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ORIGINAL ARTICLE

Manure Application to a Strawberry Garden: Changes in Some Soil and Plant Properties Under Semi-arid Climate Conditions

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Abstract
To address challenges like high pH and low organic matter for sustainable strawberry production in semi-arid regions, this study investigated the effects of manure (10 and 20 Mg ha^{-1}) on 'Albion' strawberry yield/quality and alkaline soil properties. In the first year, manure significantly improved soil organic matter (SOM), total nitrogen (TN), and aggregate stability (WAS), while decreasing bulk density (Db), penetration resistance (PR), and pH ($P<0.01$) compared to the control. Plant yield and several quality parameters also significantly increased ($P<0.05$). In the second year, significant improvements persisted for soil pH, SOM, WAS, and key plant yield/growth parameters ($P<0.05$). Conclusively, manure application enhanced soil properties and strawberry yield/quality under these challenging conditions, with PCA confirming the significant influence of soil changes on plant characteristics.

Keywords Alkaline soils · Manure · Strawberry · Semi-arid climate · Soil quality · PCA analysis

Introduction

Turkey is one of the major strawberry producers, ranking 4th worldwide in strawberry production with 676,818 tons in 2023 (FAO 2025). However, high soil pH is a significant limitation for strawberry cultivation, particularly in semi-arid regions with continental climates. The most common method used to eliminate the negativities in these areas is the use of animal manure. Numerous researchers have confirmed that applying manure enhances strawberry yield and quality (Rubeiz et al. 1998; Palomaki et al. 2000; Kepenek et al. 2002; Leskinen et al. 2002; Neri et al. 2002; Svesson 2002; Çakaryıldırım 2004; Kumar et al. 2020; Sahana et al. 2020). Cultivation in calcareous soils can lead to issues like yield loss, slow growth, and chlorosis (Hancock 1999; Balcı 2021, 2022). Since soil responses to manure vary significantly based on ecology, application method, and dose, region-specific trials are necessary to determine optimal application rates.

Therefore, the objectives of this study were (i) to determine changes in selected soil quality indicators, (ii) to investigate the effects of different manure doses applied to a strawberry orchard established on alkaline soils in Central Anatolia, and (iii) to reveal the relationships between measured soil quality indicators and determined plant traits.

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Material and Method

Trial Site

This study was conducted at Yozgat Bozok University Agricultural Application and Research Station with an altitude of 1106 m and coordinates 4383930N and 685545D (UTM) (Fig. 1). The average precipitation in the region, which is located in the semi-arid climate zone, is 560 mm and the average annual temperature is 9 °C (Anonymous 2018) (Table 1).

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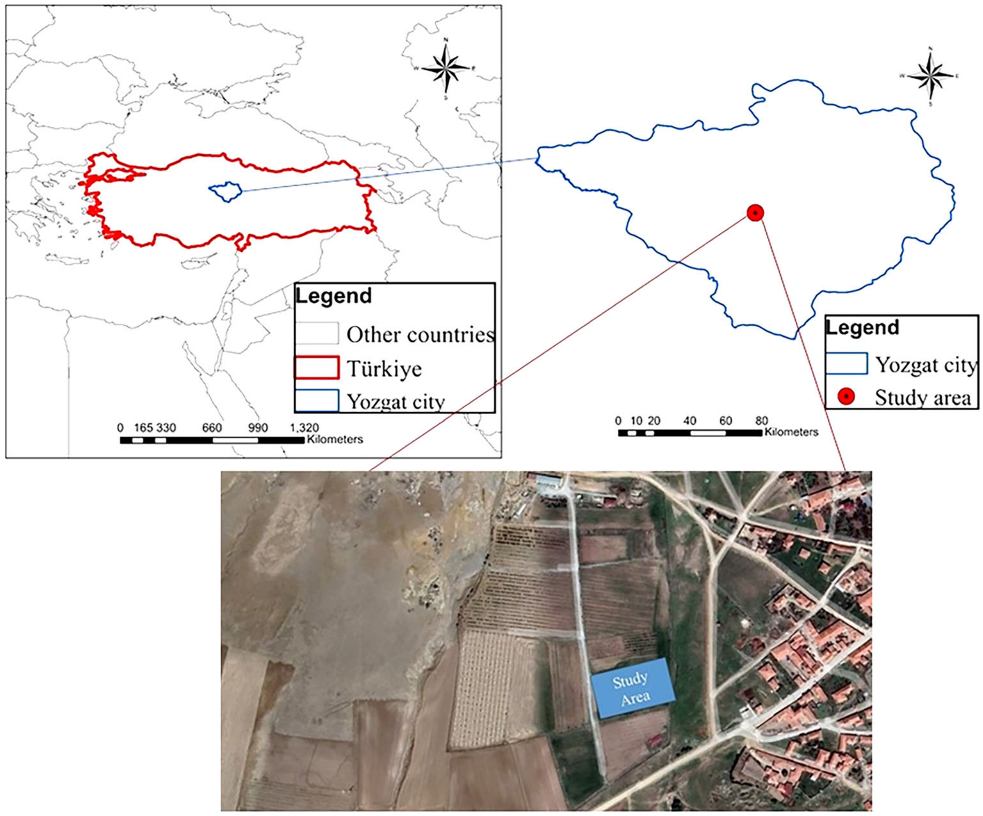

Fig. 1 Location map of the trial site

Table 1 Properties of soil on trial site (Yakupoglu 2018)

pH	*EC (dSm^{-1})*	*SOM (%)*	*$CaCO_3$ (%)*	*Clay (%)*	*Silt (%)*	*Sand (%)*	*Textural class*	*TN (%)*
7.91	0.82	0.99	5.36	29.9	8.9	61.2	SCL	0.05
P (µgg^{-1})	*K (µgg^{-1})*	*Ca (µgg^{-1})*	*Mg (µgg^{-1})*	*ESP (%)*	*Fe (µgg^{-1})*	*Cu (µgg^{-1})*	*Zn (µgg^{-1})*	*Mn (µgg^{-1})*
5.76	215	7561	167	< 15	2.05	0.42	0.29	4.44

EC electrical conductivity corrected at 25 °C, *SOM* soil organic matter content, *TN* total nitrogen, *P* available phosphorous content, *K, Ca* and *Mg* potassium, calcium, and magnesium determined by ammonium acetate extraction, respectively, *Fe, Cu, Zn* and *Mn* iron, copper, zinc and manganese determined by DTPA extraction, respectively

Manure

Amended manure was used in the experiment. Prior to application, it was homogenized by sieving through a 20 mm mesh. Key properties of this manure are provided in Table 2.

Soil Preparation and Establishment of the Trial

Twelve 10 × 4 m plots were prepared in the experimental area and tilled. In September 2018, burnt and sieved manure was applied at doses of 10 Mg ha^{-1} or 20 Mg ha^{-1} to the respective plots and mixed into the 0–15 cm soil depth using a cultivator. Control plots without manure were included for each treatment and received the same cultural management. The research utilized a randomized complete block design with 3 replications.

In May 2019, 'Albion' frigo strawberry seedlings were planted onto mulched beds. All plots received 150 kg ha^{-1} of 18:18:18 compound fertilizer via fertigation one month af-

Table 2 Properties of the manure (Yakupoğlu et al. 2022)

OM (%)	*OC (%)*	*WOM (mg L^{-1})*	*TN (%)*	*N-min (%)*	*NH_4^+-N (µgg^{-1})*	*NO_3^-N (µgg^{-1})*	*N-org (%)*	*P (%)*
35.7	20.7	47.2	1.695	0.248	189.3	2293.9	1.676	2.662
K (%)	*Ca (%)*	*Mg (%)*	*Fe (µgg^{-1})*	*Cu (µgg^{-1})*	*Zn (µgg^{-1})*	*Mn (µgg^{-1})*	*Cr (µgg^{-1})*	
3.941	1.99	6.17	46833	392.35	15961	1603	718.13	

OM organic matter, *OC* organic carbon, *WOM* water soluble organic matter, *TN* total nitrogen, *N-org* organic nitrogen
Other mineral elements have been given as total

ter planting and then every two months during the growing period throughout the experiment.

Soil sampling occurred in early September, near the end of harvest, from four representative points within each plot at a 0–15 cm depth. Disturbed soil samples were collected using an Adelman auger, while undisturbed samples were taken with 100 cm^3 steel cylinders. Following sampling, five penetration resistance measurements were conducted at undisturbed locations within the plots, focusing on the planting rows. The experiment covered two growing seasons (2018–2019 and 2019–2020), and the same cultural treatments, sampling procedures, and field measurements were repeated in the second season.

Measurements and Analyses for Strawberry

Plant measurements included: yield per plant (PY, g $plant^{-1}$), average fruit weight (AFW, g $fruit^{-1}$), fresh (FCW, FLW, g) and dry (DCW, DLW, g) weights of crowns and leaves, leaf area (LA, cm^2, ADC BioScientific Area Meter AM300), crown number (CN, pcs), and crown diameter (CD, mm) (Balcı et al. 2017). Fruit quality parameters measured were: color (L, a, b, Konica Minolta CR 400), total soluble solids (TSS, %), titratable acidity (TA, %) (Balcı et al. 2017), and vitamin C content (VIT C, mg 100 ml^{-1}) via spectrometer (Kılıç et al. 1991).

Soil Analyses

Total organic matter (SOM, %) in soil samples according to Kacar (1994), soil pH according to Rowell (1996), total nitrogen (TN, %) according to Kjeldahl method (Kacar 1994), soil bulk weight (Db, g cm^{-3}) according to Moradi et al. (2020), Penetration resistance (PR, MPa) according to Herrick and Jones (2002) Aksakal and Öztaş (2010), Aggregate stability (WAS, %) according to Kemper and Rosenau (1986) was determined.

Evaluation of Dataset

Analysis of variance (ANOVA) was used to test the effects of treatments on soil and plant properties, with mean differences compared using Duncan's multiple range test ($\alpha < 0.05$). T-tests were employed to compare the two growing seasons for each measured variable. To explore the relationships between plant and soil properties, principal component analysis (PCA) was performed separately for each growing season, incorporating all measured variables. In the PCA, components with eigenvalues greater than 1 and variables with factor loadings exceeding |0.50| were considered significant. To simplify interpretation by minimizing variables loading onto multiple factors, varimax rotation was applied (Erşahin and Karaman 2000). All statistical evaluations were conducted using the IBM SPSS 22.0 package program.

Results and Discussion

Changes in Soil Properties

At the end of the first harvest season, the 20 Mg ha^{-1} manure dose yielded the highest soil organic matter (SOM) at 2.82% (Table 3). Although SOM decreased by the second season (e.g., to 1.49% with the high dose), it remained higher than the control. Soil pH decreased with manure application compared to the control. After the first season, pH was highest in the control (8.17) and lowest with the high manure dose (7.47). In the second year, higher pH values were still observed in the control (8.10) and low-dose manure plots (7.96).

Total nitrogen (TN) was lowest in the control plot (0.12%), and both manure doses successfully increased TN levels, building upon the initial soil TN of 0.05% using manure with 1.69% TN (Tables 1 and 2). Water aggregate stability (WAS) in the first year was around 35% in the control but nearly doubled (62.4%) with the high manure dose. By the end of the second year, WAS in the low-dose plots returned to control levels, while it remained elevated (above 46%) in the high-dose treatment. Bulk density (Db) was highest in the control plot (1.20 g cm^{-3}), decreasing to 1.10 g cm^{-3} and 1.02 g cm^{-3} with the 10 and 20 Mg ha^{-1} manure doses, respectively. Similarly, penetration resistance (PR) was highest in the control (2.49 MPa) and decreased

Table 3 Average values of soil variables determined at the end of the first and second growing seasons

		Variables					
Growing season	Application	pH	SOM (%)	TN (%)	Db (g cm^{-3})	PR (MPa)	WAS (%)
I	Control	8.17	1.04	0.12	1.20	2.49	35.1
	10 Mg ha^{-1}	7.47	2.58	0.22	1.10	1.62	46.3
	20 Mg ha^{-1}	7.42	2.82	0.30	1.02	1.26	62.4
II	Control	8.10	1.07	0.11	1.19	2.53	34.0
	10 Mg ha^{-1}	7.96	1.16	0.16	1.16	2.60	35.5
	20 Mg ha^{-1}	7.82	1.49	0.13	1.18	2.42	46.1

pH soil reaction, *SOM* soil organic matter content, *TN* total nitrogen, *Db* bulk density, *PR* penetration resistance, *WAS* wet aggregate stability

Table 4 Average values of strawberry variables determined at the end of the first and second growing seasons

		Variables							
Growing season	*Application*	*PY (g plant^{-1})*	*AFW (g fruit^{-1})*	*TSS %*	*TA %*	*VIT C (mg/100 g)*	*L*	*a*	*b*
I	Control	51.87	4.24	10.47	0.91	34.77	19.20	17.79	7.28
	10 Mg ha^{-1}	72.42	5.62	11.30	0.87	38.48	19.90	18.35	7.27
	20 Mg ha^{-1}	95.21	6.69	11.10	0.88	37.07	19.37	18.68	7.23
	Application	*FCW (g)*	*FLW (g)*	*DCW (g)*	*DLW (g)*	*LA (cm^2)*	*CN (number)*	*CD (mm)*	
	Control	1.40	13.38	0.35	2.91	1273.28	1.32	9.53	
	10 Mg ha^{-1}	2.72	21.63	0.73	5.91	1969.35	1.31	11.27	
	20 Mg ha^{-1}	3.35	20.86	0.77	4.76	1751.65	1.34	11.56	
II	*Application*	*PY (g plant^{-1})*	*AFW (g fruit^{-1})*	*TSS %*	*TA %*	*VIT C (mg/100 g)*	*L*	*a*	*b*
	Control	74.88	10.23	11.27	1.12	30.99	19.18	17.11	5.78
	10 Mg ha^{-1}	123.55	10.69	12.10	1.08	41.95	19.71	18.06	6.01
	20 Mg ha^{-1}	127.19	11.31	10.90	1.20	33.97	19.93	16.53	5.25
	Application	*FCW (g)*	*FLW (g)*	*DCW (g)*	*DLW (g)*	*LA (cm^2)*	*CN (number)*	*CD (mm)*	
	Control	7.66	54.24	4.12	20.06	1273.28	3.05	11.21	
	10 Mg ha^{-1}	9.67	85.41	5.44	32.58	1954.35	3.33	12.18	
	20 Mg ha^{-1}	10.62	57.18	8.24	23.24	1751.45	4.00	11.99	

PY plant yield, *AFW* average fruit weight, *TSS* total soluble solids, *TA* titratable acidity, *VIT C* vitamin C, *L* ruit shine, *a* red color intensity, *b* green color intensity, *FCW* fresh crown weight, *FLW* fresh leaf weight, *DCW* dry crown weight, *DLW* dry leaf weight, *LA* leaf area, *CN* crown number, *CD* crown diameter

Table 5 ANOVA results of applications (source of variation) over measured variables.

Groving season	Variables						
I	PY	AFW	TSS	TA	VIT C	L	a
	*	ns	ns	ns	ns	ns	ns
	FCW	FLW	DCW	DLW	LA	CN	CD
	*	ns	*	*	*	ns	*
	b	pH	SOM	TN	Db	PR	WAS
	ns	**	**	**	**	**	**
II	PY	AFW	TSS	TA	VIT C	L	a
	**	ns	ns	ns	ns	ns	ns
	FCW	FLW	DCW	DLW	LA	CN	CD
	ns	**	*	**	*	ns	ns
	b	pH	SOM	TN	Db	PR	WAS
	ns	**	**	ns	ns	ns	*

PY plant yield, *AFW* average fruit weight, *TSS* total soluble solids, *TA* titratable acidity, *VIT C* vitamin C, *L* fruit shine, *a* red color intensity, *b* green color intensity, *FCW* fresh crown weight, *FLW* fresh leaf weight; *DCW* dry crown weight; *DLW* dry leaf weight; *LA* leaf area; *CN* crown number, *CD* crown diameter; *pH* soil reaction, *SOM* soil organic matter content, *TN* total nitrogen, *Db* bulk density, *PR* penetration resistance, *WAS* wet aggregate stability, *statistically significant at level of 0.05, **statistically significant at level of 0.01, ns: not significant statistically

significantly to 1.62 MPa (low dose) and 1.26 MPa (high dose).

Changes in Plant Properties

Over the two experimental years, plant yield (PY) increased from a range of 51.87–95.21 g plant^{-1} in the first year to 74.88–127.19 g plant^{-1} in the second. Average fruit weight (AFW) similarly rose from 4.24–6.69 g fruit^{-1} (Year 1) to 10.23–11.31 g fruit^{-1} (Year 2). Key fruit quality metrics showed ranges of: TSS 10.30–11.30% (Year 1) and 10.47–12.43% (Year 2); titratable acidity (TA) 0.88–0.91% (Year 1) and 1.08–1.20% (Year 2); and Vitamin C (VIT C) 34.77–38.48 mg 100 g^{-1} (Year 1) and 30.99–41.95 mg 100 g^{-1} (Year 2).

Color parameters (L, a, b) exhibited slight variations: L values remained consistent around 19.20–19.90; ‘a’ values ranged from 17.79–18.68 (Year 1) to 16.53–18.06 (Year 2); and ‘b’ values decreased from 7.23–7.28 (Year 1) to 5.25–6.01 (Year 2). Vegetative growth generally increased substantially from the first to the second year for fresh crown weight (FCW: 1.40–3.35 g to 7.66–10.62 g), fresh leaf weight (FLW: 13.38–21.63 g to 54.24–85.41 g), dry crown weight (DCW: 0.35–0.77 g to 4.12–8.24 g), and dry leaf weight (DLW: 2.91–5.91 g to 20.06–32.58 g). Leaf area (LA) ranged from 1273.28–1969.35 cm^2 in the first year to 1273.28–1954.35 cm^2 in the second. Crown number (CN) increased from an average of 1 (Year 1) to 3.05–4.00 pieces plant^{-1} (Year 2), while crown diameter (CD) showed a slight increase from 9.53–11.56 mm (Year 1) to 11.21–12.18 mm (Year 2) (Table 4).

Interpretation of Changes in Plant and Soil Properties

ANOVA results for measured plant and soil variables are presented in Table 5. Duncan test results (α = 0.05) for significant variables are shown in Fig. 2 (first growing season) and Fig. 3 (second growing season).

Consistent with numerous studies, applying organic amendments like manure increased soil organic matter (SOM) and total nitrogen (TN) (Li et al. 2015; Saltalı 2015; Sithole et al. 2019; Yakupoglu et al. 2021; Saltalı and Kara 2022; Kara et al. 2022). The decrease in soil pH, significant even at 10 Mg ha^{-1} and reaching 7.47 with the high dose, is likely due to organic acid formation and CO_2 release during manure decomposition under the polyethylene mulch, potentially forming H_2CO_3 (Neina 2019). Manure significantly increased TN, reaching 0.30% with the high dose in the first year, aligning with literature showing manure boosts SOM, TN, and other nutrients (Sommerfeldt et al. 1988; Zhang et al. 2018; Yagüe et al. 2016; Yang et al. 2015).

Water aggregate stability (WAS) increased significantly with manure compared to the control, though without statistical difference between the two doses (Fig. 2). This supports findings that organic amendments improve aggregation and soil physical properties (Tisdall and Oades 1982; Martens 2000; Rezacova et al. 2021). Significant first-year improvements were also seen in physical properties like bulk density (Db) and penetration resistance (PR) ($P < 0.01$). Db decreased significantly with increasing manure dose, reaching 1.02 g cm^{-3} (Fig. 2). While both manure doses significantly reduced PR compared to the control, there was no difference between them. These results cor-

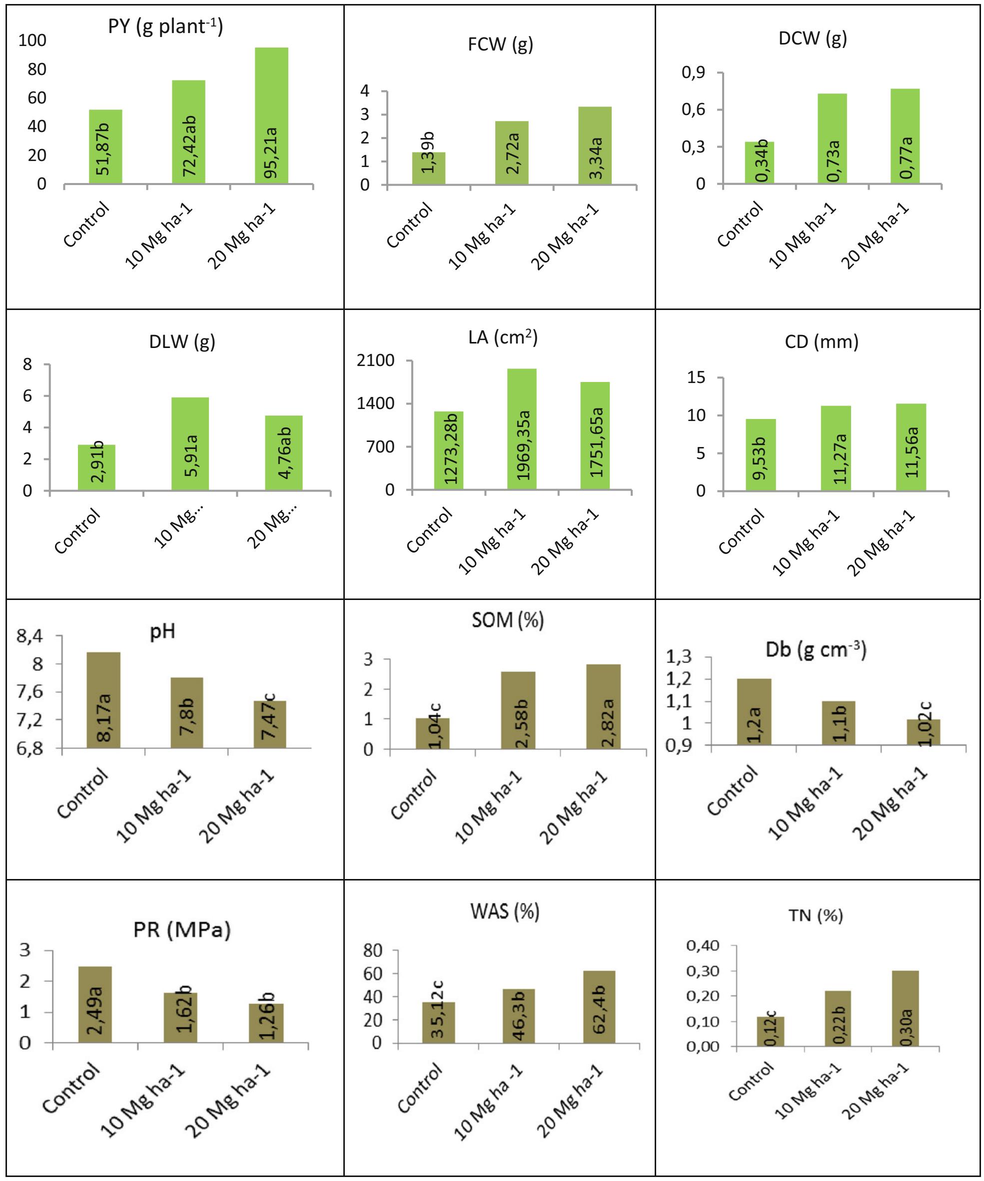

Fig. 2 Duncan test results of variables with significant F value according to ANOVA test for the first growing season results ($\alpha = 0.05$)

roborate literature indicating organic amendments enhance physical properties, reducing compaction and PR (Durigan et al. 2017; Are et al. 2018; Zhang et al. 2018; Mubaraka et al. 2022; De Moraes et al. 2019; Haruna et al. 2020; Startsev et al. 2020).

Regarding plant performance (Fig. 2), the highest yield per plant (PY) was achieved with 20 Mg ha^{-1} manure (95.21 g plant^{-1}), significantly exceeding the control (51.87 g plant^{-1}). This yield is comparable to previous findings for 'Albion' at the same location (100.32 g plant^{-1}; Balcı et al. 2017) and falls within the range reported in similar climates (52.05–283.7 g plant^{-1}; Ağgün et al. 2018; Geçer et al. 2018). Fresh crown weight (FCW) was also highest with 20 Mg ha^{-1} manure (3.35 g), consistent with the known positive yield-crown weight relationship (Balcı et al. 2023), although lower than ranges reported in some studies (e.g., 12.69–31.54 g plant^{-1} by Balcı et al. 2023; 6.68–32.28 g plant^{-1} by Çiylez and Eşitken 2018).

Similarly, dry crown weight (DCW) increased from 0.34 g (control) to 0.77 g (high dose), aligning more closely with Balcı (2018) (0.35–0.44 g plant^{-1}) than Balcı et al. (2023) (5.17 g plant^{-1}). Dry leaf weight (DLW) peaked with 10 Mg ha^{-1} manure (5.91 g) compared to the control (2.91 g plant^{-1}), falling within the wide range previously reported (0.87–27.25 g plant^{-1}; Balcı et al. 2023; Balcı 2018). Leaf area (LA) was lowest in the control (1273.28 cm^2 plant^{-1}) and highest with 10 Mg ha^{-1} manure (1969.35 cm^2 plant^{-1}), exceeding ranges reported by Al-Shatri et al. (2020) (1038.21–1464.44 cm^2 plant^{-1}) and Balcı et al. (2023) (363.27–789.88 cm^2 plant^{-1}).

By the end of the second year, the diminishing effectiveness of the organic material meant that significant changes

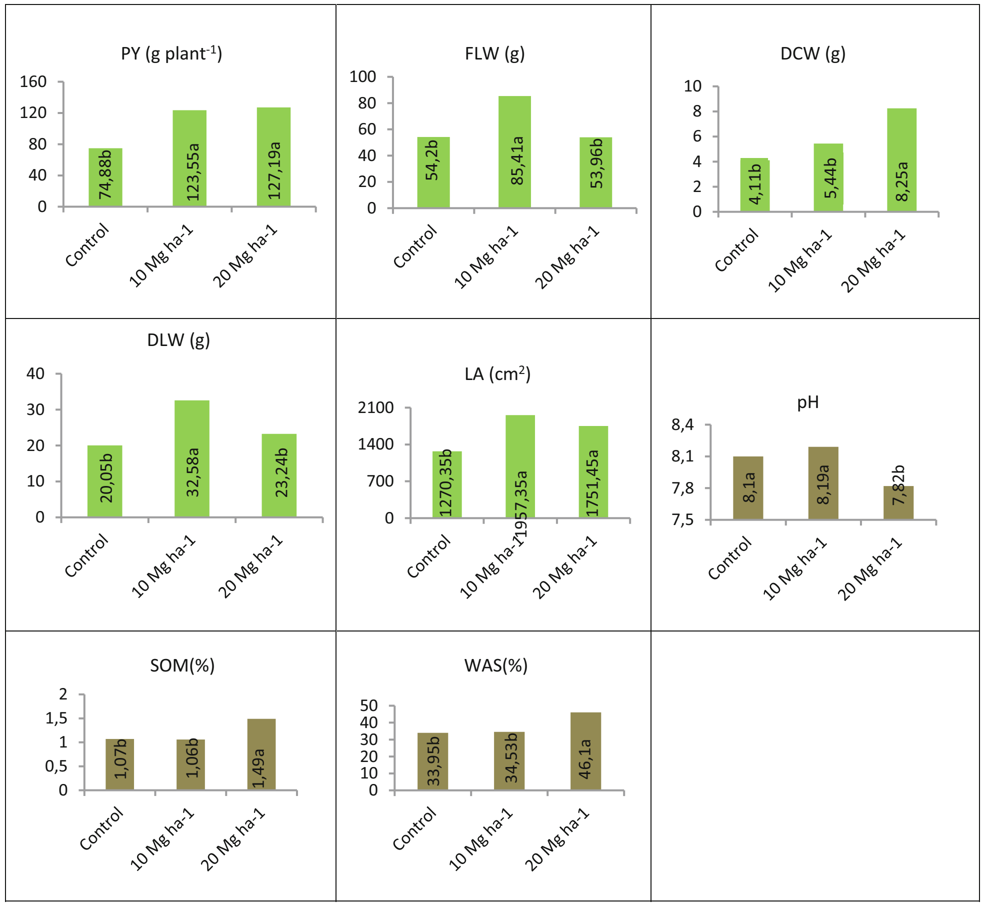

Fig. 3 Duncan test results of variables with significant F value according to ANOVA test for the second growing season results (α = 0.05)

compared to the control were only observed for soil pH, SOM, and WAS (Fig. 3). Notably, only the high manure dose (20 Mg ha⁻¹) successfully maintained a lower pH and higher SOM and WAS levels; the 10 Mg ha⁻¹ dose lost its significant effect. This aligns with the understanding that the impact of applied organic matter decreases over time (Yakupoglu et al. 2021).

Regarding plant performance in the second year (Fig. 3), yield per plant (PY) significantly increased from 74.88 g plant⁻¹ (control) to 123.55 g plant⁻¹ (low dose) and 127.19 g plant⁻¹ (high dose). These yields fall within the range reported for 'Albion' in similar locations during the second year (12.60–208.63 g; Balcı et al. 2017; Geçer 2020). Fresh leaf weight (FLW) was highest with the low dose (85.41 g), while the control (54.20 g) and high dose (53.96 g) were statistically similar. Dry crown weight (DCW) only increased significantly with the 20 Mg ha⁻¹ dose (to 8.25 g). These FLW and DCW values are comparable to those found by Balcı et al. (2023) (82.98 g plant⁻¹ and 12.23 g plant⁻¹, respectively, for the 2nd year). Leaf area (LA) increased with both manure doses (1957.35 cm² with 10 Mg ha⁻¹ and 1751.45 cm² with 20 Mg ha⁻¹) compared to the control (1270.35 cm²). This observation, particularly the reduced effect compared to the first year, is consistent with findings that manure's positive impact on LA can decrease in the second year (Balcı 2012).

Statistically significant differences between the growing seasons were observed for soil organic matter (SOM), total nitrogen (TN), and penetration resistance (PR) (Table 6). This temporal variation is likely due to the diminishing effectiveness of the applied manure over time, as noted by Yakupoglu et al. (2021), who indicated that the rate of change in soil properties decreases as organic matter effects lessen. Similarly, numerous plant variables (PY, AFW, TA, b, FCW, FLW, DCW, DLW, CN, CD) also differed sig-

Table 6 Comparison of growing seasons with t-test on measured variables.

Variables						
PY	AFW	TSS	TA	VIT C	L	a
**	**	ns	**	ns	ns	ns
FCW	FLW	DCW	DLW	CN	CD	LA
**	**	**	**	**	*	ns
b	pH	SOM	TN	Db	PR	WAS
**	ns	*	*	ns	**	ns

ns not significant statistical
*statistically significant at level of 0.05, **statistically significant at level of 0.01

Table 7 Rotated component matrix produced by principal component analysis (PCA)

	Component												
	The First Growing Season						The Second Growing Season						
Variables	1	2	3	4	5	6	1	2	3	4	5	6	7
PY		0.780									0.589		
AFW		0.911							0.866				
TSS												–0.928	
TA						0.932				0.602			0.522
VIT C					0.896		0.748						
L				0.746						0.869			
a					0.756					0.767			
b		–0.667			0.600					0.577			
FCW	0.842										0.700		
FLW			0.642				0.909						
DCW		0.512	0.543					0.686			0.524		
DLW			0.841				0.975						
CN				0.862			0.517					0.591	
CD	0.540			0.693							0.842		
LA			0.720				0.894						
pH	–0.843							–0.886					
SOM	0.740							0.858					
Db	–0.952								–0.860				
PR	–0.619	–0.638							–0.839				
WAS	0.842							0.906					
TN	0.908												
% of variance	31.12	16.05	14.18	11.38	11.11	7.51	19.65	18.98	13.02	11.67	11.47	8.59	8.53
Cumulative %	31.12	47.17	61.35	72.74	83.85	91.36	19.65	38.63	51.65	63.32	74.79	83.38	91.91

nificantly between the seasons (Table 6). This aligns with findings that the impact of organic amendments on strawberry yield and growth is often more pronounced in the first year compared to the second (Balcı 2012).

Interactions Between Plant and Soil

Principal component analysis (PCA) results are detailed in Table 7, with a corresponding 3D visualization provided in Fig. 4. The analysis, incorporating 15 plant traits and 6 soil properties, grouped these variables into 6 factors for the first growing season and 7 factors for the second. This PCA model successfully explained 91.36 and 91.91% of the total variance within the dataset for the first and second growing seasons, respectively (Table 7; Fig. 4).

Principal component analysis (PCA) for the first year revealed strong relationships between soil improvements and plant performance (Table 7). In Factors 1, 2, and 3, key soil parameters improved by manure (SOM, WAS, TN) showed positive loadings with several strawberry plant growth and yield variables (PR, AFW, FCW, FLW, DCW, DLW, LA, CD). Conversely, soil variables associated with poorer conditions (pH, PR, Db) showed inverse relationships with these plant quality and yield parameters. Factor 4 grouped plant variables L, CN, and CD positively, while Factor 5 linked VIT C, a, and b. These results clearly indicate the positive impact of manure application on strawberry yield and quality, consistent with reports highlighting significant positive relationships between SOM and plant performance (Cayuela et al. 1997; Hargreaves et al. 2009; Balcı et al. 2017; Khalil and Agah 2017; Kilic et al. 2021). The findings align with those of Yakupoğlu et al. (2022), confirming that manure-induced soil improvements directly enhanced strawberry yield and quality in the first year (Table 7).

In the second year's PCA, Factor 1 showed strong positive loadings among plant variables VIT C, FLW, DLW, CN, and LA. Factor 2 linked plant variable DCW positively with soil variables SOM and WAS, and negatively with pH, supporting the positive effect of SOM on aggregate stability (Mainuri and Owino 2013; Zhang et al. 2018). Factor 3 indicated an inverse relationship between AFW and soil parameters Db and PR, likely associated with SOM content. Factor 4 showed strong positive relationships among plant variables TA, L, a, and b, with a weaker positive link to TN (Factor 7). Factor 5 grouped yield-related traits (PY, FCW, DCW, CD) positively.

Overall, the second-year PCA results showed similar patterns to the first year, but the positive effects were diminished. This was attributed to the decrease in the elevated SOM levels observed in the first year. These findings support extensive research demonstrating significant relationships between SOM content, soil properties, and plant yield (Johnston 1986; Bauer and Black 1994; Rasmussen and Collins 1991; Li et al. 2015). Numerous studies specifically report increased strawberry yield with various organic amendments (Arancon et al. 2004; Türemis 2002; Wang and Lin 2002), attributing this to SOM promoting growth, alleviating high-pH induced chlorosis, and thus positively affecting leaf area and plant weight (Singh and Singh 2009; Rajbir et al. 2010).

Conclusions

Manure application to challenging alkaline, low-SOM soils in a semi-arid region significantly improved soil properties (increasing SOM, TN, WAS; decreasing pH, PR, Db) and enhanced strawberry yield and quality over two years. While the soil benefits were most pronounced in the first year, with some reduction in SOM, TN, and WAS effects by year two, positive impacts on the plants persisted. Key parameters like PY, FCW, DCW, LA, and CD (Year 1) and PY, FLW, DCW, DLW, and LA (Year 2) significantly increased compared to controls. PCA confirmed the strong positive link between improved soil conditions and plant performance, particularly in the first year. Conclusively, manure

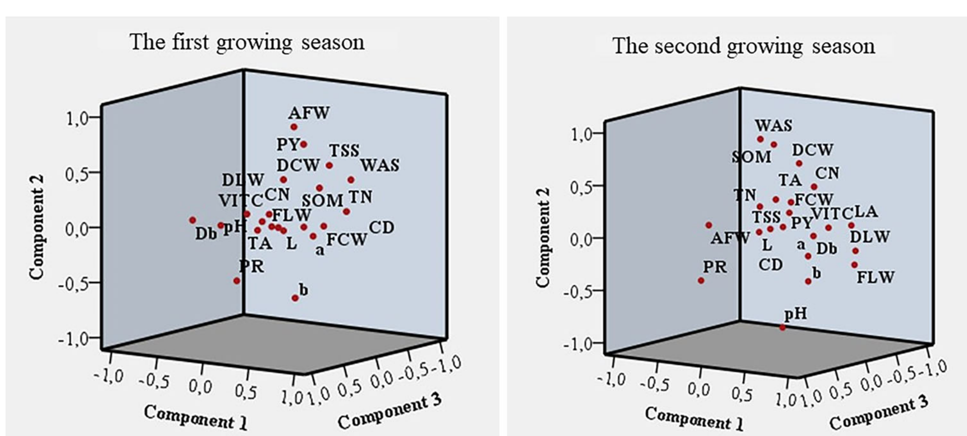

Fig. 4 Component plots space produced by PCA

effectively enhances both soil health and strawberry productivity under these conditions. A rate of 20 Mg ha⁻¹ manure is recommended for similar regions, although the optimal dose should be tailored to specific soil characteristics.

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