #5 obtained varying compost amendment respectfully (10%, 30%, 50% and 70% of compost). The last block (#6) kept its native soil and was treated with a 14-14-14 fertilizer shown in Table 1. Rate of addition was 161 grams for the 4ft by 4ft plot (1.2x1.2m).

Wire fencing was to protect the plants from local predators including: chipmunks, rabbits, deer, squirrels, and field mice. The fine mesh deterred pests by creating a barrier. The bottom portion of the fence was stapled and secured to the wooden frame to prevent access via tunneling.

2.3. Vegetable cultivation

Each soil plot received 15 plants, to allow for sufficient samples for analysis. Commencement began at that latter part of June; one grow cycle was examined. Propagation began inside the lab, with seeds and starters. The soil medium was a commercial starter soil. This process was purchased and supplied by Carolina Biological. Three seeds per vegetable were planted in each cell as recommended by the distributor; separate starter trays were assigned for arugula and radish. Germination occurred after one week (shown in Figure 1). Plants were thinned out to one per insert and then followed by relocation and transplanting to the raised bed. Equal amounts of plants per plot as well as adequate spacing were completed.

Figure 1. Vegetable germination, transplants, and grown in the raised bed.

During the growth phase, the crops were watered three times a week within the morning hours; this is crucial to encourage root growth. Weeds were readily removed, at least once a week among the rows. Neither pesticides nor herbicides were implemented over the growing cycle. Based on observed maturity, both vegetables were harvested 37 days after transplanting to the raised bed; seed to harvest totaled to 44 days.

2.4. Sampling and testing

Samples of compost, soils, and plant tissues were collected and forwarded to a laboratory for analysis. Compost was tested before integration with the soil, to monitor and prove the exact source of the nutrients. Soil chunks reaching up to a foot (30 cm) of profundity was extracted from each of the six blocks in the raised bed before mixing and after harvesting. Nutrient change in soil before and after growing was tracked. All vegetables were harvested with all entireties from each plot and carefully segregated. To determine precise yields, each plant was measured, weighed, and recorded. The analysis of the plant tissue was to correlate soil treatment to plant and human nutrient uptake. All samples were stored in plastic sampling bags and shipped to the Penn State Agriculture Lab for testing. Items for testing include:

1) Compost Test: percent solids, organic matter, pH, soluble salts, total nitrogen, total carbon, C: N ratio, ammonium nitrogen, phosphorus, potassium, aluminum, calcium, magnesium, manganese, sodium, copper, iron, sulfur and zinc.
2) Soil Test: pH, Mehlich buffer lime requirement, phosphorus, potassium, magnesium, calcium, total N, total C, ammonia, and organic matter.
3) Plant tissue analysis: nitrogen, phosphorus, potassium, calcium, magnesium, manganese, iron, copper, boron, zinc, total N, and total C.

The standard methods for testing can be referenced to the Penn State Agriculture Lab.

3. Results and discussion

3.1. Arugula growth and nutrient contents

The yields of both vegetables are shown in Figure 2. The Single Arugula graph depicts the average weight of a single plant (presenting size of the plant) produced in each compost treatment block. Even though 15 replicates were transplanted to each block, some plants were not successful and were removed from the bed; therefore, the final numbers of plants harvested varied in each block. The Total Yield of Arugula illustrates the total weight (presenting the yield in the box) of all plants of each treatment ratio in the raised bed. The produce of arugula and radish in each compost treatment block is included in the supporting information (SI).

Arugula yield and size heightened respectfully with the increase of the compost amendments. The soil treated with 70% compost obtained the largest produce, 2.7 times in size and 2.4 times in yield as compared to soil without compost (0%). The results justified the use of compost could promote vegetable growth consistent with the study by Brown and Cotton 2013 and the study by Evanylo, Sherony, Spargo et al. [22], in which compost at higher rate were confirmed to add benefits than that of low rates of compost application. The results were also consistent to the study by Eksi [25], which concluded that addition of 60 and 80% compost in soil could obtain the greatest plant growth and fruit yields. In contrast to high percentage, the results at Kean reveal the 10% compost amendment yielded even lower Arugula than the non-treated soil (0%), which indicates compost amendments at low rates cannot promote a vigorous arugula yield. A compatible outcome was found in an experiment hosting spinach, where compost concentrations of 25% produced less than the untreated soil [26]. Overall, small leafy vegetables will only thrive at high compost treatment rates (>50%).

When reviewing the major nutrients found in arugula plant tissue, a parallel between the N content and compost concentration is noticed. A boost in total nitrogen (N) in arugula is seen with high compost concentrations. In particular, a gain in over 20% of total N content was noted in the 70% compost treated soil, as compared to the control plot (0 %). This is attributed to the superior nitrogen load within the compost as to the naturally occurring in the original bed soil (shown in Table 1). Hence, the more compost blended, the more N was readily available to the arugula, permitting greater uptake and improved yields. As similarly stated earlier, only high compost amendment will stimulate leaf growth; the N in 10% and 30% were indeed lower than that of no compost at all. This coincides with the imperative reliance plants hold on nitrogen for appropriate growth and development as well as yield and quality [27]. For phosphorus (P), the compost amendment did not promote uptake in arugula. Instead, P contents amidst all compost treated soils were lower than that of the untreated plot. This implies that compost was unable to promote P uptake in green leafy vegetables. Lastly, the potassium (K) in arugula was improved through the addition of compost. The increase of K in plant tissue was also observed in study by Lopez-Guadrado, Ruiz-Fernández, Masaguer et al. [28], where green waste compost was used to grow *Pelargonium* zonale. Notably, the K element saw gains of 12% in the 70% compost amendment as to the control plot (0%). The accumulation is traced to the compost, which possessed the much high potassium than bed soil. In addition, arugula is recognized to contain high levels of K as to other vegetables. Therefore, land with prevalent loads will trigger uptake in leaves.

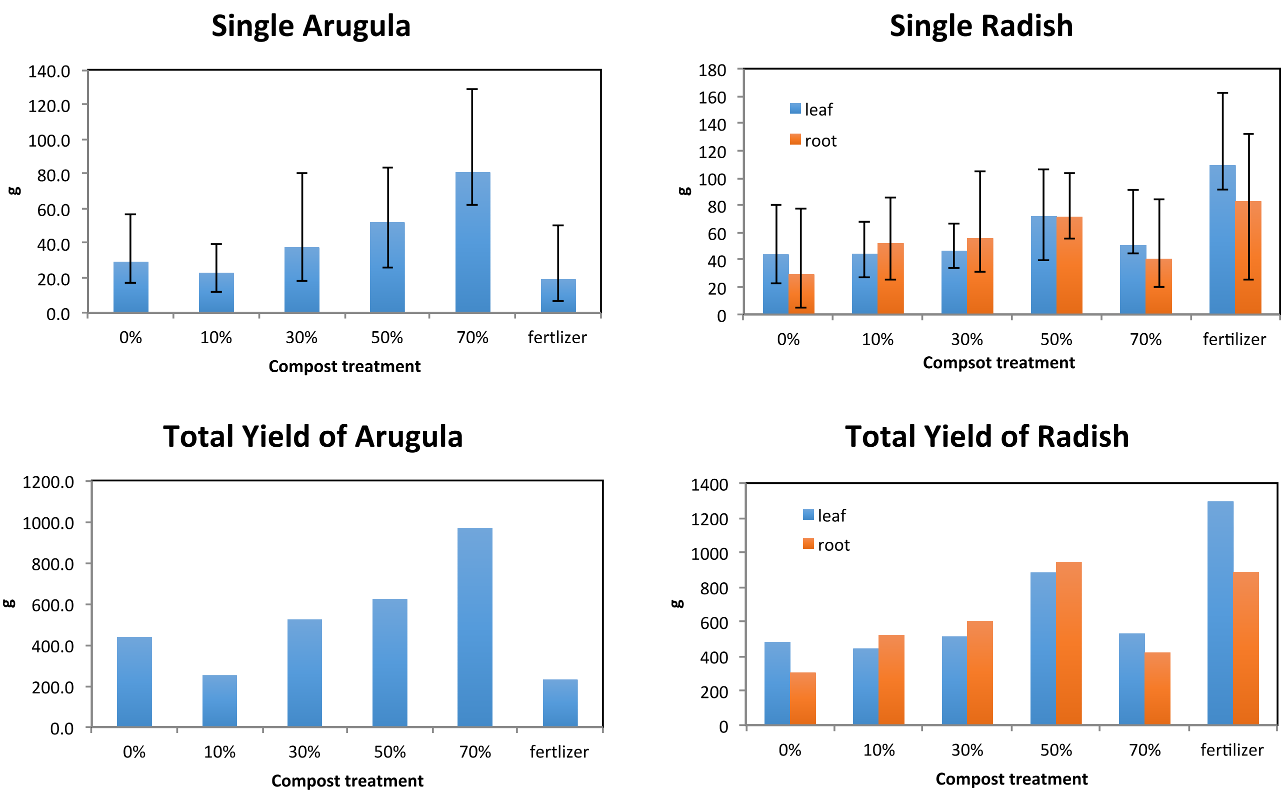

Figure 2. Arugula and Radish size and yield at different compost treatment rates.

As for the degree of change among the minerals Al, Fe, Na, and Zn were significant (>5%) but others were relatively small. In addition, the changes of mineral contents did not exhibit a unanimous trend. The contents of Ca, Mg, Cu, Al, and Fe were highest at the 10% compost amendment, whereas the components of Zn, Mn and Na were highest at the 70%. Collectively, as the compost rate increased from 0% to 70%, mineral contents of Ca, Mg, Mn, Al, and Fe decreased implying contents of those minerals were promoted at lower compost application rates in leafy vegetables. However, a significant factor must be stated: even with a slight dip in specific mineral content, the total uptake of such nutrients increased as the increase of the compost amendment rate. This is because the total yields of arugula increased along the compost rate, where the highest compost applied gave way to the largest vegetable yield.

A disclaimer must be announced to clarify the diminished output pertaining to the fertilizer plot. At one point during the growing stage, an animal invaded block #6 through force and damaged the metal mesh fence. As a result, a decent fraction of the total output of arugula went unaccounted for in this block. Shown in the figures 2, the yield was even lower than the original bed soil (0%). For that reason, it is not valid to use other existing data to estimate how much fertilizer can be replaced by adding compost for arugula cultivation. Although the yield is not suitable for comparison, the leaf analysis is applicable. Arugula settled in plot #6 did attain similar or even higher nutrient contents when contrasting with tissue analyses from compost treated arugula. This is explained through the properties of fertilizer which contains nutrients that are easy uptake.

3.2. Radish growth and nutrient contents

As stated earlier, the number of radishes harvested in each box was varied due to crop success. Figure 1 shows the average size and the total yield of radish. In addition, the study counted the radish leaves and roots separately. Even though the root is usually the desired harvest, nutrients in soil were transferred to both parts, and therefore it is necessary to check nutrients in both leaves and roots. The plant tissue analysis provided nutrient components and is labeled in Table 2.

Table 2. Vegetable yields and nutrient contents.

	Weight g/plant	Yield g	N %	P %	K %	Ca %	Mg %	S %	Cu mg/kg	Zn mg/kg	Mn mg/kg	B mg/kg	Al mg/kg	Fe mg/kg	Na mg/kg
Arugula															
Fertilizer	19.2 ±13.8	229.8	5.55	0.57	7.65	2.54	0.53	1.88	18.10	102.38	54.99	33.89	499.90	570.89	1149
0%	29.2 ±17.0	404.2	4.98	0.77	6.97	2.54	0.40	1.99	16.49	102.72	52.06	32.27	696.44	712.43	727
10%	22.9 ±10.9	251.9	4.31	0.68	7.66	3.52	0.49	2.01	17.96	102.30	53.39	35.83	890.22	872.26	833
30%	43.8 ±30.2	611.8	4.43	0.69	7.57	2.37	0.41	1.26	13.38	98.58	36.86	38.95	322.61	378.55	1246
50%	51.9 ±16.2	622.3	5.22	0.73	7.17	2.68	0.44	1.46	17.27	109.70	47.02	39.23	366.34	446.20	1127
70%	80.8 ±31.0	969.2	6.02	0.69	7.80	2.28	0.39	1.75	17.19	125.22	54.17	35.78	240.86	329.80	1863
Radish Leaf															
Fertilizer	99.4 ±26.5	1292.8	5.46	0.57	5.97	3.68	0.70	1.43	11.19	71.81	57.23	46.24	286.66	348.58	5395
0%	36.8 ±21.0	479.3	3.72	0.49	4.06	4.95	0.60	1.15	10.09	57.43	56.43	47.04	352.58	403.52	5459
10%	44.2 ±10.6	441.9	3.97	0.49	5.31	4.12	0.47	0.95	13.10	52.49	54.39	44.69	297.94	348.93	4608
30%	42.8 ±13.7	513.7	4.06	0.62	4.47	4.02	0.56	0.86	13.60	68.59	60.59	51.99	315.94	389.92	8777
50%	58.7 ±26.3	881.1	4.81	0.53	3.77	4.21	0.54	0.68	10.79	61.35	63.95	44.46	267.79	339.73	12140
70%	48.1 ±18.8	528.2	5.10	0.52	5.60	3.35	0.56	0.78	11.98	65.79	94.65	48.02	203.67	282.55	15206
Radish Root															
Fertilizer	68.2 ±43.5	886.4	3.65	0.48	9.49	0.68	0.30	0.93	6.29	140.62	15.67	37.52	51.70	86.73	4516
0%	23.3 ±14.9	302.7	2.41	0.56	6.37	0.57	0.22	0.96	5.68	117.17	11.47	30.41	44.97	71.30	2992
10%	52.1 ±17.7	520.8	2.44	0.63	7.31	0.66	0.22	0.91	6.30	111.74	13.51	32.91	64.93	105.04	2802
30%	50.2 ±24.4	602.5	2.43	0.59	7.79	0.57	0.19	0.75	6.09	130.69	11.88	33.25	22.96	54.91	5481
50%	62.9 ±22.4	943.4	3.49	0.58	9.13	0.68	0.27	0.56	6.90	140.80	14.00	36.30	40.60	67.80	10250
70%	38.1 ±20.9	419.6	3.65	0.54	7.89	0.51	0.26	0.72	6.99	179.52	17.98	32.47	22.28	60.14	8376

Yield and size of both the root and leaf portions of the radish were intensified with the compost amendment rates of 10% until 50%. This indicates the compost treated soil does possess the ability to enhance radish growth. Unlike the arugula, the yields of both leaves and roots of the radish living in the 10% compost were higher than the control (0%). At a 50% compost to soil ratio, the largest individual size and total yield were recorded by an increase in leaf yield by 80% and leaf size by 60%, whereas the root yield swelled by 200% and similarly root size by 300%. A noteworthy observance was made at the 70% compost soil where the yield and size receded. This signifies adding too much compost in soil will stunt radish productivity. Therefore, the best compost treatment rate for radish is found to be at 50% ratio. In addition, the study showed the leaf segment weighed higher than the root when the radish grew under a natural setting (0%). Once compost was applied, the root outweighed the leaf at amendment rates of 10%, 30% and 50%. However, the leaf once again dominated in potency, possessing higher weights than the roots at intense amounts of compost (70%). The outcome demonstrates the benefit of compost for root vegetable growth at low to medium compost treatments.

The nitrogen content in the radish leaves were higher than the roots at all mixing rates, whereas the phosphorous and potassium contents in the leaves were lower than the roots. Additionally, the study revealed the N, P, and K within the leaf fragment generally rose with the increase of the compost treatment, similarly to that of arugula. Nonetheless, the N, P, and K contents recovered in the roots ascended but peaked at 50%, and then declined. Compost at high levels (70%) will promote nutrients for the leaf but will impede nutrients in the root. Consequently, the cultivation of root vegetables is better paired with lower to equal portions (50%) of compost and soil.

Mineral contents within the radish leaf are similar to that of arugula. That is the Ca, Mg, and Cu contents in the leaf generally decreased when increasing the compost amendment rate. Possible explanations are that more Ca, Mg, and Cu went into root production. Further, the analysis presented those same contents in the root to be increased. For the Zn, Mn, and Na, their contents in both leaves and roots increased with the higher compost application rate, whereas the contents of Al and Fe in both leaves and roots dropped with higher compost treatment. In addition, except for Zn, all minerals for radish leaves were higher than that of radish roots. Essentially, a surge in compost will spur a boost for root nourishment, but at the same time, will deteriorate mineral sustenance to the leaves.

Lastly, the study investigated radish grown under a synthetic fertilizer condition. The commercial fertilizer did promote exceptional root and leaf growth based on data collected. Comparing to the untouched soil (0%), leaf yield increased by 165%, whereas the root yield increased by 190%. This validates the assistance fertilizer had on the radish. When comparing to the best compost amendment condition (50%), radish with fertilizer were 58% larger in leaf and 6% weightier in root. For total yield, the fertilizer grown radish were 31% more in amount per leaf but 6% lower in roots. Such discrepancy indicates the properties found in compost attend better to the needs of root development than to leaves for radish. Thus, a more sufficient source of nutrients will come from compost, and not from synthetic fertilizers. A call for the replacement of fertilizers to compost will better cultivate this root crop.

Fertilizer lent to the increase of all nutrients and minerals in the radish when compared to soil without compost (0%). The N, K, Mg, and S contents in the fertilizer radish acquired higher amounts than that of radish grown with compost treatment. Remaining nutrients and minerals were marginally close to but slightly lower than the high compost treated plots. This implies the fertilizer could promote nutrients and minerals contents in radishes, but compost has the potential to completely substitute of fertilizer. With 50% compost treatment, compost in general can sufficiently replace fertilizer in growing root vegetables, while it can replace at least 63% of all fertilizer use in growing leafy vegetables, based upon the data gathered from radish leaves.

3.3. Nutrients use efficiency

Further computation was completed by the study. A nutrient use efficiency of the following three elements were conducted: nitrogen (N), phosphorous (P), and potassium (K). They are portrayed in Figure 3 as NUE, PUE, and KUE respectfully for radish among the compost increments. The nutrient use efficiency is an important parameter indicating plant growth in response to nutrients availability.

It depicts how nutrients in compost and soil are utilized for plant growth. Calculations were done as a ratio of nutrients within the vegetable to the nutrients available in the soil and compost. For example, the nitrogen use efficiency (NUE) of the radish leaf in certain compost treatments are equal to nitrogen content (%) in leaves multiplies total leaf produce (kg) and then divided by the nitrogen available in soil and compost (kg), shown in Equation 1. For radishes, the nutrient use efficiency was presented by leaf use efficiency (LNUE) and root use efficiency (RNUE).

$$LNUE\% = \frac{N\% in\ leave * total\ leaf\ harvet\ (kg)}{N\ in\ original\ soil(kg) + N\ provided\ by\ compost(kg)} \quad \text{E1}$$

For nitrogen use efficiency (NUE), the LNUE and RNUE for radish were highest at the 10% compost treated area, and the lowest at 70% compost treated area. The NUE, LNUE and RNUE in 10% compost amendment were even higher than those in non-treated soil, whereas NUE, LNUE and RNUE in 30% –70% compost application were all lower than those in non-treated soil. This implied the compost promotes NUE in the low amendment rate. This result is consistent to the study which claimed compost treatment increased the NUE of maize but the higher NUE was achieved in lower (25%) compost rate than 50% compost rate [12]. In addition, from 10% to 70% compost treatment, NUE, LNUE, and RNUE dropped gradually with the increase of compost rates, with the exception of 30% compost where the NUEs were lower than the 50% compost. This observation is broadly consistent with previous literatures, which claimed the NUE often decreases with increasing N applications in plant species [29]. Lastly, the result showed the LNUE was higher than RNUE in all sectors, proving leaves have higher intake rates of nitrogen (N).

In terms of the PUE, LPUE, and RPUE, the results showed that the 10% compost retained the highest PUE (0.69%), LPUE (0.24%), and RPUE (0.44%). The PUE then decreased with the increase of compost rates. Similarly, to NUE, the compost amendment promoted the phosphorus (P) utilization in soil at lower treatment rates. Unlike LNUE and RNUE, the LPUEs were lower than RPUE in all compost treatment rates depicting stronger P uptake in roots than in leaves. When checking KUE, the LKUE and RKUE all dropped from 0% to 70%, which indicate the compost treatment could not promote K use efficiency.

Then, the NUE, PUE, and KUE of radish grown in the fertilizer treated soil were evaluated. A significant uptake of all N, P, and K was seen. The NUE, PUE, and KUE of radish in fertilizer were 380%, 180%, and 290% greater than that of the control plot (0%). Also, the fertilizer promoted a more distinguished nutrient uptake than that of compost; the NUE, PUE, and KUE of radish in fertilizer were drastically higher than compost. Based on this analysis, the study proposes the combination of both compost and synthetic fertilizers to the land will promote nutrient use efficiency.

3.4. Impacts on soil nutrients

This study also briefly checked the nutrients change in soil with compost amendment. After harvest, the same six plots were examined for nutrient content, as shown in Table 3. Bed soil was soil before growing vegetables in the raised bed. The 0% was none treated soil after harvesting. Soil in this block (0%) received a sharp loss in major elements; the C, N, K, Mg, and Zn components were depleted by 39%, 29%, 55%, 15%, and 78% respectively. Since the radish is a K and Zn rich plant, the depletion of K and Zn in soil was the highest. However, P, Ca, and Cu increased, and this may be caused by nutrients leached from outside sources such as rain and runoff.

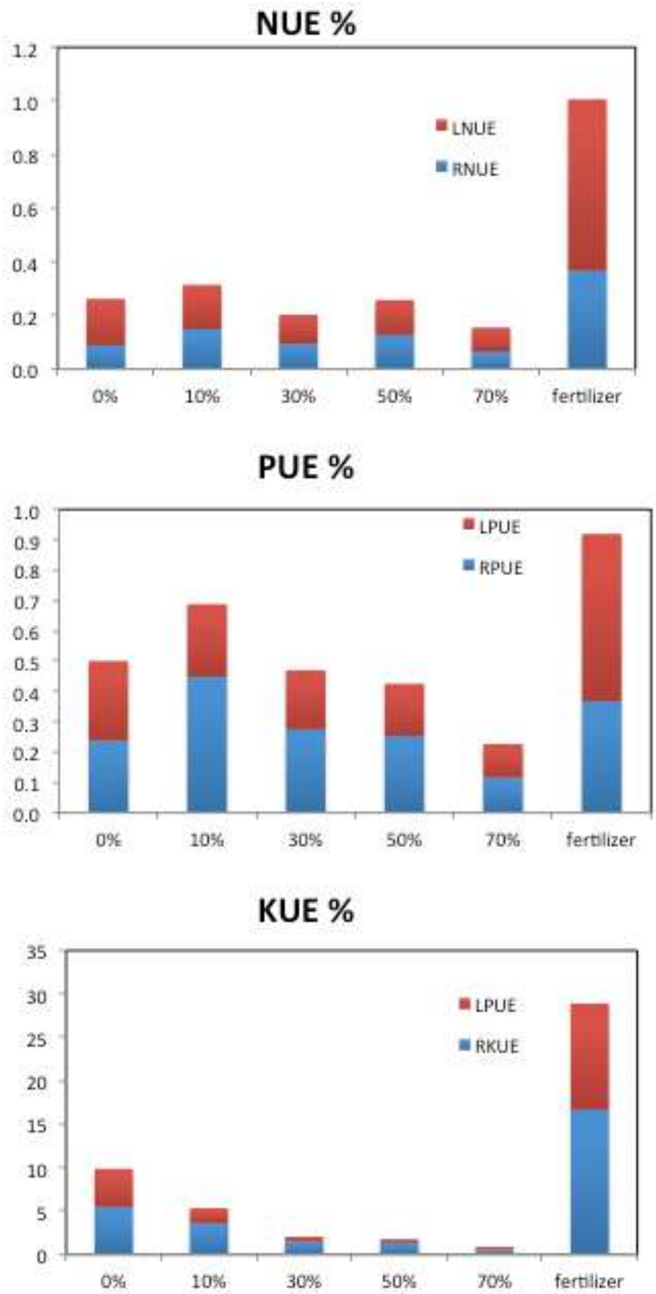

Figure 3. N, P and K use efficiency of radish at different compost treatment rates.

Once the compost was applied, the nutrients of C, N, and K among the soil were generally increased alongside the compost application rate. Compost rates higher than 30%, witnessed amplified amounts of C, N, and K higher than the original bed soil. This points out, compost can improve soil fertility at medium to high treatment rates. Another study recorded a similar conclusion, that at high rates of compost (50%), an increase of soil C and N were found after growing crops, and the low rate compost was rapidly mineralized [22]. The study at Kean additionally reported the remaining C and N amounts found in fertilizer treated soil, were at levels equal to and lower than the original bed soil. This finding lends to say fertilizers do not improve soil C and N qualities. On the contrary, the C and N components were remarkably higher in compost treated soil (50%) after the harvest. Thus, it is confidently stated, compost will improve soil C and N more than fertilizer. A decrease of C:N ratio was detected, from the original 16:1 to 11:1. This decline in proportion can have a minor negative effect on the microbes living beneath the soil. A probable reason to such occurrence is the relatively high N content within the compost itself.

Table 3. Soil properties after planting vegetables.

	Bed soil	0%	10%	30%	50%	70%	Fertilizer
C%	5.75	3.52	5.19	6.50	7.18	11.15	5.23
N %	0.34	0.24	0.37	0.52	0.54	1.02	0.39
P mg/kg	295.00	334.00	327.00	285.00	265.00	332.00	513.00
K mg/kg	146.00	65.00	190.00	335.00	370.00	846.00	826.00
Ca mg/kg	2595.00	2739	2667.00	2094.00	2195.00	1517.00	2589.00
Mg mg/kg	326.0	276.0	284.0	277.0	299.0	290.0	351.0
S mg/kg	25.80	26.40	23.50	21.60	20.90	26.80	338.10
Cu mg/kg	22.40	24.80	24.30	18.20	14.60	8.50	26.20
Zn mg/kg	90.00	19.2	21.60	23.80	20.30	24.10	18.90
pH	6.4	6.7	6.5	6.4	6.5	6.	5.8
Cd mg/kg	0.39	0.37	0.33	0.38	0.33	0.30	0.38
Cr mg/kg	27.44	31.69	26.54	25.59	32.15	22.79	27.22
Pb mg/kg	36.33	40.72	35.75	42.14	39.25	24.35	35.47
Ni mg/kg	24.46	26.42	23.07	22.61	22.25	18.48	23.03
Acidity meq/100g	3.40	2.00	2.20	2.80	2.20	***	4.50

For minerals Mg and Zn, their contents in soil increased with compost amendment, but did not meet preharvest levels found in the original soil. This is because Zn and Mg contents in compost are lower and close to that of the bed soil. Compost treatment did not provide enough Zn and Mg for plant growth, and therefore, the remaining Zn and Mg in soil dropped.

For minerals P, Ca, and Cu, their contents in soil decreased with the increase of compost treatment. The results of this study were contrary to other studies such as the study by Cao, Huang, Wang et al. [30] in which the compost increased phosphorous (P) in soil around 50%. In lower compost treatment, the remaining minerals were even higher than bed soil. The only explanation is the nutrients were brought in from other sources.

3.5. Factors related to effects of compost amendment

As claimed by Stewart-Wade [20], the compost can stimulate plant growth and replace synthetic fertilizers, but the effects vary by plant species and waste feed to composters. The study proved this conclusion and showed that the plant promotion effects varied with different plant species. Even for the same vegetable, the stimulation effects are different in leaves and roots. A wide variety of vegetables, fruits, and flowers have been examined with compost form various wastes as a soil amendment. As the vegetables here used food waste compost, the study focused on discussing green waste compost produced from food and yard residues.

Many studies recommended the treatment rate up to 30 % [31,32] because high amendment rates may cause toxicity and an increase of pH in soil [33]. For example, the green waste compost was used as peat substitutes in growing *geranium* in the study by Gong, Li, Son et al. [34]. It reported a reduction in *geranium* yield in 50% and 100% amendment of green waste compost. However, plant growing experiments in this study showed a medium to high amendment rate could stimulate plants better than low rates. Also, the soil pH did not increase with the amendment rates because the pH of compost produced at Kean was close to 7. Such a high quality of compost could be attributed to relatively similar food waste selected for composting. The composter accepts mostly pre-customer kitchen food wastes and combined with wood chips. If the green wastes are quite heterogeneous as green refuse, the compost amendment could negatively influence plant growth [35]. Besides, the plant tolerance for soil quality change influenced the effect to stimulate plants. In the same study by Gong et al. [34], the growth of *calendula* was stimulated in 50% and 100% green waste compost compared to growth in untreated soil. This study showed a higher tolerance of Arugula and Radish to soil quality change.

In addition to stimulating yield, many studies showed the other benefits of compost amendment. For example, it could improve disease resistance, enhance water uptake efficiency, increase microbes diversity [20]. This study did not examine those characteristics because of such tests need a long-time observation.

Soil nutrient remediation via compost was also determined by many factors, including the wastes to composters, the original soil properties, and the plant uptakes [36]. For the green waste compost amendment, some studies showed that the N and P leaching in soil was reduced by more than 50% indicating the soil nutrients increased more than 50% [37–39]. However, the study here only showed an increase of N and K in soil, but not P. With a comparison of nutrients in soil and compost, the study found out only when the nutrients within the compost greatly exceed the untreated soil, there would be an abundance in nutrients left and lead to an increase of soil nutrients. For example, the C, N, and K in compost were much higher than those in the bed soil. Therefore, adding more compost increased these soil nutrients. Especially, the K in compost is 30 times to the K in the bed soil. Even though there was a large amount of K utilized by the radish, the K in soil composition was still much improved. In contrast, the contents of P in compost are two times that of the bed soil. Adding compost could increase P available to plants, but could not compensate P uptake by plants, and therefore the leftover in soil was less than the soil without compost treatment (0%). As the radish yields increased across 10% until 50% amendments, the plant took more P, resulting in an overall reduction of P after harvest. Only at 70%, where the yield dropped, and so the nutrients leftover was greater. Therefore, the P in the soil after harvesting first decreased from 10% to 50% amendment and increased at 70%.

The results have demonstrated a huge variety of effects and the complexity of this issue. Many literatures concluded that the compost could improve other soil physical properties [36], including bulk density, infiltration rate, hydraulic conductivity, and water content. Those properties were not examined in this study, but they are worth to be tested for a better understanding of compost amendment in the future.

4. Conclusion

Compost treatment can promote vegetable growth, but the effect varied by compost amendment rates. For leafy greens, yield increased with the higher application of compost present. Specifically, at the 70% application rate, the yield was several times the amount of that of the untreated soil. For future cultivation of leafy vegetables, a high compost treatment rate would better to mixed into topsoil to improve output. For root vegetables, the yield will be highest at equal compost treatment rates (50%), where root growth outgrew that of leaves.

Nutrient contents in vegetables were enhanced by compost. A boost in nutrients and minerals were recorded when growing in compost treated soil. Treatment rates of compost at high concentrations promoted N, P, K, Na, Mn, Zn, and Mg, whereas low compost treatment rates promoted Ca, Al, and Fe. Greater increments of compost to soil will increase mineral contents within the roots of radish, but will decrease mineral contents within its leaves. In promoting plant nutrients of N, P and K, the fertilizers were better than composts, whereas the compost promoted plant mineral of Ca, Cu, Zn, Mn, Fe, and Na levels in radish better. Besides, compost amendment can also promote nutrient use efficiency at lower treatment rates (< 20%). As the compost treatment rate increased, the nutrient use efficiency decreased. Soil nutrients can be reinforced at medium to high treatment rates of compost. Specifically, the compost improved soil C and N amounts more than the fertilizer efforts.

Based on the results, for a root vegetable, 50% compost treatment can replace the synthetic fertilizer use completely without significant reduction to yields and nutrients. For leafy vegetables, the 50% ratio can replace at least 63% of the total synthetic fertilizer use.

Ultimately, the study must point out that the basis of the analyses was on data collected from one growing cycle of two vegetables in the first year the compost was applied. To obtain a full, in-depth understanding of compost treated soil along with vegetable development, a further long-term set of monitoring and testing is necessary. A record of solid numbers for vegetable yields, nutrient contents, and soil fertility change will only be achieved through repeated trials. This study at Kean University is to add to the further developing database of natural, holistic methods to realize a sustainable agricultural system.

Acknowledgement

The study was funded by the STEMPact grant and Spf grant at Kean University.

Conflict of interest

There is no known conflict of interest to declare.

References

1. UN. 2018. 68% of the World Population Projected to Live in Urban Areas by 2050, Says UN. UN DESA Department of Economic and Social Affairs. United Nations. United Nations. https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html.
2. Knorr D, Khoo CSH, Augustin M A (2017) Food for an urban planet: challenges and research opportunities. *Front Nutr* 4: 73.
3. Romeo D, Vea EB, Thomsen M (2018) Environmental impacts of urban hydroponics in Europe: a case study in Lyon. *Procedia CIRP* 69: 540–545.
4. UNEP. 2002. Vital Water Graphics: An Overview of the State of the World's Fresh and Marine Waters. UNEP. https://www.unenvironment.org/resources/report/vital-water-graphics-overview-state-worlds-fresh-and-marine-waters.
5. Stephen L (2018) 75% of Earth's land areas are degraded. National Geographic website. Available from: https://news.nationalgeographic.com/2018/03/ipbes-land-degradation-environmental-damage-report-spd/
6. Miller G, Spoolman S (2014) Chapter 10 Food Production and the environment. Environmental Science, 15th Ed. Cengage Learning: Boston, MA.
7. Gunders D, Bloom J (2017) Wasted: how America is losing up to 40 percent of its food from farm to fork to landfill. NRDC, R: I7-05-A.
8. USEPA Website a. Overview of Greenhouse Gases. Methane Emissions. USEPA, Washington DC. Available from: https://www.epa.gov/ghgemissions/overview-greenhouse-gases
9. Saer A, Lansing S, Davitt NH, et al. (2013) Life cycle assessment of a food waste composting

system: environmental impact hotspots. *J Clean Prod* 52: 234–244.
10. USEPA (2009) Backyard Composting It's only natural. USEPA, Washington DC.
11. Warman PR (2005) Soil fertility, yield and nutrient contents of vegetable crops after 12 years of compost or fertilizer amendments. *Biol Agric Hortic* 23: 85–96.
12. Iqbal S, Thierfelder C, Khan HZ, et al. (2017) Maximizing maize quality, productivity and profitability through a combined use of compost and nitrogen fertilizer in a semi-arid environment in Pakistan. *Nutr Cycl Aagro*ecosys 107: 197–213
13. Hepperly P, Lotter D, Ulsh CZ, et al. (2009) Compost, manure and synthetic fertilizer influences crop yields, soil properties, nitrate leaching and crop nutrient content. *Compost Sci Util* 17: 117–126.
14. Kumar B, Kumar S, Prakash D, et al. (2011) A study on sugar mill pressmud compost for some heavy metal content and their bio-availability. *Asian J Plant Sci Res* 1:115–122
15. Mikkelsen R, Hartz TK (2008) Nitrogen sources for organic crop production. *Better Crop* 92: 16–19.
16. Zhang Y, Li C, Wang Y, et al. (2016) Maize yield and soil fertility with combined use of compost and inorganic fertilizers on a calcareous soil on the North China Plain. *Soil Till Res* 155: 85–94.
17. Sarangi BK, Mudliar SN, Bhatt P, et al. (2008) Compost from Sugar mill press mud and distillery spent wash for sustainable agriculture. *Dyn Soil Dyn Plant* 2: 35–49.
18. Farhad W, Cheema MA, Saleem MF, et al. (2011) Response of Maize Hybrids to Composted and Non-composted Poultry Manure under Different Irrigation Regimes. *Int J Agric Biol* 13.
19. Brown S, Cotton M (2011)Changes in soil properties and carbon content following compost application: results of on-farm sampling. *Compost Sci Util* 19: 87–96.
20. Stewart-Wade SM (2020)Efficacy of organic amendments used in containerized plant production: Part 1–Compost-based amendments. *Sci Hortic* 266: 108856.
21. Bonanomi G, D'Ascoli R, Scotti R, et al. (2014) Soil quality recovery and crop yield enhancement by combined application of compost and wood to vegetables grown under plastic tunnels. *Agr Ecosyst Environ* 192: 1–7.
22. Evanylo G, Sherony C, Spargo J, et al. (2008) Soil and water environmental effects of fertilizer-, manure-, and compost-based fertility practices in an organic vegetable cropping system. *Agr Ecosyst Environ* 127: 50–58.
23. Möller K (2018) Soil fertility status and nutrient input–output flows of specialised organic cropping systems: a review. *Nutr Cycl Aagroecosys* 112: 147–164.
24. Mu D, Horowitz N, Casey M, et al. (2017) Environmental and economic analysis of an in-vessel food waste composting system at Kean University in the US. *Waste Manage* 59: 476–486.
25. Eksi M, Rowe DB, Fernández-Cañero R, et al. (2015) Effect of substrate compost percentage on green roof vegetable production. *Urban For Urban Gree* 14: 315–322.
26. Tavarini S, Cardelli R, Saviozzi A, et al. (2011) Effects of green compost on soil biochemical characteristics and nutritive quality of leafy vegetables. *Compost Sci Util* 19: 114–122.
27. Leghari SJ, Wahocho NA, Laghari GM, et al. (2016) Role of nitrogen for plant growth and development: A review. *Adv Environ Biol* 10: 209–219
28. López-Cuadrado MC, Ruiz-Fernández J, Masaguer A, et al. (2005) Utilization of different organic wastes from madrid as growth media for Pelargonium zonale[C]//International Symposium on Growing Media. 779: 623–630.
29. Jiang Y, Li Y, Nie G, et al. (2016) Leaf and root growth, carbon and nitrogen contents, and gene expression of perennial ryegrass to different nitrogen supplies. *J Am Soc Hortic Sci* 141: 555–562.

30. Cao Y, Huang H, Wang J, et al. (2020) Crop response and quality of soil as affected by hyperthermophilic compost in Tai-Lake region of China. *J Plant Nutr* 43: 1000–1015.
31. Ceglie FG, Elshafie H, Verrastro V, et al. (2011) Evaluation of olive pomace and green waste composts as peat substitutes for organic tomato seedling production. *Compost Sci Util* 19: 293–300.
32. Mugnai S, Pasquini T, Azzarello E, et al. (2007) Evaluation of composted green waste in ornamental container-grown plants: effects on growth and plant water relations. *Compost Sci Util* 15: 283–287.
33. Barrett GE, Alexander PD, Robinson JS, et al. (2016) Achieving environmentally sustainable growing media for soilless plant cultivation systems–A review. *Sci Hortic* 212: 220–234.
34. Gong X, Li S, Sun X, et al. (2018) Green waste compost and vermicompost as peat substitutes in growing media for geranium (Pelargonium zonale L.) and calendula (Calendula officinalis L.). *Sci Hortic* 236: 186–191.
35. Massa D, Malorgio F, Lazzereschi S, et al. (2018) Evaluation of two green composts for peat substitution in geranium (Pelargonium zonale L.) cultivation: Effect on plant growth, quality, nutrition, and photosynthesis. *Sci Hortic* 228: 213–221.
36. Kranz CN, McLaughlin RA, Johnson A, et al. (2020) The effects of compost incorporation on soil physical properties in urban soils–A concise review. *J Environ Man* 261: 110209.
37. Faucette LB, Jordan CF, Risse LM, et al. (2005) Evaluation of stormwater from compost and conventional erosion control practices in construction activities. *J Soil Water Conserv* 60: 288–297.
38. Logsdon SD, Sauer PA, Shipitalo MJ (2017) Compost improves urban soil and water quality. *J Water Res Prot* 2017: 345–357.
39. Mohammadshirazi F, McLaughlin R A, Heitman J L, et al. (2017) A multi-year study of tillage and amendment effects on compacted soils. *J Environ Man* 203: 533–541.