Impact of Compost Application Rate on Lettuce Plant Growth and Soil Agrochemical Status

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Summary

One way to reduce environmental stress and safeguard soil fertility and ecological sustainability in crop production is by adding compost to the soil substrate. Supplying the soil with organic matter improves its chemical and physical characteristics, leading to better plant growth and development and increasing yield. The study presents a pot experiment with lettuce on leached cinnamon forest soil (Chromic Luvisol). Research has studied changes in soil NPK before and after vegetation and the effects of the compost on plant production and quality. Increasing the amount of compost in the soil substrate led to an increase in the fresh mass and yield of lettuce and to an increase in the accumulated N, P, and K (%) in the plant tissues (R^2 = 0.91, 0.96 and 0.68, respectively). After the experiment's conclusion, the soils remained very well stocked in P_2O_5 content. The K_2O stock in the soil was medium, i.e. when compost is applied, plant-available potassium increases relative to the initial soil. Total N remained very low; the applied composts provided large amounts of nitrogen for growing lettuce but did not leave the soil in good ecological status.

Key words

soil sustainability, *Lactuca sativa*, compost, nitrogen, phosphorus, potassium

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Introduction

Sustainable land use and soil fertility protection are our time's most significant challenges. Optimal fertilizer management and effective use of nutrients are crucial to obtaining maximum yield with high quality (Fageria, 2016). In vegetable production, the predominant use of mineral fertilizers is observed because of their precise chemical composition and rapid absorption by plants (Sady et al., 1995). However, according to Kapoulas et al. (2017), organic production can achieve a higher yield and better nutritional qualities of the produce. One of the main advantages of organic over mineral fertilization is the provision of nutrients to plants over a more extended period due to their gradual release, which is of key importance when planning and managing organic fertilization, according to Hernandez et al. (2015).

In recent years, there has been a growing demand and use of organic fertilizers and soil improvers as an alternative to conventional fertilization. Through them, the protection of soil fertility and ecological sustainability in crop production should be ensured (Martínez-Blanco et al., 2013; Demiraj et al., 2018; Vasileva et al., 2021).

Adding organic matter, vermicompost, and compost to the soil improves its chemical and physical characteristics, leading to better plant growth and development and increased yields (Stopes et al., 1996). According to Khater (2012), composts should be considered more as soil conditioners than fertilizers because of their high organic matter content (90-95%) and significantly lower nitrogen, phosphorus and potassium content than found in mineral fertilizers.

For optimal management and planning of organic fertilization, and the efficient use of plant nutrients, the proportion (and/or dosage) of organic compost: soil used for the preparation of the substrate and information on the effect of compost on subsequent crops are essential to avoid unnecessary soil fertilization (Lustosa Filho et al., 2015; Burnett et al., 2016).

In the present work, lettuce (*Lactuca sativa* L.) was chosen as a test crop because of its rapid growth and visible morphological changes. Lettuces are among the world's most widely grown and consumed leafy vegetables. As a crop with short vegetation, lettuce has specific soil nutrient requirements. Recommendations for optimal fertilization rates are described by Rankov et al. (1991) and are as follows: 40-80 kg N ha^{-1}, 50-60 kg P_2O_5 ha^{-1}, and 50-60 kg K_2O ha^{-1}.

More information needs to be provided on the effectiveness of substrate reuse in vegetable production. Data on the use of composts in the preparation of substrates and determination of the compost:soil ratio is of great importance for sustainable development.

The present work aims to evaluate the influence of different compost:soil ratios on some growth indicators and yield of lettuce and to follow the condition of the soil after the end of their vegetation.

Materials and Methods

The article covers a greenhouse pot experiment conducted on leached cinnamon forest soil (Chromic Luvisol) from Chelopechene, ISSAPP "Nikola Poushkarov" field. The experiment duration was 45 days. Test variants containing 100, 200, and 300 g compost were prepared in pots with a capacity of 2 kg. The substrates were composted for 30 days, and 60% water humidity was maintained. The content of nitrogen, phosphorus, and potassium in the compost was 1.74% N, 1.50% P, and 0.30% K.

The soil before planting was defined as poorly stocked with mineral N (23.0 mg kg^{-1}) and medium stocked in terms of K_2O (21.9 mg 100 g^{-1}) and P_2O_5 (8.2 mg 100 g^{-1}).

The experimental scheme included four options:

1. soil without compost – control;
2. variant – 5% compost: 95% soil (100 g);
3. variant – 10% compost: 90% soil (200 g);
4. variant – 15% compost: 85% soil (300 g).

Each variant had three replications, with four plants in each pot from pre-produced seedlings. The yield and content of chlorophyll pigments were recorded. The concentration of total N was measured by the Kjeldahl (Horneck and Miller, 1998) method, and K_2O and P_2O_5 in the plants were determined by Stanchev et al. (1982). The content of ammonium and nitrate nitrogen in the soil was determined according to Keeney and Bremner (1966), and the content of K_2O, P_2O_5 in the soil was determined by acetate-lactate method (Ivanov, 1984) before planting and post-harvest. Multi-factor ANOVA and Duncan Multiple Range Test (DMRT) at the 5% confidence level were performed using Stat graphics Centurion statistical software product.

Results and Discussion

Deteriorating soil fertility is one of the main challenges facing agriculture today. One of the main factors in the chemical depletion of the soil is that it has continuous periods of exploitation to satisfy the food of the growing world population. On the other hand, excessive and unbalanced mineral fertilization is the reason for the nutritional imbalance in plants, a severe prerequisite to problems not only with the finished product but also with the environment.

Using compost increases the soil's nutrient content and acts as a slow-release fertilizer, dynamically providing N, P, and K during plant growth (Purbajanti et al., 2016). Our experiment presents soil substrates with different ratios of compost:soil. The contents of the main macronutrients before planting the plants, following the influence of the compost, are shown in Table 1.

After composting, in all variants, there is an increase in the soil reaction, and the soil becomes neutral from/to slightly acidic. All variants have an increased content of NO_3-N, P_2O_5 and K_2O, and the change in nutrients follows in proportion to the percentage of applied compost.

According to some scientists, organic soil improvers are mainly a source of N and P since about 98% of N and between 33 and 67% of total P in the soil are bound to its organic matter (Fuente et al., 2006). This could explain the significantly increased content of NO_3-N (on average over 2.5 times) and P_2O_5 (on average over six times) in the soil after composting compared to the control variant. Soil conservation in total N and P_2O_5 changes from poor and medium to very good in the composted variants, respectively. The highest content of NO_3-N and P_2O_5 is recorded in the variant with the highest % of compost added, 159.0 mg N kg^{-1} and 77.5 mg P $100g^{-1}$ (Table 1).

According to Melgarejo et al. (1997), the release of nutrients from organic soil improvers does not depend on their total content but on the dynamics of the degradation processes. He points out that some elements can become more available with changes in pH, moisture, aeration and composting. In our experiment, the potassium content was low in compost (0.30%), but after composting with soil, it showed high bioavailability; logically, the breakdown of organic materials was the reason for this. Furthermore, an increase in K_2O in the soil after composting was observed in proportion to the amounts of compost applied; the soil from medium became well-stocked. The highest K_2O content was measured at the variant with 15% compost (33.3 mg 100 g^{-1}) (Table 1).

Composts can increase microbial activity in the soil, thereby increasing plant-available nutrients. Moreover, the elements are released dynamically and can respond to the plants' changing needs during their vegetation – this leads to improved growth and development (Subaedah et al., 2016; Slamet et al., 2017). Growth indicators were compared depending on the percentage of compost applied to account for the influence of compost on the development of lettuce (Table 2). The data is comparable to those reported by other authors (Stancheva and Mitova, 2002; Hernández et al., 2010; Slamet et al., 2017). No significant differences existed between the composted variants in the number of leaves, plant height and width. The results obtained for the fresh mass of the whole plant and the aerial part significantly differed depending on the compost:soil ratio. Maximum values of fresh mass were in the variant with 15% compost (68.52 ± 10.049 and 63.85 ± 10.035, respectively), and the differences were statistically proven at $P < 0.05$. Our results are comparable to those of Mostafa et al. (2019), who also found that increasing the amount of compost in the soil substrate increased the fresh biomass of lettuce.

According to Serio et al. (2001), the gradual release of nutrients from the compost over a more extended period and the rapid growth of lettuces, especially during the last 2-3 weeks of their vegetation, positively affect yield formation. Fig. 1 shows a summary of the yields obtained in the present work. At variants of 5, 10 and 15% applied compost, there was a proportional increase in lettuce yield, the growth being 47, 69 and 101% higher than the control. The results are consistent with Folefack (2008), who reported that the lettuce yield increased by 21.9% when compost was applied. Brito et al. (2014) also indicated that compost application resulted in a 63% increase in lettuce yield. This beneficial effect of compost on lettuce yield may be due to higher soil nutrient status, increased activity of enzymes involved in the N and P cycle and improved soil physical properties (Trupiano et al., 2017). In addition, adding organic matter promotes better root development (Table 2), which helps absorb water and nutrients, and leads to increased yield (Brady and Weil, 2005; Ibrahim et al., 2011; Osoro et al., 2014).

The lowest yield was expectedly recorded in the control variants (95.18g) and the maximum - from the variant with 15% compost (191.56g). Mostafa et al. (2019) reported similar results – in a field experiment, they reported the highest yield at the highest compost rate (9t). They also observed a proportional increase in production as compost application increased.

The decisive factor in the purchase of vegetables is their visual appearance, mainly the product's color, associated with their nutritional qualities and degree of ripening. In lettuce, the intense green color is related to chlorophyll pigments and is, therefore, one of the essential quality assessment indicators.

The content of photosynthetic pigments in lettuce at the end of the experiment was measured (Table 3). The data shows that the amount of applied compost does not significantly affect the pigment content of lettuce, similar to results reported by Chiconato et al. (2014) and Hernandez et al. (2015).

The use of compost improves the physicochemical and biological properties of the soil and increases the cation exchange capacity (CEC) and the available nutrients. In this way, plant growth and nutrient uptake are stimulated (Li et al., 2017; Mostafa et al., 2019).

Table 1. Soil analysis before and after experiment

	Before and after composting					After lettuce vegetation				
	$pH_{(KCl)}$	NO_3-N	NH_4-N	P_2O_5	K_2O	$pH_{(KCl)}$	NO_3-N	NH_4-N	P_2O_5	K_2O
		mg kg^{-1}		mg 100 g^{-1}			mg kg^{-1}		mg 100 g^{-1}	
0	5.92	18.7	4.3	8.19	21.9					
1	6.22	56.6	0.43	8.57	23.8	6.23	0.76	1.46	8.9	20.8
2	6.52	120.0	1.19	29.1	29.8	6.59	2.03	1.73	35.4	22.8
3	6.64	138.0	0.49	48.7	31.2	6.71	3.66	1.23	61.2	23.4
4	6.71	159.0	0.39	77.5	33.3	6.82	3.67	1.11	66.0	24.3

Note: * 0. Initial soil, 1. Control, 2. 5% Compost, 3. 10% Compost, 4. 15% Compost.

Table 2. Effect of application rate of compost on Lettuce Growth Parameters (40 DAT)

Treatment*	Leaves per plant		Height		Width		Fresh Weight					
							Plant + Root		Plant		Root	
			cm				g per plant^{-1}					
1	11.67	a	11.07	a	7.67	a	34.42	a	31.73	a	2.69	a
2	13.33	a	15.83	b	10.67	b	50.46	b	46.77	b	3.69	ab
3	11.00	a	14.10	b	10.40	b	58.03	b	53.47	b	4.56	b
4	13.67	a	14.77	b	11.13	b	68.52	c	63.85	c	4.66	b
Average	12.42		13.94		9.97		52.85		48.95		3.90	
SD	1.929		2.280		1.580		13.755		13.000		0.970	
SE	1.041		0.902		0.478		3.081		3.077		0.341	
LSD ($P \leq 0.05$)	3.394		2.943		1.558		10.049		10.035		1.111	

Note: * 1. Control; 2. 5% Compost, 3. 10% Compost, 4. 15% Compost

** Different letters in the column indicate significant differences ($P < 0.05$) between treatments

Table 3. Effect of application rate of compost on Photosynthetic Pigments in Lettuce

Treatment*	Chlorophyll a		Chlorophyll b		Ch a+b		Carotenoids		Total	
	mg g^{-1}									
1	0.409	b	0.142	a	0.551	a	0.168	a	0.719	a
2	0.333	ab	0.113	a	0.446	a	0.136	a	0.582	a
3	0.161	a	0.099	a	0.260	a	0.170	a	0.429	a
4	0.331	ab	0.112	a	0.443	a	0.137	a	0.581	a
Average	0.309		0.116		0.425		0.153		0.578	
SD	0.1340		0.0472		0.1726		0.0708		0.2122	
SE	0.0640		0.0300		0.0903		0.0466		0.1240	
LSD ($P \leq 0.05$)	0.2087		0.0978		0.2946		0.1519		0.4043	

Note:* 1. Control; 2. 5% Compost, 3. 10% Compost, 4. 15% Compost.

** Different letters in the column indicate significant differences ($P < 0.05$) between treatments

The lowest NPK content in the lettuce was recorded in the control variants without added compost (Fig. 2). The total nitrogen content in lettuce plants varied from 1.31 to 2.60%, within limits described in the literature of 2.5-4% (Mitova and Marinova, 2012; Zabochnicka-Swiatek, 2019) and in sync with the fact that plant N concentration followed compost N content. In other words, its content in plants increases as its content in compost increases. The higher percentage of compost in the soil substrate explains the maximum reported total nitrogen content in the lettuce from the variant with 15% compost input. Furthermore, Fig. 2 clearly shows the relationship between total nitrogen concentration in lettuce and % added compost ($R^2 = 0.91$).

The P_2O_5 content of lettuce is about 0.2%, but some authors cite a range of 0.4-1.0% (Hernández et al., 2010). In the present work, the concentration of P_2O_5 in plants varies from 0.29-0.46%, with the maximum value reported from variants with 15% compost (Fig. 2). The good stocking of the soil after the introduction of high % compost (Table 1) and the amounts of compost significantly influence the uptake of phosphorus by lettuce with $R^2 = 0.96$ (Fig. 2), which may be due to the type of compost used – well-rotted. According to Cooperband et al. (2002), the maturity of the composts significantly affects the plants' mobilization and phosphorus uptake. According to them, immature compost leads to the immobilization of P_2O_5 in the soil. Using 15% compost gives

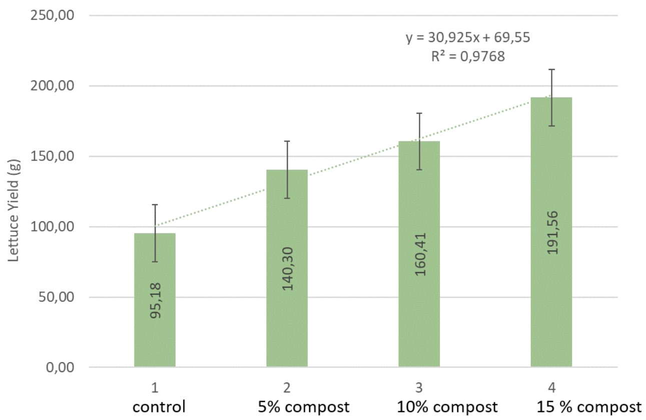

Figure 1. Effect of application rate of compost on lettuce yield

Note: * 1. Control; 2. 5% Compost, 3. 10% Compost, 4. 15% Compost; ** Vertical bars indicate mean standard error

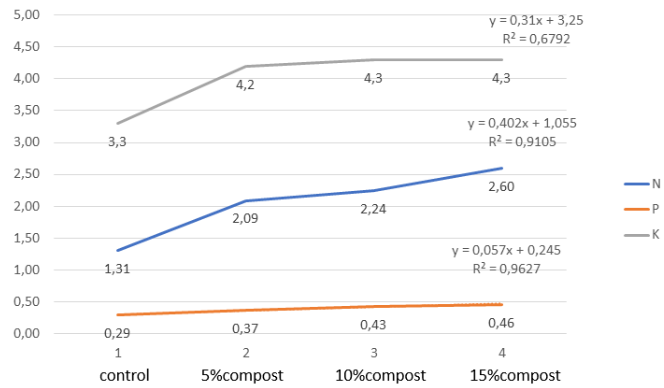

Figure 2. Effect of compost application rate on lettuce concentration of NPK (%)

Figure 2. Effect of compost application rate on lettuce concentration of NPK (%).

Note: * 1. Control; 2. 5% Compost, 3. 10% Compost, 4. 15% Compost

maximum values – 4.4%, but in all variants, the reported values were lower than those recommended by Jones et al. (1991) – 6%.

The influence of the compost:soil ratio on the content of K_2O in lettuce plants is the lowest – the coefficient of determination is 0.68; increasing the amount of applied compost would, to a lesser extent, lead to an increase in the accumulated potassium in lettuce (Fig. 2).

Soil samples were taken after the completion of the experiment to assess the soil status. The data is summarized and presented in Table 1. Under all variants, a slight increase in pH was observed compared to the initial soil and the soils after composting (Table 1).

The NO_3-N content of the initial soil, 18.7 mg kg^{-1}, significantly increased after composting (Table 1). Lettuce is a plant that prefers NO_3-N as a nitrogen source and is easily leached by irrigation water. After harvesting, the NO_3-N content in the soil was extremely low in all variants – from 0.76 to 3.67 mg kg^{-1} (Table 1). However, there was an increase in the content of NH_4-N at the end of the experiment (Table 1).

Low total nitrogen was measured in all variants after the harvest. Applied composts provide nitrogen for plant growth and development but are insufficient to leave the soil in good condition after the growing season. When planting the next crop on these soils, it is necessary to perform nitrogen fertilization or feeding.

The reported content of P_2O_5 in the soil in the control variant before and after the experiment shows a slight increase compared to the initial soil (8.57 mg 100 g^{-1}; 8.90 mg 100 g^{-1} and 8.19 mg 100 g^{-1}) - the phosphorus supply of the soil is medium. The data shows that using compost significantly improves the concentration of P_2O_5, and there is a significant increase in all composted variants. After harvesting the lettuce, the soils remained stocked with phosphorus, with maximum values at 15% compost (66.0 mg 100 g^{-1}) (Table 1).

After the experiment ended, the soil was medium-stocked with K_2O, i.e. when compost was applied, the potassium available to the plants increased (Table 1), but as a potassium-loving crop, lettuce absorbed relatively high amounts. Nevertheless, the K_2O content in the composted variants after the plants were harvested was higher than that measured in the initial soil (Table 1). Moreover, maximum values were recorded for potassium when applying 15% compost (24.3 mg 100 g^{-1}).

Conclusion

Using compost has proven to improve the soil's nutritional status. After composting, the contents of NO_3-N, P_2O_5 and K_2O increased in all variants, and the change was proportional to the soil:compost ratio.

The gradual release of nutrients from the compost during the lettuce vegetation has a positive effect on the formation of their yield. The results obtained in the present work show that increasing the amount of compost in the soil substrate leads to an increase in fresh biomass and lettuce yield. Compared to the control, the yield increased by 47, 69, and 101% for the composted variants, proportional to the amount of the compost applied (5%, 10%, and 15%).

After harvest, the soil remained with an insufficient stock of total nitrogen, i.e., the applied composts provided nitrogen during the lettuce vegetation but were insufficient to leave the soil in good condition after the end of the vegetation. When planting the next crop on these soils, it is necessary to apply nitrogen fertilization. The soil, however, remained well stocked in terms of P_2O_5 and K_2O content, and subsequent crops could be grown without fertilizing with these nutrients.

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