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Effect of variations in solid and liquid organic compost on the plant growth of leek (*Allium porrum* L.)

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ABSTRACT

This study examined the effects of various combinations of solid compost, liquid extract-compost, and inorganic fertilizers on the growth and nutrient uptake of leek (*Allium porrum* L.). The objective was to identify the most effective nutrient management strategy to enhance crop performance. Solid compost was produced from cattle manure, and liquid extract-compost was prepared through aqueous extraction and aeration. Six treatment groups with different nitrogen (N) applications were designed, including pure organic and integrated organic-inorganic combinations. Results revealed that 3/3N solid compost significantly improved early plant height and leaf yield. However, the combination of 2/3N solid compost with 1/3N inorganic fertilizer achieved the highest total biomass and nitrogen-use efficiency (NUE). Treatments with higher liquid compost application exhibited initial growth suppression due to ammonium toxicity but gradually improved over time. These findings highlight the importance of balanced nutrient management in maximizing crop yield and ensuring sustainable farming practices.

Keywords: solid compost, liquid extract-compost, nitrogen-use efficiency, leek growth, sustainable agriculture.

INTRODUCTION

Agricultural productivity has long been dependent on the use of inorganic fertilizers, particularly nitrogen (N) fertilizers, to meet the growing global demand for food. Approximately 60% of the world's population relies on nitrogen fertilizers for their nutritional needs (Fixon and West, 2002). However, this dependency has led to significant environmental concerns, as less than half of the applied nitrogen is effectively absorbed by plants, with the remainder lost to the environment through leaching, volatilization, and runoff. This inefficiency not only reduces the cost-effectiveness of nitrogen fertilizers but also contributes to environmental degradation, including water pollution, soil acidification, and greenhouse gas emissions (Gerendas et al., 1997; Britto and Kronzucker, 2002). The pressing need to mitigate the adverse environmental impacts of inorganic fertilizers has driven interest in the adoption of sustainable agricultural practices. One promising solution is the integration of organic fertilizers into nutrient management systems. Organic fertilizers, especially those derived from animal manure, have garnered attention as environmentally friendly alternatives that can enhance soil health, improve nutrient cycling, and sustain crop yields (Chang et al., 2007). Among various organic amendments, solid compost and liquid extract compost have shown considerable potential in providing essential nutrients to crops. Solid compost offers a slow and steady release of nutrients, improving soil structure and microbial activity, while liquid extract compost provides readily available, water-soluble nutrients that can be quickly absorbed by plants (Sutton et al., 1986).

Vegetable crops, such as leek (*Allium porrum* L.), require a consistent and adequate supply of nitrogen to support vigorous growth and high-quality yields. The use of solely inorganic fertilizers has been effective in boosting crop productivity but at the cost of environmental sustainability. Conversely, organic fertilizers offer a sustainable alternative, but their nutrient release rates and immediate availability often fall short compared to inorganic fertilizers. Combining solid compost with liquid extract compost may bridge this gap by offering both immediate and sustained nutrient availability, potentially matching or surpassing the efficacy of inorganic fertilizers in supporting plant growth (Siddiqui et al., 2009).

Despite the recognized benefits of organic fertilizers, research exploring the synergistic effects of solid and liquid compost combinations on vegetable crops remains limited. Most studies have examined these components separately or in comparison to inorganic fertilizers without fully investigating their combined impact on plant growth performance. This gap in research necessitates a comprehensive analysis of how different combinations of solid compost, liquid compost extract, and inorganic fertilizers influence the growth and nutrient uptake of leek plants.

This study aims to address this research gap by evaluating the effects of solid compost and combined solid compost with liquid extract compost relative to combined solid compost with inorganic fertilizer on the leaf and root development of leek. By systematically comparing these nutrient management strategies, the study seeks to identify optimal fertilization practices that enhance crop yield while minimizing environmental impact. The novelty of this research lies in its integrated approach, which contrasts with prior studies that have predominantly focused on singular fertilizer applications. By investigating the combined effects of solid and liquid organic composts, this study provides valuable insights into sustainable nutrient management for vegetable crops.

The central hypothesis of this research posits that integrating solid compost with liquid extract compost will result in superior growth performance and greater nutrient uptake in leek plants compared to the use of solid compost or inorganic fertilizers alone. This combination is expected to improve NUE and biomass production, offering a sustainable alternative to traditional fertilization methods. To test this hypothesis, the study evaluates multiple nutrient treatments, including solid compost alone, solid compost combined with liquid extract compost, and solid compost combined with inorganic fertilizer. The objective is to determine the most effective nutrient application strategy for optimizing leek growth and maximizing nutrient use efficiency. By identifying the optimal balance between organic and inorganic inputs, this study aims to contribute to the development of sustainable agricultural practices that support high crop yields and environmental conservation. Preliminary findings indicate that leek plants treated solely with solid compost exhibited enhanced initial plant height and leaf yield during early growth stages. However, the combination of solid compost with inorganic fertilizers resulted in the highest total biomass and root development. Treatments incorporating solid compost and liquid extract compost improved nitrogen uptake but were marginally less effective than inorganic treatments. Notably, the highest nitrogen-use efficiency was observed in treatments combining solid compost with inorganic fertilizers, reaching up to 84%, demonstrating superior nutrient utilization. Organic treatments, while slower in nutrient release, provided a sustained nutrient supply that supported continuous plant growth.

In conclusion, the integration of solid and liquid organic composts presents a promising strategy for enhancing leek growth and yield. Although solid compost alone can support early plant development, its combination with liquid extract compost or inorganic fertilizers significantly improves overall growth performance. The superior results observed in treatments combining solid compost with inorganic fertilizers highlight the potential for maximizing nitrogen-use efficiency and crop productivity. Nonetheless, organic fertilizers, when applied in optimized combinations, offer a sustainable and environmentally friendly alternative to inorganic fertilizers. Future research should further explore diverse organic materials and microbial enhancements to refine nutrient delivery systems and adapt these practices to various crop types, ultimately contributing to sustainable agricultural development.

MATERIALS AND METHODS

Preparation of materials

The solid compost used in this study was derived from commercial cattle manure, which was enhanced by incorporating a microbial additive containing thermophilic bacteria, following the procedure described by Nepal et al. (2011). To produce the liquid extract-compost, the solid compost was placed in a tea bag and immersed in hot water at 60 °C with a 1:4 weight-to-volume (w/v) ratio. The mixture was aerated using an aquarium pump for 24 hours. Afterward, the tea bag was removed, and the aeration process continued until the liquid extract-compost was ready for application. Both solid compost and liquid extract-compost were stored at 4 °C for chemical analysis. Liquid fertilizer was prepared by dissolving chemical fertilizers in distilled water to match the nutrient content of the liquid extract-compost. Table 1 presents the nutrient composition of the solid compost, liquid compost, and liquid fertilizer.

Soil properties and experimental setup

The soil used in the experiment was a grey lowland soil taken from a paddy field. The soil had pH 5.6, electrical conductivity 6.1 mS m^{-1}, N 1.2 g kg^{-1}, P 1.4 g kg^{-1}, and K 2.9 g kg^{-1}. A 12 kg of the dried-soil was filled in each 1/2000a Wagner's pot for cultivating plants. A 1.2 kg of the dried gray lowland soil was filled into a 1/10000a Wagner's pot for measuring inorganic nitrogen (ammonium-N and nitrate-N). In this experiment, a treatment without additional N was used as a control treatment (T1), and the other one was received 2.5 g N kg^{-1} or 0.5 g N of the solid compost as a recommended N dose of each 1.0 kg soil (equal to 50 kg N ha^{-1}) for cultivating plant and measuring inorganic-N, respectively denoted 3/3N (T2). The other four treatments were received 2/3N from the solid compost and 1/3N from the liquid extract-compost (T3); 2/3N from the solid compost and 1/3 from the liquid chemical fertilizer (T4); 1/3N from the solid compost and 2/3N from the liquid extract-compost (T5); and, 1/3N from the solid compost and 2/3N from the chemical fertilizer (T6). Each treatment was replicated three times. All treatments excluded control were received equal amount of N on the day of transplanting (Table 2). The solid compost was mixed roughly with the soil in each pot, pour the liquids (extracted compost and chemical fertilizer) to the soil in each pot, according to the treatments. During the experimental period, each

Table 1. Nutrient composition of solid compost, liquid compost, and liquid fertilize

Nutrient	Solid compost	Liquid compost[1]	Liquid Fertilizer[2]	
	(g kg^{-1})	(g L^{-1})	(g L^{-1})	Chemical source (g L^{-1})
Nitrogen (N)	27.07	1.00	1.01	NH_2CONH_2
Phosphorus (P)	10.71	0.31	0.31	K_2HPO_4
Potassium (K)	23.46	4.18	4.21	K_2HPO_4 (0.78); K_2SO_4 (0.63); KCl (2.81)
Calcium (Ca)	21.44	0.11	0.12	$CaCl_2.2H_2O$
Magnesium (Mg)	5.85	0.15	0.15	$MgSO_4.7H_2O$
Sulfur (S)	3.83	0.45	0.45	K_2SO_4 (0.26); $MgSO_4.7H_2O$ (0.20)

Note: [1]the liquid was made by extracting the solid compost in warm water with the ratio of 1:4 (w/w), [2]the liquid was made by dissolving in appropriate amount of the chemical sources.

Table 2. Treatments and nutrient application rates

Treatments		Nutrient application (g pot^{-1})						Total nutrient (g pot^{-1})					
		N	P	K	Ca	Mg	S	N	P	K	Ca	Mg	S
T1	None (control)	---------------NA---------------						--------------- NA ---------------					
T2	Solid compost (3/3)	2.52	1.00	2.18	1.99	0.54	0.36	2.52	1.00	2.18	1.99	0.54	0.36
T3	Solid compost (2/3)	1.68	0.66	1.45	1.33	0.36	0.24						
	Liquid extract-compost (1/3)	0.84	0.26	3.48	0.09	0.12	0.37	2.52	0.92	4.93	1.42	0.48	0.61
T4	Solid compost (2/3)	1.68	0.66	1.45	1.33	0.36	0.24						
	Liquid fertilizer (1/3)	0.84	0.26	3.51	0.10	0.12	0.38	2.52	0.92	4.96	1.43	0.48	0.61
T5	Solid compost (1/3)	0.84	0.33	0.73	0.66	0.18	0.12						
	Liquid extract-compost (2/3)	1.68	0.52	6.96	0.19	0.25	0.75	2.52	0.85	7.69	0.85	0.43	0.87
T6	Solid compost (1/3)	0.84	0.33	0.73	0.66	0.18	0.12						
	Liquid fertilizer (2/3)	1.68	0.52	7.02	0.19	0.25	0.75	2.52	0.85	7.75	0.86	0.43	0.87

Note: [1] not applied.

treated soils was kept at about 60% water holding capacity by weighing pot and watering for 14 days before transplanting.

Plant cultivation and measurement

Leek seedlings (*Allium porrum* L.) aged one year were transplanted into six holes per pot, five seedlings per hole. Plants were trimmed to an 8-cm height on August 18. Plant height was measured weekly, and SPAD values were recorded using a SPAD-502 meter. Harvesting was done at 44, 86, 128, and 170 days after transplanting (DAT). Leaves were trimmed to 8 cm in the first three harvests and fully harvested in the fourth. Roots were collected at 170 DAT. Plant samples were oven-dried at 70 °C for three days and ground into powder.

Soil sampling and chemical analysis

Soil samples were collected at 1, 12, 22, 37, 49, 65, and 84 days post-application. Moisture content was measured using a Moisture Analyzer (ML-50). pH and electrical conductivity were determined in a 1:2.5 and 1:5 (w/v) ratio using a WM-22EP EC/pH meter. Total carbon and nitrogen were analyzed with a CN Analyzer (Sumigraph NC-220F). Ammonium-N and nitrate-N were extracted with 1.3 M KCl and measured colorimetrically. Total phosphorus, potassium, calcium, and magnesium were assessed using inductively coupled plasma spectrometry (ICPS-8000) after digestion with H_2SO_4-H_2O_2. magnesium (Mg) in soil, leaf, and compost samples were analyzed by inductively coupled plasma spectrometry (ICPS-8000, Shimadzu Co., Tokyo, Japan) after digestion of the samples with H_2SO_4-H_2O_2 in a microwave digestion system (MWS-3, Berghof Products, Eningen, Germany).

RESULTS

Air temperature

Throughout the experimental period, air temperature within the vinylhouse was continuously recorded every hour. The average daily temperature fluctuated between 7 °C and 32 °C. A gradual decline in temperature was observed in December, followed by an increase in January due to the installation of an air conditioner set to 17 °C starting from December 30 (Figure 1).

Plant height

Plant height measurements demonstrated distinct growth patterns across four growth phases, with significant differences observed among treatments (Figure 2). During the first growth phase, no significant differences in plant height were noted among all treatments in the first two weeks. However, from the third to the sixth week, the T2 treatment (3/3N solid compost) exhibited

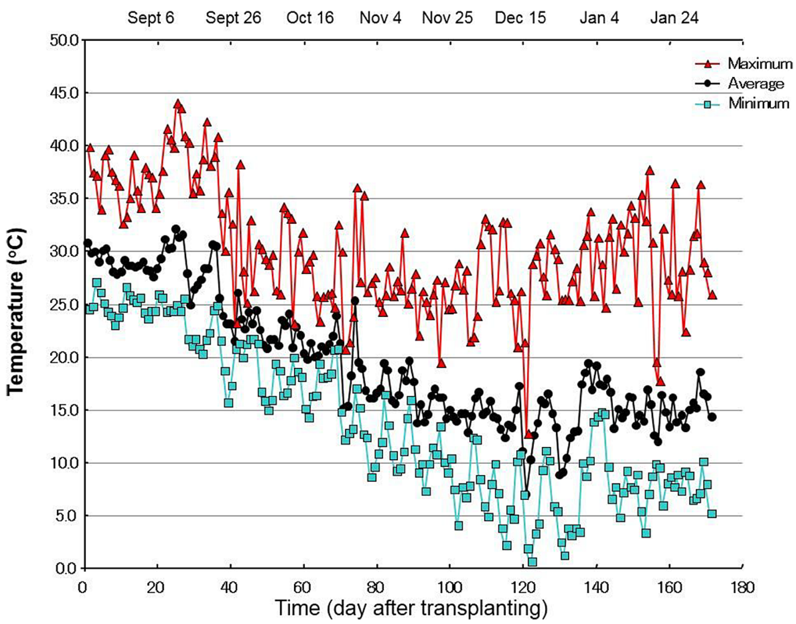

Figure 1. Daily air temperature fluctuations in the vinylhouse throughout the experimental period

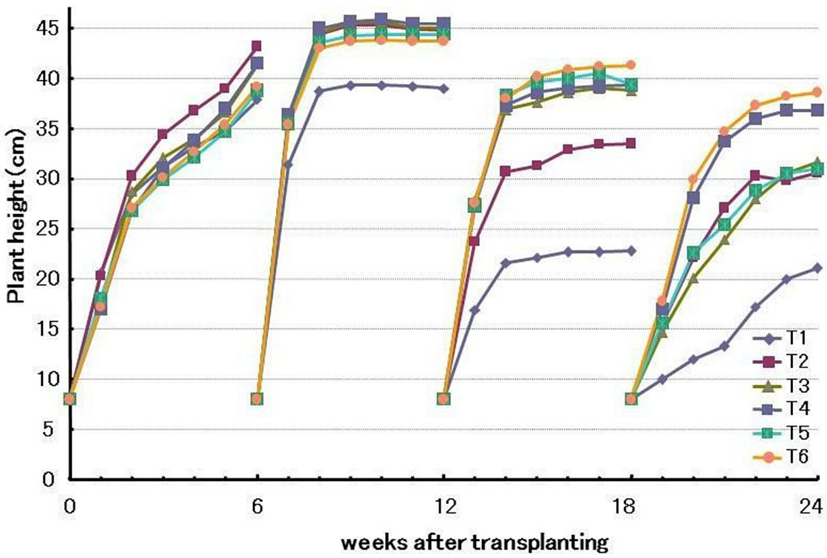

Figure 2. Plant height of regrowth leek over six weeks during the experimental period

significantly greater plant height compared to T5, T6, and the control (T1).

In the second growth phase, rapid growth was evident within the first two weeks, stabilizing thereafter. Plants treated with solid compost combined with either liquid extract-compost or chemical fertilizers (T3, T4, T5, T6) displayed significantly higher plant heights than those in the control treatment (T1). During the third growth phase, the plant heights in T2 were notably lower than in T4, T5, and T6 at various intervals, particularly at the second and third weeks. The fourth growth phase indicated that T2, T3, and T5 treatments produced similar plant heights, which were higher than T1 but significantly lower than T4 and T6.

Biomass dry matter

The leaf biomass of leek in T2 at the first harvest was tended to be higher than that in T4, and significantly higher than other treatments (Figure 3). Leaf biomass exhibited varying trends across four harvests. In the first harvest, T2 displayed the highest leaf biomass, significantly surpassing all other treatments. T5 and T6 exhibited leaf biomass similar to the control (T1). In the second harvest, T4 produced the highest leaf biomass, significantly

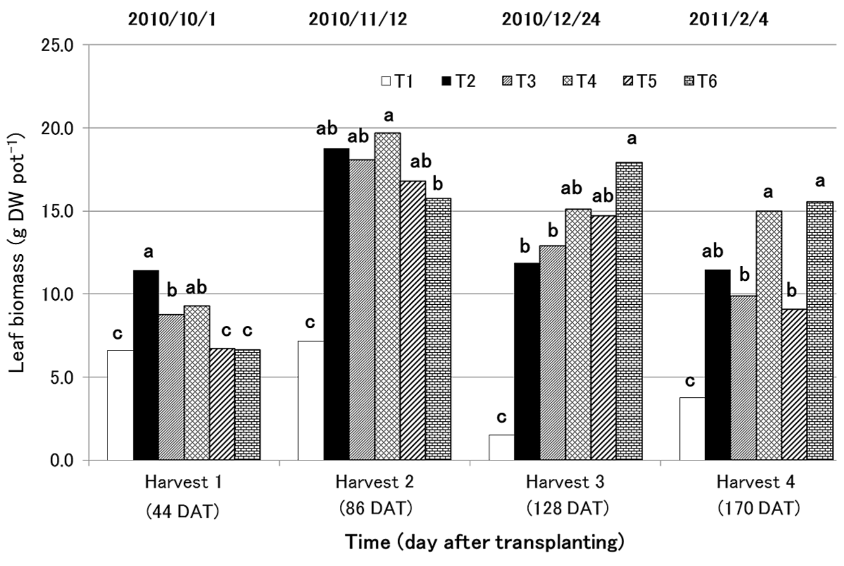

Figure 3. Leaf biomass of leek across four harvests. Different letters indicate significant differences among treatments (LSD, $P < 0.05$)

exceeding T2, T3, T5, and T1, while T6 was significantly higher than T1. During the third harvest, T6 yielded the highest leaf biomass, significantly outperforming T2 and T3. All treated plants showed significantly higher leaf biomass compared to the control. The fourth harvest highlighted that T4 and T6 had significantly higher leaf biomass than T2, T3, and T5. Overall, T4 produced the highest total leaf biomass across all harvests.

Totally in four harvests, the leaf biomass in T4 was not significantly higher than that in T2, T3 and T6, but significantly higher than that in T5 (Table 3). All treated plants had significant higher leaf biomasses than that in T1. The pattern of total leaf biomass was similar to that of root biomass.

SPAD values

SPAD measurements were taken at 78, 118, and 158 days after transplanting (DAT) Table 4. At 78 DAT, T2 showed significantly higher SPAD values than other treatments, while T1 had the lowest values. At 118 DAT, T2 maintained higher SPAD values than T1 but was significantly lower than T4. By 158 DAT, SPAD values were highest in T4 and T6, with T2 remaining significantly higher than T1 but lower than treatments receiving liquid extract-compost or chemical fertilizers.

Nitrogen concentration and content

Leaf nitrogen concentration was highest during the first harvest and declined over subsequent harvests. T2, T3, and T4 showed significantly higher nitrogen concentrations than the control in all harvests. T4 and T6 consistently displayed the highest nitrogen concentrations and content, particularly in the third and fourth harvests (Table 5).

Leaf N concentration of plants that received additional N was significantly higher than that in T1, except for T2, T3 and T5 at the third harvest. According to each harvest, leaf N concentration at the first harvest was similar among plants that received additional N from solid compost or together with liquid extract-compost or chemical fertilizer. In the second harvest, leaf N concentration in T2 was similar level with T3 and T4, but it was significantly lower than in T5 and T6. The leaf N concentration in T3 and T4 was similar level with that in T5 and T6.

Table 3. Total leaf and root biomasses of leek

Parameter	Total leaf biomass (g DW)		Root biomass (g DW	
T1	19.1	c	28.5	c
T2	53.5	ab	63.5	a
T3	49.6	ab	57.3	ab
T4	59.1	a	62.6	a
T5	47.3	b	53.9	b
T6	55.8	ab	55.3	ab
LSD (0.05)	10.1		8.4	

Note: Different letters in the column represent significantly different among treatments according to least significant difference (LSD) at $P < 0.05$. AVE: Average; SD: Standard deviation.

Table 4. SPAD value of leek during the growth stage

Parameter	SPAD value					
	78 DAT		118 DAT		158 DAT	
T1	51.1	c	40.1	d	30.8	d
T2	60.3	a	51.1	c	40.8	c
T3	55.4	b	54.7	ab	44.5	b
T4	54.9	b	56.1	a	51.8	a
T5	53.7	bc	53.3	bc	43.0	bc
T6	54.9	b	53.3	bc	50.3	a
LSD (0.05)	3.5		2.7		3.0	

Note: Different letters in the column represent significantly different among treatments according to least significant difference (LSD) at $P < 0.05$.

Table 5. Nitrogen concentration and content in leek leaves and roots

Parameters			N concentration (mg g-1)		N content (mg pot-1)	
Leaf	Harvest 1	T1	36.31	b	240.74	c
		T2	47.18	a	534.68	a
		T3	50.53	a	441.97	ab
		T4	51.15	a	473.81	ab
		T5	49.10	a	332.07	c
		T6	52.09	a	348.27	bc
	LSD		5.11		127.60	
	Harvest 2	T1	33.06	c	269.92	bc
		T2	43.04	b	808.62	a
		T3	46.16	ab	825.25	a
		T4	46.51	ab	907.72	a
		T5	47.40	a	795.57	a
		T6	48.97	a	774.68	a
	LSD		4.26		139.40	
	Harvest 3	T1	34.37	c	52.48	d
		T2	35.99	bc	341.27	bc
		T3	36.23	bc	472.09	b
		T4	38.91	ab	590.17	ab
		T5	36.05	bc	528.14	abc
		T6	41.04	a	742.81	a
	LSD		3.81		208.80	
	Harvest 4	T1	14.29	d	54.39	d
		T2	20.47	c	210.83	cd
		T3	22.37	bc	224.60	bc
		T4	25.44	ab	385.06	ab
		T5	23.67	bc	215.60	cd
		T6	27.27	a	440.60	a
	LSD		3.44		166.60	
Root		T1	7.07	b	201.99	d
		T2	7.40	b	431.84	bc
		T3	7.29	b	418.68	bc
		T4	9.18	a	571.86	a
		T5	7.31	b	393.49	cd
		T6	9.56	a	533.60	ab
	LSD		1.45		134.80	

Note: Different letters in the column represent significantly different among treatments according to Least significant difference (LSD) at $P < 0.05$.

In the third harvest, leaf N concentration in T2 was similar level with that in T3, T4 and T5, but it was significantly lower than that in T6. The leaf N concentration in T4 was not significantly different compared to that in T6. In the fourth harvest, leaf N concentration in T2 was similar to that in T3 and T5, but it was significantly lower compared to T4 and T6. The leaf N concentration in T3 and T5 was similar to that in T4, but it was significantly lower than that in T6. In addition, root N concentrations in T1, T2, T3 and T5 were similar level, but they were significantly lower than that in T4 and T6.

Generally, leaf N content of leek treated with additional organic-N and inorganic-N was significantly higher than that in T1 as a control. In the first harvest, leaf N content of leek in T2 was tended to be higher than that in T3 and T4, and significantly higher than that in T5 and T6. All treatments treated with the additional N had similar leaf N content in the second harvest. In the third harvest, the leaf N content in T2 was not significantly lower than that in T3, T4 and T5, but it was significantly lower than that in T6. In the fourth harvest, the leaf N content in T2 was similar level with that in T3 and T5, but it was significantly lower than that in T4 and T6. In addition, the N content of root in T2 was similar level with that in T3 and T5, and it was not significantly lower than that in T6, but significantly lower than that in T4.

Ammonium-N and nitrate-N of soils

Ammonium-N levels peaked immediately after application and gradually decreased. T6 consistently had the highest ammonium-N levels, followed by T4. In contrast, nitrate-N levels in T2 were significantly higher than in other treatments during the first day after application but decreased more rapidly than in T4 and T6 over time (Figure 4).

Phosphorus and mineral content

Table 6 shows phosphorus (P) and mineral (K, Ca and Mg) contents of leaf and root of leek. In the first harvest, the leaf of leek in T2 had higher P, K, Ca and Mg contents than that in other treatments. In the second harvest, the leaf P, Ca and Mg contents in T2 were higher than that in other treatments, while the leaf K content in T2 was not significantly lower than that in plants treated with organic-N and inorganic-N. In the third harvest, the leaf P and Mg contents in T2 were higher than that in other treatments. Meanwhile, T2 had significant lower leaf K content than T4, T5 and T6, and it had no significant lower leaf Ca content than T4 and T6. In the fourth harvest, the leaf P and K contents in T2 were not significantly lower than that in plants treated with additional N, except for the leaf P content in T4 and the leaf K content in T6. Moreover, the leaf Ca and Mg contents in T2 were similar level with that in plants treated with additional N. In addition, the root P and Ca contents in T2 were higher than that in other treatments. However, the root K content in T2 was significantly lower than that in T4 and T6. The root Mg content in T2 was similar level with that of plants treated with additional. Overall, integrating solid compost with liquid extract-compost or inorganic fertilizers significantly improved leek growth and nutrient uptake, with T4 and T6 showing superior results across multiple growth parameters.

DISCUSSION

The findings of this study provide important insights into the effects of varying solid and liquid organic compost applications on the growth performance and nutrient uptake of leek (*Allium porrum* L.). The use of 3/3N solid compost (T2) demonstrated significant benefits in early plant growth, particularly in plant height and leaf yield during the first regrowth phase. This positive effect can be attributed to the gradual release of nutrients from the solid compost, providing a steady supply of nitrogen (N) essential for plant development. The presence of beneficial microbes in the compost likely facilitated the decomposition of organic matter into inorganic forms, increasing nutrient availability (Nepal et al., 2011). In

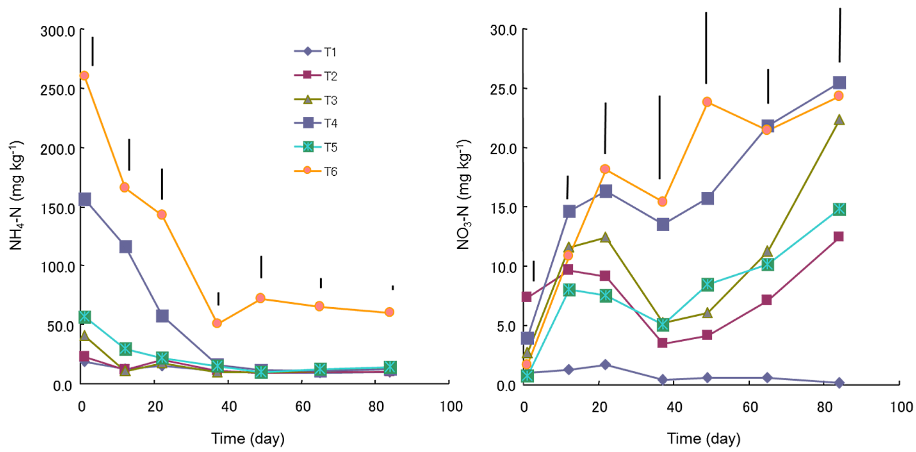

Figure 4. Ammonium-N and nitrate-N concentrations in soil across treatments

Table 6. Phosphorus and mineral contents in leek leaves and roots. Nutrient content (mg pot^{-1})

Parameters		P	K	Ca	Mg
Leaf 1	T1	4.33 bc	43.84 c	14.47 bc	6.59 ab
	T2	8.28 a	169.81 a	24.49 a	7.98 a
	T3	5.92 b	147.88 ab	16.02 b	5.25 bc
	T4	6.47 ab	149.42 ab	19.07 ab	5.75 b
	T5	4.63 b	110.78 b	11.92 bc	4.00 c
	T6	4.55 bc	109.54 b	11.75 bc	4.07 c
	LSD	1.91	41.18	5.51	1.74
Leaf 2	T1	5.06 c	62.01 c	13.56 c	6.65 c
	T2	11.37 a	266.01 ab	31.51 a	12.19 a
	T3	9.94 ab	293.41 a	27.32 ab	8.24 bc
	T4	10.21 ab	309.12 a	30.50 ab	8.81 b
	T5	9.13 ab	267.24 ab	23.70 b	7.19 bc
	T6	8.05 b	235.73 b	25.10 b	6.94 bc
	LSD	2.45	47.13	5.70	2.03
Leaf 3	T1	1.89 b	14.37 c	3.94 c	1.46 c
	T2	9.49 a	142.81 b	21.38 ab	9.10 a
	T3	9.29 a	205.65 ab	20.45 b	6.71 b
	T4	8.73 a	208.52 a	24.02 ab	8.13 ab
	T5	8.58 a	228.01 a	18.59 b	6.02 b
	T6	8.86 a	257.00 a	25.65 a	7.61 ab
	LSD	2.36	63.77	5.15	1.65
Leaf 4	T1	1.93 c	20.77 c	11.21 c	5.12 a
	T2	7.19 b	98.93 b	24.31 ab	8.12 a
	T3	7.13 b	121.87 b	20.73 b	6.25 a
	T4	10.14 a	172.76 ab	29.47 ab	9.15 a
	T5	6.23 b	110.23 b	19.69 bc	6.08 a
	T6	7.38 b	189.64 a	31.73 a	8.95 a
	LSD	2.29	62.51	9.37	NS
Root	T1	10.88 bc	42.59 c	9.62 b	5.81 c
	T2	21.56 a	84.65 b	20.22 a	12.63 ab
	T3	20.09 a	94.20 ab	16.46 ab	10.17 b
	T4	19.61 a	112.73 a	20.06 ab	13.14 a
	T5	17.26 ab	83.58 b	11.55 b	8.95 b
	T6	14.22 b	115.76 a	14.82 b	9.81 b
	LSD	4.51	23.35	5.29	2.83

Note: Different letters in the column represent significantly different among treatments according to Least significant difference (LSD) at $P < 0.05$.

contrast, treatments with higher proportions of liquid applications, such as T5 (1/3N solid compost + 2/3N liquid extract-compost), resulted in lower leaf yields during the first regrowth. This phenomenon may be explained by the initial high concentration of ammonium-N released from the liquid compost, which can inhibit seedling establishment and early plant growth due to ammonium toxicity (Britto and Kronzucker, 2002). However, as the plants acclimated and soil ammonium-N levels decreased, leaf yields in organic treatments improved during the second growth phase, highlighting the dynamic nutrient release patterns inherent to organic amendments.

The superior NUE observed in treatments combining solid compost with inorganic fertilizers, particularly T4 (2/3N solid compost + 1/3N inorganic fertilizer), reaching 84.36%, underscores the effectiveness of integrating organic and inorganic nutrient sources. This combination likely provided an optimal balance between immediate and sustained nutrient availability, supporting continuous plant growth and maximizing biomass production. Conversely, treatments solely reliant on organic inputs demonstrated lower NUE (approximately 60%), indicating that while organic fertilizers can sufficiently support leek cultivation, their efficiency can be further optimized by adjusting application rates and combinations.

The SPAD values, which serve as indicators of chlorophyll content and photosynthetic efficiency, further corroborated the role of nutrient availability in plant growth. T2 exhibited the highest SPAD values during the initial stages, reflecting enhanced chlorophyll synthesis due to sufficient nitrogen supply. Over time, SPAD values in treatments involving liquid applications (T4 and T6) surpassed those of T2, likely due to the immediate availability of nutrients in these treatments, enhancing photosynthetic activity and subsequent growth. Biomass accumulation patterns across harvests revealed that treatments incorporating inorganic fertilizers (T4 and T6) consistently outperformed purely organic treatments in total leaf and root biomass. However, it is notable that the yield gap between organic and inorganic treatments diminished in later harvests, suggesting that organic amendments, when adequately decomposed, can support sustained crop productivity. The lower potassium (K) input in the 3/3N solid compost (T2) may have limited its performance in later growth stages, highlighting the need for balanced nutrient management to prevent potential deficiencies.

Soil ammonium-N and nitrate-N dynamics offer further insights into nutrient availability and plant uptake. The rapid decline in ammonium-N concentrations following liquid fertilizer applications in T4 and T6, coupled with a gradual increase in nitrate-N, suggests a conversion process that eventually benefits plant growth. However, the initial spike in ammonium-N may have posed a risk of toxicity, particularly in treatments with higher liquid fertilizer proportions. This underscores the importance of managing nutrient release rates to align with plant uptake capacities, minimizing growth inhibition.

Phosphorus (P), calcium (Ca), and magnesium (Mg) contents in plant tissues were consistently higher in T2 during early harvests but were eventually surpassed by T4 and T6 in later stages. This transition reflects the more immediate availability of these nutrients in inorganic forms, as opposed to the slower mineralization processes associated with organic amendments. Potassium content, in particular, was markedly higher in treatments with greater liquid fertilizer input, emphasizing the role of liquid applications in supplying readily available K.

The gradual nutrient release from solid compost and the immediate nutrient supply from liquid fertilizers collectively influenced plant growth patterns. Treatments with balanced combinations, such as T4, achieved superior performance by leveraging both nutrient release mechanisms. In contrast, treatments with disproportionate nutrient sources, either solid or liquid, faced challenges in meeting the plants' evolving nutrient demands throughout the growth cycle. Despite these promising findings, certain limitations must be acknowledged. The potential phytotoxic effects of liquid extract-compost, due to high salt and ammonium concentrations, may have hindered root and microbial activity during early growth stages. Future studies should investigate strategies to mitigate these effects, such as staggered applications or dilution adjustments. Additionally, the study focused solely on leek, a crop relatively tolerant to ammonium-N, and the findings may not be directly transferable to other crops with differing nutrient sensitivities.

Further research is warranted to explore the effects of various organic composts derived from different raw materials and processed with diverse microbial additives. Such studies could provide a more comprehensive understanding of how organic inputs influence nutrient dynamics and plant growth across different soil types and crop species. Additionally, long-term field trials are necessary to evaluate the sustainability and environmental impacts of integrating organic and inorganic fertilizers on a larger scale.

CONCLUSIONS

This study provides comprehensive insights into the impact of solid compost and liquid extract-compost, individually and in combination with inorganic fertilizers, on the growth and nutrient uptake of leek (*Allium porrum* L.). The findings indicate that the application of 3/3N solid compost significantly enhances early plant height and leaf yield due to its gradual nutrient release and microbial-assisted nutrient availability.

However, the combination of 2/3N solid compost with 1/3N inorganic fertilizer (T4) was the most effective in maximizing total biomass production and NUE, demonstrating the advantage of integrating organic and inorganic nutrient sources.

Organic treatments alone, while beneficial, exhibited lower NUE compared to combined organic-inorganic treatments, highlighting the limitations of relying solely on organic fertilizers for sustained growth. The initial inhibitory effects of high ammonium-N concentrations in liquid compost underscore the need for careful management of nutrient sources to prevent phytotoxicity. This research contributes to the growing body of knowledge on sustainable agriculture by emphasizing the critical role of balanced nutrient management. It provides valuable recommendations for integrating organic and inorganic fertilizers to optimize crop yields and support environmental sustainability. Future studies should investigate diverse organic amendments and microbial applications to further improve nutrient efficiency and long-term soil health.

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