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Effects of kitchen waste compost and chemical fertilizer application on spinach (*Spinacia oleracea* L.) c.v. Matador plant growth and nitrate accumulation

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ABSTRACT

In this study, the effects of organic and chemical fertilizer sources on some essential nutrient elements content, nitrate (NO_3^- -N) accumulation, and the growth of spinach plant (*Spinacia oleracea* L.) were investigated. The experiment was carried out in a randomized plot design under greenhouse conditions, with two levels. 1st level; applications with chemical fertilizer. 2nd level; applications without chemical fertilizer. One compost material (kitchen waste compost = KWC), five different doses (0, 0.4, 0.8, 1.2, and 1.6%), and three replications. For chemical fertilization, nitrogen (N) dose of 150 kg ha^{-1} was applied by using 15-15-15 NPK ($\text{N:P}_2\text{O}_5:\text{K}_2\text{O}$) fertilizer. Overall, KWC applications increased plant growth and nutrient content. However, the most significant increases occurred in the trial subjects where chemical fertilizer and KWC were applied together. The use of KWC together with chemical fertilization increased the leaf width, leaf and stem length, fresh weight, and dry weight, as well as nitrate accumulation, N, potassium (K), and iron (Fe) content of the plant. The highest values of these parameters were obtained at 0.8% dose of KWC + NPK medium. As a result, compost applications were effectively uptake of nutrients and nitrate accumulation remained at acceptable values.

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Compost; fertilizer; kitchen waste; nutrition; plant growth; *Spinacia oleracea*

Introduction

Spinach (*Spinacia oleracea* L.) is an annual cool climate, green leafy, edible vegetable belonging to the Amaranthaceae family (Deveci et al. 2018). Spinach is among the vegetables whose leaves are usually consumed the most in the world (Abubaker et al. 2010; Koh, Charoenprasert, and Mitchell 2012; Massa et al. 2018). Spinach can be found in markets throughout the year (Ribera et al. 2021). Spinach is considered a functional food because it is a rich supply of beta carotene, folic acid, flavonoids, omega-3 fatty acids as well as rich in lutein and zeaxanthin. Spinach contains vitamins A, C, E, and K, and some minerals, such as calcium (Ca), magnesium (Mg), selenium (Se), and Fe (Correll et al. 2011; Singh et al. 2018; Giménez et al. 2021). Spinach grows rapidly in soils rich in organic matter and comes to harvest maturity in a short time (Maftoun et al. 2004). Spinach is susceptible plant to fertilization, especially N fertilization. However, excessive and unconsciously used nitrogenous chemical fertilizers increases the plants nitrate accumulation, which is harmful to human health (Gryźna 2005; Souri, Rashidi, and Kianmehr 2018; Souri and Hatamian 2019). Excessive use of inorganic fertilizers affects the soil texture and structure, decreases the soil organic matter content, and inhibits microbial activities in the soil

(Nirgude et al. 2019). New paths in plant production achieve importance due to environmental problems caused by agricultural chemicals used extensively in traditional methods (Gupta and Sharma 2014; Ozenc and Senlikoglu 2017). It has been stated that the combined application of inorganic and organic fertilizers to the vegetables increases the yield, and could be used a method to prevent environmental problems (Yusheng et al. 2005). Furthermore, many farmers have low financial resources to purchase sufficient inorganic fertilizers to supply N nutrients adequately. So due to the high cost of imported agricultural inputs, many farmers need for stable and quality materials produced locally (Anwar et al. 2017; Thapa et al. 2021). The use of composts has been improving soil aggregation, structure, and fertility, increasing microbial diversity and populations, improving the moisture-holding capacity of soils, increasing the soil cation exchange capacity, and increasing crop yields (Rahman and Akter 2017; Machado et al. 2020). In addition, the application of compost may induce resistance against soil-borne diseases and increasing antioxidant capacity (Giménez et al. 2021). The compost can meet crops nutrient demand and significantly reduce synthetic fertilizers use (Jakhro et al. 2017). The destinations of urban sludge and other biosolids provoke environmental problems and their agricultural reuse as a compost is essential to avoid those problems (Reis et al. 2014). Materials typically suitable for composting include kitchen waste, biodegradable municipal waste, and other enriched organic waste streams, such as sewage sludge, agricultural, and food processing wastes (Furukawa and Hasegawa 2006; Rahman and Akter 2017).

Economic development and population growth have significantly increased food consumption and thus the generation of kitchen waste in recent years (Hafid et al. 2017). Kitchen waste is commonly mixed with other municipal wastes and ends up in landfills but food waste could be converted for beneficial use (Kadir, Azhari, and Jamaludin 2016; Ghinea and Leahu 2020). Recently, studies on the evaluation of kitchen waste for its sustainable management have been increasing (Yang et al. 2019). Previous lab research demonstrated that food-based composts can increase soil nutrient content relative to manure-based composts, but these benefits need to be tested more within a crop system (Kelley et al. 2022).

In this study the effects of organic vs. combined inorganic fertilizer with organic sources of nutrients on the growth, and the accumulation of nitrates in the leaves of a c.v. Matador spinach was compared. Composted kitchen waste is used for organic fertilization whereas standard NPK fertilizer applied by farmers in the area is used for the inorganic fertilizer material. Fertilization from both sources was applied at a different dose during the autumn season in the same soil. The effects of compost and cumulative fertilization on spinach plants were studied. The aim of this study carried out under the greenhouse conditions was to evaluate the effects of chemical fertilizer use and KWC applications on the development of spinach (*S. oleracea* L.) plants. Our main target was to recommend the appropriate KWC dose to increase spinach yield with considering the nitrate values.

Materials and methods

Materials

The pot experiment was carried out in the greenhouse of Bursa Uludag University, Faculty of Agriculture (40° 13' 36" N latitude, 28° 51' 35" E longitude), Department of Soil Science and Plant Nutrition during the autumn of 2021. The soil used in the experiment was taken from the land of Bursa Uludag University, Faculty of Agriculture, Agricultural Application and Research Center at 0–20 cm depth. The soil used in the experiment is in the class of Vertisol (Typic Haploxerert) according to the soil classification system and Eutric Vertisol according to the FAO/Unesco classification system (Aksoy et al. 2001). It has a sandy clay loam texture, is

Table 1. Some physical and chemical properties of the soil used in the research.

Properties	Unit	Value	Status	References
pH		7.25	Neutral (6.5–7.5)	Richards 1954
EC	mS cm ⁻¹	0.09	None saline (0–4)	Rhoades 1982
CaCO ₃	%	1.55	Very low (1–5)	Ulgen and Yurtsever 1988
Organic matter	%	1.10	Low (1–2)	Jackson 1958
Clay	%	27.85		
Silt	%	18.75		
Sand	%	53.46		
Texture	Sandy clay loam			USDA 2013
Field capacity	%	36.10		
Total N	%	0.09	Low (0.045–0.09)	Ulgen and Yurtsever 1988
Available P	mg kg ⁻¹	8.43	Moderate (5–10)	Olsen and Dean 1965
Exchangeable K	me 100 g ⁻¹	0.46	Moderate (0.39–0.51)	Pizer 1967
Exchangeable Ca	me 100 g ⁻¹	19.75	High (17.6–50.0)	FAO 1990
Exchangeable Mg	me 100 g ⁻¹	2.41	Sufficient (1.34–4.0)	FAO 1990
Exchangeable Na	me 100 g ⁻¹	0.49	None sodic (<30.4)	Anonymous 1951
Available Fe	mg kg ⁻¹	9.54	Good (>4.5)	Lindsay and Norvell 1978
Available Cu	mg kg ⁻¹	2.25	Sufficient (>0.2)	Lindsay and Norvell 1978
Available Zn	mg kg ⁻¹	1.12	Sufficient (0.7–2.4)	FAO 1990
Available Mn	mg kg ⁻¹	19.48	High (>5)	FAO 1990

Table 2. Some physical and chemical properties of the KWC used in the research.

Analysis		KWC	Analysis		KWC	
Reaction (pH)		6.05	Total	%	N	5.64
EC, mS cm ⁻¹		5.81			P	0.15
C/N ratio		8.61			K	1.37
%	Dry weight	45.65			Ca	0.44
	Organic material	83.63			Mg	0.16
	Organic carbon	48.51			Na	0.11
	Humic matter	9.25		mg kg ⁻¹	Fe	165.00
	Humic acid	3.16			Cu	17.00
	NH ₄ ⁺ -N	0.20			Zn	26.00
	NO ₃ ⁻ -N	0.29			Mn	125.00

neutral, non-saline, and is in the low class in terms of organic matter content. In terms of content, total N was low while, available phosphorus (P) and K were moderate (Table 1).

KWC was obtained as a source of organic matter by collecting the fruit and vegetable wastes from the kitchen of a family of four, in a short period in the autumn-winter season and mixed with fine sawdust used as a carbon source. Then prepared by keeping it in a simple and small-scale home composter under greenhouse conditions after the 121 days composting process waited in bulk (Voběrková et al. 2020). The 15-15-15 NPK [15% (ww⁻¹) N—15% (ww⁻¹) P₂O₅—15% (ww⁻¹) K₂O] chemical fertilizer was used as an inorganic N, P, and K source. To define the soil and compost material used in the experiment, some basic physical and chemical analysis results were given in Table 2. The Matador variety from Amaranthaceae family was selected as spinach seed.

Methods

Experiment set up

The experiment was conducted in a randomized plot experimental design. The experiment has two levels. Level 1; chemical fertilizer applied, level 2; no chemical fertilizer applied. One compost material (KWC), five compost rates; 0, 0.4, 0.8, 1.2, and 1.6% (w.w⁻¹), one plant variety (Spinach c.v. Matador), was randomly allocated in three replications (30 pots in total). The experiment was carried out in 5.5 L polyethylene pots (diameter: 21 cm; height: 16 cm). In the trial, soil was sieved

through a 4 mm sieve. Each pots were filled with 2.5 kg of soil separately. Then, KWC was prepared separately at the determined rates filled into the pots, and grouped for each application. The NPK chemical fertilizer was calculated from the application of 150 kg N ha⁻¹ (Rouphael et al. 2018) and applied to the pots in the group of chemical fertilizer applications had done. So that the NPK compound fertilizer was given to fifteen pots before planting and all fertilization processes were completed. The soils were incubated at field capacity for 20 days under greenhouse conditions (Gulser, Demir, and Ic 2010). Later spinach seeds were planted in the pots at a depth of 3–4 cm at intervals and the pots were watered with pure water up to 40% of the field capacity. The 3 plants showing the best emergence and germination were left in pots and thinned out. All the planting procedures of the experiment were completed in one day. Until the end of the experiment, the necessary cultural processes were carried out in spinach cultivation. The trial was harvested ~90 days later. Some experimental photos are shown in Figure 1.

Analysis methods

Before the plants were harvested, the leaf color of each plant was determined by a portable chlorophyll meter (Konica Minolta Spad-502; Konica Minolta Sensing, Inc., Japan) and given as SPAD value. The harvesting process of the plants was carried out from the root collar part (Kacar and Inal 2008). The leaf lengths of the harvested plants were measured with the help of a ruler by carefully separating the leaves from the knuckle without wasting time. The fresh weights of plants were taken by a micro scales after this measurement. The plants were washed first with tap water, 0.01 M hydrochloric acid (HCl) solution, then with distilled water, respectively. The leaf samples were oven-dried at 65 °C for 48 h (Kacar and Inal 2008). The dry weights were also taken after the plants were dried. The leaf samples were grounded in a stainless steel mill to pass through a 0.5 mm sieve (Kacar and Inal 2008). The leaf samples were digested with 2 ml hydrogen peroxide (H₂O₂, 30%) and 8 ml nitric acid (HNO₃, 65%) in closed pressured vessels in a microwave oven (Anonymous 1994). The plant samples were dissolved for total element analysis, microwave-assisted acid decomposition was performed at high temperature and pressure (Berghof speedwave MWS-2). The Fe, zinc (Zn), copper (Cu), manganese (Mn), and Mg contents in the digest were analyzed with an inductively coupled plasma emission spectrometer (PE Optima 8300 ICP-OES). Total N was determined by the Kjeldahl method reported by Bremner (1965). Total P was determined by the vanado molybdo phosphoric acid method (Kacar and Inal 2008). Total K, Ca, and sodium (Na) were determined as reported by Kacar and Inal (2008) by flame photometer (Eppendorf Elex 6361). Care was taken to prevent contamination at all steps in the process. The NO₃⁻-N accumulation in the plant was determined colorimetrically by nitriding of salicylic acid method according to Cataldo et al. (1975).

To determine the properties of the trial soil, soil samples taken from 0 to 20 cm depth were air-dried and then sieved from the 2 mm sieve. The soil texture was determined using the hydrometer method (Bouyoucos 1951) and identified using the U.S. Department of Agriculture soil taxonomy (USDA 2013), bulk weight, and field capacity according to Tan (2005). The soil reaction (pH) and electrical conductivity (EC) were measured in a 1:2.5 soil to water ratio mixture (Jackson 1958). The soil organic carbon was determined by the wet oxidation method of Walkley and Black (1934). Exchangeable cations (Ca, Mg, and K) were determined after extraction with 1 M ammonium acetate (NH₄OAc) at pH 7.0 (Kacar 2009). The extract was analyzed for Ca and K by Eppendorf Elex 6361 model flame photometer and for Mg by PE Optima 8300 ICP-OES. Available P was extracted by 0.5 M sodium bicarbonate (NaHCO₃) at pH 8.5 (Olsen and Dean 1965) and concentration was measured colorimetrically after developing the blue color with ascorbic acid. Available Fe, Zn, Cu, and Mn contents of the soils were extracted by 0.005 M diethylene triamine penta acetic acid (DTPA) extractant (Lindsay and Norvell 1978). The concentration was measured by PE Optima 8300 ICP-OES. Some physical and chemical soil characteristics are given in Table 1.



Figure 1. Views from the trial in different growth periods.

Some properties of the KWC were determined after maturation. Samples were oven-dried at 65 °C for 48 h (Kacar and Kutuk 2010). The dry weights were also taken after the composts were dried. The compost samples were grounded in a stainless steel mill to pass through a 0.5 mm sieve (Kacar and Kutuk 2010). The KWC samples were digested with 2 ml H₂O₂ (30%), and 8 ml HNO₃ (65%) in closed pressured vessels in a microwave oven (Anonymous 1994). The humic acid and humic matter were determined according to Swift et al. (1996), pH and EC were determined in a 1:10 (w/v) compost to water ratio suspension by using WTW 3110 pH meter and WTW 3310 EC meter, respectively (Kacar and Kutuk 2010). The amount of organic carbon was determined according to the modified Walkley-Black method (Kacar and Kutuk 2010). Also, the organic matter content was determined by multiplying the amount of organic carbon with the Van Bemmelen factor (Kacar and Kutuk 2010). Ammonium (NH₄-N) was determined by Indophenol Blue Method (Solorzano 1969) and NO₃-N was determined colorimetrically according to nitration of salicylic acid in the presence of sulfuric acid (Robarge, Edwards, and Johnson 1983). Total N was determined by the Kjeldahl method as reported by Bremner (1965). The total P content was determined by using a Bausch & Lomb brand Spectronic 20 model spectrophotometer according to the vanadomolybdophosphoric yellow color method (Kacar and Inal 2008). The total Na, K, and Ca amounts of the KWC samples were determined according to the dry burning method, with the Eppendorf Elex 6361 model flamephotometer device. Total Mg was determined with the Perkin Elmer Optima 2100 model ICP-OES device (Pratt 1965). The Fe, Cu, Zn, and Mn amounts of KWC samples were determined by, Perkin Elmer Optima 2100 model ICP-OES device (Kacar and Inal 2008).

The data obtained at the end of the experiment were analyzed with the analysis of variance according to the randomized parcels trial design in the 'JUMP' package program, and the LSD multiple comparison test was applied at 1 and 5% significance levels to determine the difference between the applications in the statistically significant results. The results are expressed as letters next to the averages.

Results and discussion

Leaf length and stem length

Applying KWC to the soil at increasing rates caused significant differences in the leaf length and stem length of the spinach plant. Especially, the application of chemical NPK fertilizers with KWC was more effective on plant leaf growth (Table 3). In the study, the leaf length varied between 14.00 and 17.11 cm (mean 15.15 cm) depending on KWC added doses to the soil. With the combined application of KWC + NPK fertilizers, leaf lengths changed between 17.39 and

Table 3. The effects of KWC and chemical fertilizer applications on some leaf characteristics of spinach plant.

NPK Fertilizer application	% KWC doses	cm Leaf length	cm Stem length	cm Leaf width	g Fresh weight	g Dry weight	Spad
NPK added	0	17.39 bcd	7.83 b	7.50	42.43 bc	4.41 bcde	49.30 bc
	0.4	18.89 b	8.05 b	7.83	55.29 a	5.07 abc	53.26 ab
	0.8	22.27 a	10.49 a	9.00	54.30 a	4.92 abcd	55.20 a
	1.2	18.00 bc	8.27 b	7.00	55.32 a	5.31 a	55.70 a
	1.6	17.83 bcd	8.28 b	6.84	47.71 ab	5.23 ab	52.86 ab
Not added	0	14.00 e	5.50 e	5.65	20.23 e	2.31 g	49.20 bc
	0.4	15.05 de	6.11 cde	5.66	28.65 de	3.23 f	48.43 bc
	0.8	14.00 e	5.94 de	5.83	31.74 cd	3.59 ef	50.26 abc
	1.2	15.61 cde	7.00 bcd	6.00	39.76 bc	4.04 def	53.23 ab
	1.6	17.11 bcd	7.50 bc	7.16	40.17 bc	4.19 cde	46.20 c
F-test		*	**	n.s.	**	**	*

n.s.: not significant.

* $p < 0.005$, ** $p < 0.001$.

Means with different letters represent statistically significant differences according to least significant difference (LSD) test at $p < 0.05$.

22.27 cm (mean 18.87 cm). Combined application of KWC + NPK increased the spinach plant leaf length content by 24.55%, where the whole mean of spinach leaf length value of KWC + NPK applied plants was 18.87 cm compared to 15.15 cm for KWC alone. On the other hand, the stem length ranged between 5.50 and 7.50 cm (mean 6.41 cm) *via* KWC added doses to the pots. With the combined application of KWC + NPK fertilizers, the stem length varied between 7.83 and 10.49 cm (mean 8.58 cm). The application of KWC + NPK increased the content of spinach plant stem length by 33.85% compared to KWC alone applications. The leaf length ($p < 0.05$) and stem length ($p < 0.01$) parameters of spinach were significantly influenced by the combined application of KWC with chemical fertilizer treatments (Table 3). The most statistically significant increase in plant length was obtained by combining the application of 0.8% KWC with NPK chemical fertilizer into the soil (Table 3). Islam et al. (2011) reported that organic manure alone had no significant effect on plant height, but a manure in combination with chemical fertilizers had a significant impact on plant height. They had the longest size on spinach by using the recommended fertilizer level combined with 5 t ha⁻¹ household waste. It was stated that the yield elements of spinach plants enhanced with the increase in the doses of nitrogenous and organic fertilizers (Wang and Li 2004; Jakhro et al. 2017; Karatas and Buyukdinc 2017; Das, Dash, and Mannan 2018). This increment could be due to the presence of phytohormones in organic fertilizers that incite plant growth (Hernández et al. 2010). Although the application of KWC to the soil enhanced the leaf width of the spinach plant, there were no significant differences determined between KWC treatments with means of leaf width (Table 3). Thapa et al. (2021), suggested that some parameters of spinach can be maximized by combined application of chemical N with farm-yard manure (FYM).

Plant weight

The fresh weight and dry weight of spinach were enhanced with the application of KWC by increasing doses (Table 3). The addition of KWC alone increased the fresh weight of the spinach plant from 20.23 to 40.17 g (mean 32.11 g) and the application of NPK + KWC together increased the fresh weight of spinach from 42.43 to 55.32 g (mean 51.01 g). Combined application of KWC with NPK increased the content of spinach plant fresh weight by 58.86%. KWC addition enhanced the dry weight of the spinach plant from 2.31 to 4.19 g (mean 3.47 g) and KWC + NPK elevated the dry weight of spinach from 4.41 to 5.31 g (mean 4.98 g). Combined application of KWC + NPK increased the content of spinach plant dry weight by 43.75%. The data indicated that varied levels of organic compost and inorganic fertilizer had a significant ($p < 0.01$) effect on fresh weight and dry weight of spinach (Table 3). The highest fresh weight (55.32 g) and dry weight (5.31 g) results were obtained when 1.2% KWC was applied with NPK chemical fertilizer (150 kg N ha⁻¹). Some authors reported that spinach requires soils with high organic content and adequate mineral nutrients favored the production of higher plant fresh and dry weight (Sato et al. 2010; Irshad et al. 2014; Ozenc and Senlikoglu 2017). Previous research showed that inorganic elements and composts when applied in combination at higher rates produced an excellent performance for fresh weight and dry weight of spinach (Maftoun et al. 2004; Jakhro et al. 2017; Machado et al. 2020; Thapa et al. 2021).

SPAD values

The SPAD (Chlorophyll meter) values of the leaves, measured before harvesting the experiment were given in Table 3. KWC addition increased the SPAD values of the spinach plant from 49.20 to 53.23 (mean 49.42) compared to the control. KWC + NPK fertilizer together increased SPAD from 49.30 to 55.70 (mean 53.26) compared to the control. Combined application of KWC + NPK increased the SPAD values of the spinach plant by 7.77%. The results showed a

sustained increase with the increasing doses of KWC administered. SPAD values appear to decrease after a dose of 1.2%. SPAD values were determined statistically significant ($p < 0.05$). The highest SPAD value (55.70) was obtained with 1.2% KWC kg^{-1} + NPK inorganic fertilizer. Massa et al. (2018) reported that plants grown under suboptimal levels of N in the root zone (i.e. below Nopt) show a reduced yield and tissue content of mineral nutrients and SPAD index. Also, they stated that the use of optical sensors (e.g. the SPAD by Minolta used in the present work) can be helpful for growers to check quickly the N nutritional status of the crop; SPAD index higher than 64.0 would ensure optimal N nutrition in fresh-market spinach. Mola et al. (2020) reported that the spinach yield and SPAD index were also affected by the N rate, with an increasing trend. Cozzolino et al. (2020) reported an increase in SPAD index with increased N dose on spinach and lettuce.

Nitrate ($\text{NO}_3\text{-N}$) accumulation in leaves

The data of spinach plant nitrate content that was affected by KWC with/without NPK fertilizer were given in Table 4. In the leaf of the spinach samples, the $\text{NO}_3\text{-N}$ concentration varied from 156.05 to 717.31 mg kg^{-1} (mean 494.67 mg kg^{-1}) depending on KWC added doses to the soil. The combined application of KWC with chemical NPK fertilizers changed between 528.89 and 1062.22 mg kg^{-1} (mean 655.06 mg kg^{-1}). The combined application of KWC + NPK increased the content of spinach plant nitrate by 32%. The highest nitrate accumulation was observed in the treatment of 1.6% KWC with NPK inorganic fertilizer showed the highest nitrate concentration (1062.22 mg kg^{-1}) compared to all fertilization treatments. Previous studies have demonstrated that nitrate levels are often higher in conventional produce compared to organic produce (Bourn and Prescott 2002; Chassy et al. 2006; Mitchell, Meyers, and Koh 2008; El-Agrodi et al. 2012). While the nitrate content of the spinach plant, which was applied chemical fertilizers with KWC together enhanced significantly compared to the KWC application patterns without chemical fertilizer, it also created statistically significant ($p < 0.01$) differences (Table 4). As seen from the table, N added with chemical fertilizer application caused the nitrate content in the plant to increase considerably. Previous studies reported that the nitrate concentration in spinach was found to increase significantly with N application rates (Elia, Santamaria, and Serio 1998; Stagnari, Di Bitetto, and Pisante 2007). Spinach is one of the highest NO_3^- accumulators because of a very efficient uptake system and an inefficient reductive system (Ott, Koenig, and Miles 2008). Accumulation of nitrates results from an imbalance between the uptake and translocation of nitrates by the xylem, and the reduction of these nitrates to ammonia which is subsequently rapidly incorporated into amino acids (Ott, Koenig, and Miles 2008). Accumulation of nitrates in

Table 4. The effects of KWC and chemical fertilizer applications on some macronutrient content of spinach plant.

NPK Fertilizer application	KWC doses	mg kg^{-1} NO_3^-	%					
			N	P	K	Ca	Mg	Na
NPK added	0	528.89 e	4.27 abc	0.29	5.35 c	1.47 a	0.97	0.47
	0.4	690.27 cd	4.44 ab	0.31	5.97 bc	1.46 ab	1.01	0.47
	0.8	1009.91 ab	4.54 ab	0.30	6.92 a	1.27 abcd	0.93	0.50
	1.2	993.95 ab	4.45 ab	0.29	6.50 ab	1.17 d	0.92	0.44
	1.6	1062.22 a	4.69 a	0.30	6.92 a	1.10 d	0.92	0.42
Not added	0	156.05 e	3.57 d	0.36	5.90 bc	1.42 abc	0.67	0.40
	0.4	226.10 e	3.73 d	0.40	5.49 c	1.21 bcd	0.93	0.49
	0.8	793.12 bc	3.93 cd	0.32	5.85 c	1.18 cd	0.79	0.38
	1.2	580.76 cd	4.21 abc	0.33	6.79 a	1.15 d	0.84	0.44
	1.6	717.31 cd	4.42 ab	0.32	6.74 a	1.09 d	0.93	0.41
F-test		**	*	n.s.	**	*	n.s.	n.s.

n.s.: not significant.

* $p < 0.005$, ** $p < 0.001$.

Means with different letters represent statistically significant differences according to least significant difference (LSD) test at $p < 0.05$.

plants has been shown to be affected by some factors, such as the soil texture, the source of fertilizer-N, the $\text{NH}_4\text{-N}$ to $\text{NO}_3\text{-N}$ fertilizer-N ratio, the timing of fertilizer-N release, the low light intensity and duration, crop season, plant type and cultivar (Pavlou, Ehaliotis, and Kavvadis 2007).

Ayaz and Yurttagul (2006) reported the amount of nitrate found as 486.00–726.37 mg kg^{-1} for spinach whereas. Koh, Charoenprasert, and Mitchell (2012) obtained a lower average of nitrate at 217 $\text{mg } 100 \text{ g}^{-1}$ of fresh weight for spinach grown in the USA. The European Commission has specified nitrate levels for spinach and lettuce as the maximum acceptable limit of 3000–4500 mg kg^{-1} for winter, and 2500–3500 mg kg^{-1} for summer (MAFF 1999). According to the Turkish Food Codex, the maximum allowable nitrate amount for spinach and lettuce is 3500 mg kg^{-1} fresh weight (TFC 1997). The nitrate content of spinach samples was consistent with the values referred to above. On the other hand, the nitrate content of the spinach samples of this study was determined lower than the values reported in the codex.

Total nitrogen

KWC addition increased the N content of the spinach plant from 3.57 to 4.42% (mean 3.97%) compared to the control (Table 4). Combined application of NPK and KWC increased total N concentration in spinach from 4.27 to 4.69% (mean 4.48%) compared to the control. Comparing the mean N values of KWC + NPK between KWC shows that the combined application of KWC + NPK increased the N values of the spinach plant by 12.85% compared to the application of KWC. The effect of the KWC usage was found to be statistically significant ($p < 0.05$) on the N concentrations of the spinach plants (Table 4). The highest leaf N concentration was found at 4.69% and observed by 1.6% KWC + NPK fertilizer. The N contents of the spinach leaves were considered normal for spinach according to the nutrient sufficiency range of N (4.0–6.0%) proposed by Mills and Jones (1996). Notably, the total N amount in the spinach plant significantly increased in pots, where inorganic fertilizer was added. Plants without the addition of chemical fertilizer to the KWC showed less development, and it is considered that there is less nutrient accumulation due to the low dry matter content in these plants. Many authors reported a positive relationship between crop yield and increasing N fertilizer rate in spinach cultivated in an open field or under a greenhouse (Wang and Li 2004; Gülser 2005; Stagnari, Di Bitetto, and Pisante 2007; Massa et al. 2018; Thapa et al. 2021). In this study, the KWC with an 8.61 C/N ratio was used near the suggested range for food waste which should promote slow N mineralization. A similar C/N ratio was reported by some studies for food waste compost (Seo et al. 2004; Adhikari et al. 2008). Using organic compost combined with inorganic N could provide a strategy for overcoming the irregular release of N by compost and producing high yields (Machado et al. 2020). According to Zhang et al. (2015), N applications between 86 and 152.74 kg ha^{-1} could be recommended as the optimal treatment for spinach growth. Kelley et al. (2022) recommended N rate as 101 kg ha^{-1} .

Total phosphorus and potassium

Effects of compost and NPK fertilizer usage on P percentages of spinach plants are shown in Table 4. The P concentration of plants did not vary between NPK added and not added treatments, the average level was found with 0.32%. However, this value is sufficient compared to the limit values (0.3–0.5%) of the P content of the spinach plant (Mills and Jones 1996). El-Agrodi et al. (2012) reported that compost effects did not appear on P content of the spinach plant, whenever NPK fertilization was done. Ozenc and Senlikoglu (2017) determined a similar result in their study with the spinach plant. Mupondi, Mnkeni, and Brutsch (2006) stated that leaf N, P, and K concentrations were affected depending on the characteristics of the compost they used in

the vegetable seedlings they were working with, but the inorganic fertilization used did not affect the leaf P concentration. Some researchers (Cıttak et al. 2011; Barral et al. 2011) reported that differences in P mineralization rate among organic fertilizers due to different fixation and microbial immobilization.

Data from Table 4 shows K concentration in spinach plants as affected by KWC with/without NPK fertilization. The highest K concentration (6.79%) was determined due to KWC at the 1.2% dose. A little increase (15%) was determined in K % due to applying KWC. On the other hand under the treatment of KWC+NPK fertilization, the highest K concentration (6.92%) was obtained from 0.8 to 1.6% dose. The combined application of organic and inorganic fertilization increased the K level (29%) better. The effect of the KWC with chemical fertilizers (15-15-15) on the total K content of the spinach plant was found to be statistically significant ($p < 0.01$). El-Agrodi et al. (2012) reported a slight increase in K content due to organic fertilizer addition compared with no addition. Kelley et al. (2022) reported that food-based compost produced a higher yield and greater N, P, and K accumulation in spinach (cv 'Arrowhead'). They stated that positive relationship between compost inputs of K and plant-available N (especially $\text{NO}_3\text{-N}$) and yield. The critical values for the sufficient levels of K in spinach were given as 3–8% by Mills and Jones (1996). According to these critical values, K contents, which varied between 5.35 and 6.92% were found as sufficient.

Total calcium, magnesium, and sodium

Application of KWC with NPK chemical fertilizers reduced the Ca, Mg, and Na content of the spinach plant (Table 4). The effect of the KWC with chemical fertilizers on the total Ca content of the spinach plant was found to be statistically significant ($p < 0.05$) (Table 4). Application of KWC without chemical fertilizers slightly increased the Mg content of spinach. However, no notable difference in Mg and Na content was observed according to treatments as shown in Table 4. The critical values for the sufficient levels of this macronutrient in spinach were given as 1.0–1.5% dry weight for Ca and 0.4–1.0% for Mg by Mills and Jones (1996). According to these critical values, Ca contents, which varied between 1.09 and 1.47%, were found as sufficient and high. The Mg contents, which varied between 0.67 and 1.01%, were found as sufficient. Data also show the Na concentration in the spinach plant in Table 4. The mean Na concentrations of KWC application and combined KWC+NPK application were 0.46 and 0.42%, respectively. Comparisons between data explained that treatments did not significantly affect the Na content of spinach plants.

Singh et al. (2018), reported that organic and inorganic fertilizers increased Ca content in leaf of spinach. Organic matter (1% organic carbon) addition adsorbed the native soil Mg, thus Mg content decreased in spinach leaves. According to Gülser (2005), different application doses of mineral fertilizers, such as ammonium sulfate and urea generally cause irregular changes in Ca and Mg contents in spinach. However, these changes in the macronutrient contents of spinach were not statistically significant. Yalcintepe (2021), determined that the effect of organic fertilizer types (sheep manure, cow manure, vermicompost) on the Ca content of the spinach plant was found to be statistically insignificant, but significant for Mg. Machado et al. (2020) reported that the application of N led to an increase in leaf nutrient concentration of Ca^{2+} and Mg^{2+} . The increase in leaf Ca and Mg concentration may be related to an increase in the availability of nitrate in root medium since is known that when the nitrate is taken by plant roots, Ca and Mg uptake is enhanced (Jones, Wolf, and Mills 1991). Contrastly some researchers reported that the application of high rates of N decreased the absorption of P, K, and Ca in plants, which is presumably due to the dilution of these nutrients in plant tissues (Stagnari, Di Bitetto, and Pisante 2007; Awaad et al. 2016). Spinach is low in Na content (Pyakurel, Dahal, and Rijal 2019) but it can significantly accumulate Na and Cl in shoots and roots with increasing salinity (Ferreira et al.

Table 5. The effects of KWC and chemical fertilizer applications on some micronutrient content of spinach plant.

NPK Fertilizer application	KWC doses %	mg kg ⁻¹			
		Fe	Cu	Zn	Mn
NPK added	0	144.71 bc	9.45	34.91	120.29
	0.4	182.15 a	9.40	36.17	109.72
	0.8	132.91 bcde	10.13	33.62	97.86
	1.2	109.88 cdef	9.10	35.17	106.22
	1.6	94.72 f	14.92	31.06	112.69
Not added	0	87.64 f	8.64	26.88	135.99
	0.4	105.69 def	11.27	36.11	156.96
	0.8	95.64 ef	9.29	26.31	128.49
	1.2	133.01 bcd	9.65	33.54	128.79
	1.6	155.97 ab	9.43	33.19	133.12
F-test			n.s.	n.s.	n.s.

n.s.: not significant.

Means with different letters represent statistically significant differences according to least significant difference (LSD) test at $p < 0.05$.

2018). Na can replace the functions of K and Na somewhat promotes growth in spinach (Tomemori, Hamamura, and Tanabe 2002).

Total micronutrient contents

The impact of different doses of KWC with/without NPK fertilizer on the concentration of Fe, Cu, Zn, and Mn in the spinach plant is shown in Table 5. There is a statistically significant ($p < 0.05$) impact of KWC on the concentration of leaf Fe. Treatments with KWC slightly increased Fe contents relative to increasing compost doses. KWC addition increased the Fe content of the spinach plant from 87.64 to 155.97 mg kg⁻¹ (mean 115.59 mg kg⁻¹) compared to the control. Combined application of chemical NPK fertilizer and KWC decreased total Fe concentration in spinach relative to increasing compost doses from 144.71 to 94.72 mg kg⁻¹ (mean 132.87 mg kg⁻¹) compared to the control plants. There was a marginal decrease in the Fe content of spinach in KWC + NPK treatments. However, comparing the mean Fe values of KWC + NPK between KWC shows that the combined application of KWC + NPK increased the Fe values of the spinach plant by 14.95% compared to the mean Fe values of KWC applied pots. The highest Fe content was detected in the 0.4% KWC + NPK fertilizer treatment. Among the treatments of KWC alone, the highest Fe content was caused by the application of 1.6% KWC. The Fe content of the spinach tissues was in the sufficiency range proposed by Mills and Jones (1996), for Fe (50–200 mg kg⁻¹). Slight increases and decreases were detected in the Cu, Zn, and Mn contents of spinach leaves depending on the application doses. These changes did not have a statistically significant effect on the concentrations of these micronutrients. According to the nutrient sufficiency range for spinach proposed by Mills and Jones (1996), concentration ranges for Zn (25–75 mg kg⁻¹), Cu (5–15 mg kg⁻¹), and Mn (25–200 mg kg⁻¹) were considered normal for spinach. When the micronutrient contents of spinach leaves are evaluated, these elements are at normal levels. Machado et al. (2020) reported that the combination of organic compost with ammonium sulfate led to an increase Mn and Zn concentrations of spinach leaf. Irshad et al. (2014) reported that concentrations of elements in shoots of spinach varied in the order Fe > Zn > Mn > Cd > Pb > Cu. Also reported that increasing levels of composted manure significantly raised the shoot concentrations.

Conclusions

Based on our findings, KWC makes elements more readily available to the plants and increases soil fertility status. Applying KWC using the recommended commercial source, such as 15-15-15

NPK fertilizer added was better to obtain optimal leaf nutrient concentrations and growing aspects of the spinach plant. The data showed that KWC a rate of 0.8% + recommended NPK mineral fertilizers has a favorable effect on spinach plants. On the other hand, the application of KWC at a rate of 1.6% may contribute to reduced inorganic N application without compromising spinach fresh yield. One of the factors affecting the nitrate content of vegetables is the excessive use of N fertilizers to increase yield. This study showed that plant tissue nitrate levels generally increased as the fertilizer rates increased. However, the nitrate content of the spinach samples of this study was determined lower than the values reported in the codex. Regarding the mineral composition of spinach leaves, their micronutrient content showed no statistical differences between treatments with compost except Fe. According to the results, it is evaluated that appropriate fertilization with KWC can increase spinach growth and yield in a sandy clay loam textured soil.

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Ethical approval

The author declares that the submitted article is original; any other that it was not given to another journal for publication; not previously published Acknowledges that all kinds of permission have been obtained and that has been sent to the Publication Commission of the Journal of Cleaner Production. The author accepts responsibility by agreeing to waive the copyright of the article.

Consent to participate

The author declares that this study does not involve humans or animals.

Consent for publication

The author declares that this study doesn't contain any data from another person.

Author contributions

Serhat Gurel conceived and designed the manuscript. Serhat Gurel performed the bibliographic search and analyzed the information. Serhat Gurel wrote the manuscript and made the corresponding revisions.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The datasets generated during and/or analyzed during the current study are available from the publication.

Data deposition

The data and documentation that support the findings of this study are available in with the identifier(s) (data DOI).

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