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Evaluation of Various Organic Amendment Sources to Improve the Root Yield and Sugar Contents of Sugar Beet Genotypes (*Beta vulgaris* L.) under Arid Environments

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Abstract: Sugar beet (*Beta vulgaris* L.) is a sucrose-rich tap root crop, with its fresh root containing up to 20% sucrose contents. Natural organic fertilizers can be a good alternative to synthetic fertilizers. For this purpose, an experiment was conducted for the optimization of different organic amendments i.e., farmyard manure, poultry manure, compost, and biochar. After the optimization experiment, pre-optimized doses of different organic amendments (farmyard manure, 40 t ha^{-1}; poultry manure, 20 t ha^{-1}; compost, 40 t ha^{-1}; and biochar, 20 t ha^{-1}) were evaluated for the production and root quality of two diverse sugar beet genotypes. The experiment was repeated over time (2019 and 2020) at four locations (BZU Research Farm Layyah, Farmer Field Layyah, Farmer Field Bhakkar-A and Farmer Field Bhakkar-B). Among different organic amendments, the use of an optimized rate of poultry manure (20 t ha^{-1}) was the most useful for improvement in root yield, sugar yield and sugar quality. Improvement in root yield was attributed to better leaf growth and root yield which resulted eventually in higher reserve accumulation in roots. The performance of genotype 'California' was superior to the genotype 'Serenada'. In conclusion, growing of genotype 'California' in sandy loam soils with poultry manure application (20 t ha^{-1}) might be a pragmatic option to improve the sugar beet yield and sugar recovery.

Keywords: organic amendments; root yield; sugar yield; sugar recovery; poultry manure

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1. Introduction

Sugar beet (*Beta vulgaris* L.) is globally the second most important sugar producing crop after sugarcane, and is therefore known as an important industrial crop. Due to its short duration and increased sugar recovery, it is preferred over sugarcane [1]. The cultivation of sugar beet is increasing worldwide [2] including in Pakistan. Nonetheless, sugarcane is a long duration crop which requires a substantial input cost. It is, therefore, not affordable by small- and medium-size farmers who must then look for alternatives. Sugar beet also has a higher sucrose content (14–20%) than sugarcane (10–12%) [3,4]. Its water and fertilizer demand is ~30–40% less than sugarcane and it can be grown under various climatic conditions [5,6].

As the economic portion of the sugar beet is its root, sandy loam soils are best for its production. However, these soils are not fertile and have low soil organic matter with surplus deficiencies of micro and macro nutrients. Mubarak et al. [4] have reported that the yield of sugar beet is poor on sandy loam soils owing to a deficiency of macro and micronutrients. Although a farmer may use synthetic fertilizer, these nonetheless fulfill the crop nutrient needs for a specific season and have no long-term positive influence on soil properties and sustainable crop production on sandy soil [7,8]. The sugar beet root and sugar yield depends upon the optimum and sustained application of both organic and inorganic fertilizers. The application of phosphorous (P) plays an important role in energy transfer, photosynthesis, transformation of sugars, transfer of genetic information and nutrient movement within the plant. In sugar beet, potassium (K) plays a significant role in biosynthesis and the transfer of sucrose to storage roots [9,10]. Therefore, it is assumed that P and K fertilization increases both yield and beet quality. However, both the deficiency and excess of nitrogen are considered major sugar beet growth and productivity limiting factors. Therefore, the optimum application of nutrients results in increased root and sugar yield [10]. The soil amendment of materials which are organic in nature not only improves the soil's physical and chemical characteristics but also enhances plant growth and development by increasing the availability of plant essential nutrients [11–13]. In this scenario, the application of organic amendments in sandy loam soils may improve soil properties and eventually the root yield of sugar beet. Organic materials are sustained nutrients sources that have the bulk of a plant's macro- and micro-nutrients and enhance the soil's fertility status on a long term basis due to the slow decomposition and its involvement in natural soil processes [14,15]. Therefore, better soil properties are believed to improve the water retention and nutrient uptake which will boost sugar beet growth and yield. Studies have reported that the use of organic amendments (e.g., compost, farmyard manure, biochar, poultry manure) is an ecofriendly option to improve soil and crop productivity [16–19]. Indeed, organic amendments improve the organic carbon stock which in turn improves the cation exchange capacity and retains the essential nutrient cations in the soil, making them available for crop production [8]. The solubility of anions also increases as a result of the soil incorporation of organic amendments [20,21].

Poultry manure amendment in soil is a rich source of nitrogen (N), phosphorus (P) and potassium (K) and micronutrients, and is considered an important organic material which increases the soil's organic matter, porosity, and microbial diversity and decreases the soil bulk density [22,23]. Furthermore, amendment with poultry manure increases the crop growth rate (CGR) through which the physical and chemical characteristics of soil are improved, thus increasing the availability of soil nutrients to the crop plants. Therefore, a higher sugar beet yield and higher sugar content in the roots of said sugar beet are obtained with a soil amendment with poultry manure at 10 t ha^{-1} [7]. Moreover, soil amendments of farmyard manure improve soil health and crop productivity [7]. A long-term study in China has indicated that the application of farmyard manure decreases the soil bulk density and enhances the total soil carbon and soil porosity [24]. In another study, application of farmyard manure reduced the bulk density, and enhanced the total soil porosity, crop biomass and crop yield [25].

The soil application of compost improves soil carbon and soil microbial activities [20], enhances the availability of plant nutrients (e.g., nitrogen, phosphorous, potassium, magnesium) to crop plants [26], enhances soil porosity and water holding capacity [19], and suppresses soil-borne pathogens [27], thus enhancing the yield of crops. Although, the application of compost to agricultural soil may increase the process of nitrification, it reduces the losses of nitrogen via leaching and thus avoids groundwater nitrate contamination [13,28]. Among these organic amendments, biochar is a unique soil amendment whose carbon can remain stable in the soil over the course of several years. Studies have reported that biochar application is very useful for agricultural lands [17,29–31]. For example, application of biochar to soil reduces greenhouse gas emissions, offsets water pollution [13,32,33] and improves water holding capacity and soil fertility, thus enhancing crop yields [34–36]. Soil organic matter, leaf minerals, soil porosity, plant growth, and seed yield are also believed to be increased by the soil incorporation of biochar [36–38].

Thus, the above discussion indicates that organic amendments are useful for improving soil's physical, chemical and biological properties under diverse soil types and climatic conditions. However, there is a lack of studies which describe the comparative effects of different organic amendments on soil productivity and crop yield attributes. Therefore, the present study aimed to improve soil properties and enhance the productivity and sugar yield of sugar beet under an arid climate by using optimized rates of various organic amendments (compost, biochar, farmyard manure and poultry manure).

2. Materials and Methods

2.1. Experimental Site, Soil and Climate

This study was conducted over two years (2019 and 2020) at the following four locations: (i) Research Farm, College of Agriculture, Bahauddin Zakariya University (BZU), Bahadur Sub-Campus, Layyah (182 m above sea level); (ii) Farmer Field at Layyah; (iii) Farmer Field at Bhakkar A; and (iv) Farmer Field in Bhakkar B. The experimental soil at the BZU Research Farm Layyah had a loamy texture with 36% saturation, pH 8.00 and an electrical conductivity of 3.88 dS m^{-1} (average of both years). The experimental soil at the Farmer Field in Layyah (182 m above sea level) was sandy loam in texture with 34% saturation, pH 8.1 and an electrical conductivity of 3.90 dS m^{-1} (average of both years). The experimental soil at the Farmer Field in Bhakkar-A (159 m above sea level) was also sandy loam in texture with 39% saturation, pH 8.5 and an electrical conductivity of 3.98 dS m^{-1} (average of both years). The experimental soil at the Farmer Field in Bhakkar-B (157 m above sea level) was also sandy loam in texture with 37% saturation, pH 8.3 and an electrical conductivity of 3.80 dS m^{-1} (average of both years). The experimental soil fertility (before sowing) consisted of soil organic matter (0.755%), soil total nitrogen (448 mg kg^{-1}), soil available phosphorus (P_2O_5; 6.50 mg kg^{-1}) and soil exchangeable potassium (K_2O; 130 mg kg^{-1}). The climate of both Layyah and Bhakkar is arid with total annual rainfall of less than 250 mm with very hot summers. Weather data of the experimental duration are presented in Figure 1.

2.2. Experimental Design and Treatments and Plant Material

The experimental plots were arranged in a randomized complete block design with split-plot arrangement with three replications. Firstly, a field experiment was conducted to optimize the different doses of various organic fertilizers i.e., farmyard manure (0, 10, 20, 30, 40 t ha^{-1}), poultry manure (0, 5, 10, 15, 20 t ha^{-1}), compost (0, 10, 20, 30, 40 t ha^{-1}) and biochar (0, 5, 10, 15, 20 t ha^{-1}). The nutritional composition of FYM consisted of 11 g-kg^{-1} N, 3.6 g-kg^{-1} P_2O_5, 54 g-kg^{-1} K_2O, 176 ppm Fe and 45 ppm Mn, 3.00 ppm Cu, and 15.8 ppm Zn and 10.6 ppm B. The nutritional composition of poultry manure consisted of 19 g-kg^{-1} N, 4.1 g-kg^{-1} P_2O_5, 49 g-kg^{-1} K_2O, 230 ppm Fe and 47 ppm Mn, 5.5 ppm Cu, 35 ppm Zn and 11.7 ppm B. Similarly, the nutritional composition of biochar was consisted of 365 g-kg^{-1} C, 13.6 g-kg^{-1} N, 0.14 g-kg^{-1} P, 1.97 g-kg^{-1} K, 9.5 g kg^{-1} Ca, 253 mg kg−1 Fe and 58 mg kg−1 Mn and nutritional composition of compost was consisted of 369 g-kg^{-1} C, 23.6 g-kg^{-1} N, 14.9 g-kg^{-1} P, and 17.7 g-kg^{-1} K [13].

This experiment was followed by another experiment wherein optimized rates of organic amendments viz., farmyard manure (40 t ha^{-1}), poultry manure (20 t ha^{-1}), biochar (20 t ha^{-1}) and compost (40 t ha^{-1}), were applied to two sugar beet genotypes viz. 'California' and 'Serenada' (kept in sub-plots) during both years (2019 and 2020). The net plot size was 8 m $\times$ 2 m for organic amendments (main plot) and 4 m$\times$ 1 m for sugar beet genotypes (sub-plot). The experimental factors included types of organic amendments (04), locations (04) and sugar beet genotypes (02), where all three factors were factorially combined.

Two genotypes were evaluated under different organic amendments viz. 'California' and 'Serenada'. Seed of the genotypes (commercial cultivars) was obtained from the research and development section of Layyah Sugar Mills Limited, Punjab, Pakistan.

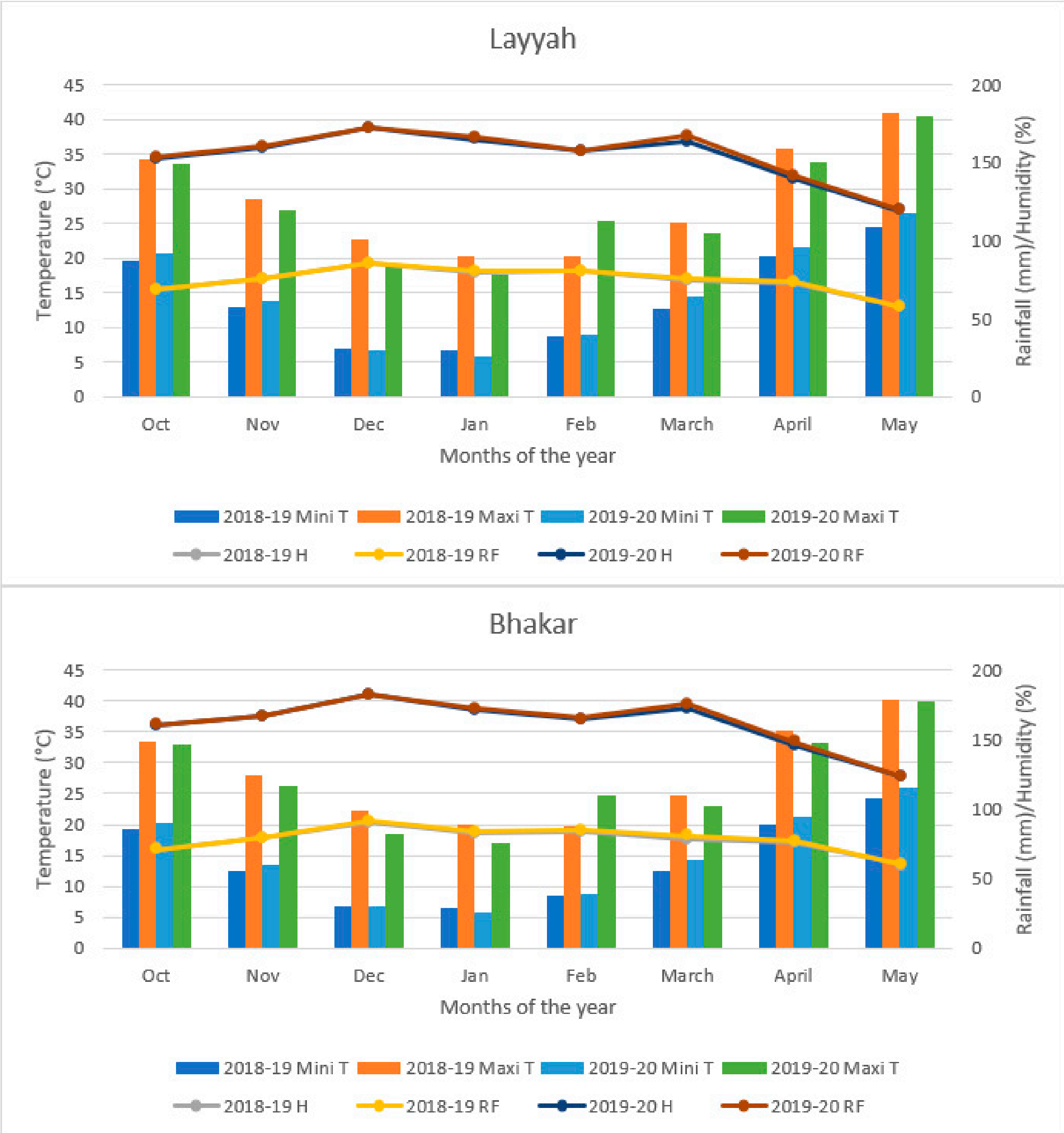

Figure 1. Weather data of experimental site recorded during the experiment at Layyah and Bhakkar locations during both years 2019 and 2020.

2.3. Crop Husbandry

The soil amendments with biochar, farmyard manure, poultry manure and compost as per treatment were carried out 30 days before the annual sowing of the sugar beet crop. After the application of the optimized doses of biochar, farmyard manure, poultry manure and compost, the soil was ploughed with a cultivator (along with a wooden planker), in order to thoroughly mix the organic amendments into the soil. Before sugar beet sowing, a pre-sowing irrigation was applied to all three sites in each year. When the soil reached a workable soil moisture, it was ploughed with a cultivator (up to 30 cm depth) two times followed by planking (one time) at each site for both years. With the help of a tractor-mounted ridger, ridges were made (45 cm apart) and the seeds were sown (10 cm apart) manually. The sowing of sugar beet was carried out in the last week of October (2019 and 2020) at the BZU Research Farm Layyah, in the first week of October (2019 and 2020) at the Farmer Field in Layyah, and during the second week of October (2019 and 2020) at both Farmer Fields in Bhakkar. Depending upon the soil condition and crop demand, subsequent irrigations (~13) were applied to critical crop growth stages of the sugar beet crop at each site during both years, though the irrigation was skipped when rainfall occurred. As the study focused on the comparison of different organic amendments, no synthetic fertilizer application was undertaken at both sites in both years. As there was no attack from insect-pests or weeds, no weedicides or insecticide was applied at any experimental site in both years. However, manual hoeing was carried out to control weeds within the treatment plots where needed. The sugar beet crop was harvested in the fourth week of May (2019 and 2020) at the BZU Research Farm Layyah, second week of May (2019 and 2020) at the Farmer Field Layyah and during the third week of May (2019 and 2020) at both Farmer Fields in Bhakkar.

2.4. Procedure for Recording the Data

From each plot, ten plants were tagged at random, and their leaves were counted to compute the average number of leaves per plant. The leaf length of ten random leaves in each plot was measured and the average was computed and expressed in centimeters. At maturity, the roots were dug up and the top leaves were separated from the roots of all the plants in a plot. These leaves were weighed in an electric balance to compute the average leaf weight per plant (in grams) and the total leaf yield (in tons) per hectare.

Ten roots were randomly taken from each plot and their length was measured in centimeters with a measuring scale. The same ten roots were weighed on an electric balance to compute the average root weight per plant (in grams). To estimate the root diameter, the root circumference was first measured using measuring tape (in centimeter) and then, by using the equation given by [39], the root diameter was determined as follows.

$$\text{Diameter (cm)} = \frac{\text{Circumference}}{3.142}$$

Root top ratio was determined by dividing the root weight of the crop from each plot to the leaf weight of the crop from that plot. Root yield was estimated by weighing all the dug-up roots from a plot and were later expressed in tons per hectare.

An SPAD chlorophyll meter was used to measure the chlorophyll contents in the sugar beet leaves. For this, five plants were tagged from each plot on a random basis and the readings of the SPAD chlorophyll contents were recorded from these plants followed by computation of the average chlorophyll contents.

For the measurement of sucrose percentage, washing, slicing and stirring of sugar beet roots was carried out for three minutes followed by mixing with distilled water and filtration. From this filtrate sugar concentration was measured by the procedure developed by [40].

The sugar yield was estimated by the following equation.

$$\text{Sugar yield}\left(\text{t ha}^{-1}\right) = \text{Root yield}\left(\text{t ha}^{-1}\right) \times \text{Sucrose percentage}/100$$

Theoretical Brix percentage was calculated according to the formula described by Legendre and Henderson (1972):

$$\text{B} = \frac{\text{SRP} - 0.4\text{S}}{(\text{S} - 0.4)0.73}$$

where: SRP = sugar recovery percentage, B = Brix percentage, S = sucrose percentage, 0.4 and 0.73 constant factors.

2.5. Data Analysis

Fisher's analysis of variance (ANOVA) technique, using the computer software "Statistix 8.1" was used to work out the difference in treatment means at 5% probability level followed by separation of treatment means using the least significant difference test [41]. The year effect was significant for all parameters, thus data are presented separately for both years for all three sites.

3. Results

3.1. Evaluation of Optimized Doses of Organic Amendments for Sugar Beet Crop

In the present research work, we found that the effects of different levels of organic amendments showed significant differences for sugar beet traits, including plant height, leaf weight per plant, root weight per plant, sugar contents, and sugar recovery percentage (Table 1). Among the different levels of farmyard manure, application of 20 t ha^{-1} showed the maximum results for the studied sugar beet traits. Similarly, application of poultry manure at 20 t ha^{-1} showed maximum results of studied sugar beet traits. Sugar beet crop produced higher values of studied sugar beet traits with the soil incorporation of biochar at 20 t ha^{-1} as compared with other levels of biochar. Furthermore, compost application at 20 t ha^{-1} showed higher values of studied sugar beet traits in comparison with other levels of compost (Table 1). These results clearly show that farmyard manure (40 t ha^{-1}), poultry manure (20 t ha^{-1}), biochar (20 t ha^{-1}) and compost (40 t ha^{-1}) are promising doses of the studied organic amendments for improved sugar beet traits and were considered to be the optimized doses of the studied organic amendments for the further exploration of their effects at the different experimental sites. Moreover, the sugar beet genotype 'California' showed the maximum studied sugar beet traits. Results of the studied sugar beet genotype 'Serinada-Kws' were also satisfactory (Table 1). Hence, both sugar beet genotypes were used to further check their responses to the optimized doses of the different organic amendments under study at the different experimental sites.

3.2. Effect of Different Optimized Doses of Organic Amendments on Sugar Beet Genotypes under Different Environmental Sites

Analysis of variance indicated that the number of leaves per plant, leaf length, leaf weight per plant, leaf yield, SPAD chlorophyll contents, root length, root weight per plant, root diameter, root top ratio, root yield, sugar percentage, sugar yield, Brix percentage and sugar recovery percentage were statistically different among all the experimental sites during both years of experimentation (Tables 2–4). Two-way interaction of the experimental sites with organic amendments was significant for leaf length for year 2019, leaf yield for year 2020, root diameter and root top ratio for year 2019, and for root length, root yield, sugar percentage, sugar yield, Brix percentage and sugar recovery percentage for the years 2019 and 2020 (Tables 2–4). Similarly, two-way interaction of experimental sites with the sugar beet genotypes was also significant for SPAD chlorophyll during year 2019, leaf/root length, root yield, sugar percentage and brix percentage for years 2019 and 2020, and sugar recovery percentage for year 2020 (Tables 2–4). Furthermore, two-way interaction of organic amendments with sugar beet genotypes was significant for the number of leaves per plant, root length for year 2019, root weight, leaf yield for years 2019 and 2020, and for root diameter for the year 2020 (Tables 2 and 3). Likewise, three-way interaction of experimental sites, organic amendments and sugar beet genotypes was significant only for root length during both years of experimentation (Table 3).

Table 1. Evaluation of optimized levels of different organic amendments for the selection of optimized doses for the experiment.

Treatment	Plant Height (cm)			Leave Weight per Plant (g)			Root Weight per Plant (g)			Sugar Contents (%)			Sugar Recovery (%)		
	Sugar Beet Varieties														
Farmyard Manure (ton ha^{-1})	California	Serenada	Mean	California	Serenada	Mean	California	Serenada	Mean	California	Serenada	Mean	California	Serenada	Mean
0	41.1	37.1	39.1 M	253.1	247.5	250.3	523.4	485.3	504.4 H	10.8	9.8	10.3 M	10.1	9.1	9.6 M
10	46.8	44.3	45.5 K	288.7	281.6	285.1	780.0	744.6	762.3 G	11.9	11.4	11.7 K	11.2	10.8	11.0 K
20	55.1	51.6	53.4 I	324.4	322.2	323.3 F	914.0	870.7	892.3 E	13.5	12.4	13.0 HI	12.8	11.8	12.3 HI
30	63.2	60.2	61.7 D	397.4	388.5	393.0	1042.3	992.6	1017.4 D	13.8	12.6	13.2 HI	13.1	11.9	12.5 GH
40	64.8	61.0	62.9 C	430.7	422.2	426.4	1065.6	1006.0	1035.8 D	14.2	13.9	14.0 CDE	13.5	13.2	13.4 CD
Mean	54.2 A	50.9 B		338.9 A	332.4 B		865.0 A	819.8 B		12.8 A	12.0 B		12.2 A	11.4 B	
Poultry manure (ton ha^{-1})															0.0
0	42.3	38.4	40.3 L	248.4	244.2	246.3	530.1	503.3	516.7 H	11.4	10.4	10.9 L	10.7	9.7	10.2 L
5	50.0	47.4	48.7 J	293.8	321.3	307.5	883.3	737.2	810.2 FG	12.5	12.0	12.3 J	11.8	11.4	11.6 J
10	58.2	54.9	56.6 G	353.3	347.7	350.5	942.5	913.3	927.9 E	14.9	13.9	14.4 BC	14.3	13.2	13.8 BC
15	70.2	65.9	68.1 B	455.2	438.9	447.1	1148.5	1082.0	1115.3 BC	15.2	14.0	14.6 B	14.6	13.4	14.0 B
20	71.1	67.7	69.4 A	453.0	436.8	444.9	1248.9	1124.3	1186.6 A	15.6	15.2	15.4 A	15.0	14.6	14.8 A
Mean	58.3 A	54.9 B		360.8 A	357.8 B		950.7 A	872.0 B		13.9 A	13.1 B		13.3 A	12.5 B	12.9 B
Biochar (ton ha^{-1})															0.0
0	41.9	38.7	40.3 L	251.3	247.4	249.3	506.6	474.9	490.8 H	10.4	9.5	9.9 M	9.8	8.8	9.3 M
5	47.9	45.2	46.6 K	276.8	269.1	272.9	880.0	755.7	817.8 F	11.6	11.1	11.3 KL	10.9	10.4	10.7 KL
10	56.6	52.7	54.6 H	311.9	301.9	306.9	908.4	909.9	909.2 E	13.3	12.3	12.8 I	12.7	11.7	12.2 I
15	61.0	57.3	59.2 F	330.4	322.1	326.2	1043.5	1058.4	1051.0 D	13.7	12.5	13.1 GHI	13.0	11.8	12.4 GHI
20	61.4	58.8	60.1 EF	398.2	390.2	394.2	1192.3	1124.3	1158.3 AB	14.1	13.7	13.9 DEF	13.4	13.0	13.2 DEF
Mean	53.8 A	50.6 B		313.7 A	306.1 B		906.1 A	864.6 B		12.6 A	11.8 B		11.9 A	11.1 B	11.5
Compost (ton ha^{-1})															0.0
0	42.6	39.1	40.9 K	251.5	246.7	249.1 J	504.0	482.7	493.3	10.7	9.7	10.2 M	10.0	9.0	9.5 M
10	49.4	46.4	47.9 J	286.6	274.3	280.4 I	1065.3	1051.9	1058.6	11.8	11.3	11.5 K	11.1	10.6	10.9 K
20	56.3	53.6	55.0 H	323.1	311.0	317.1 FG	1058.3	1060.9	1059.6	13.8	13.2	13.5 FG	13.2	12.6	12.9 FG
30	62.0	58.6	60.3 E	408.0	403.5	405.8 CD	1074.7	1058.4	1066.6	14.1	12.7	13.4 FG	13.4	12.0	12.7 FG
40	62.0	59.9	61.0 DE	413.3	407.2	410.3 BC	1200.8	1108.9	1154.9	14.3	13.9	14.1 CD	13.6	13.2	13.4 CD
Mean	54.5 A	51.5 B		336.5 A	328.5 B		980.6 A	952.6 B		12.9 A	12.1 B		12.3 A	11.5 B	
LSD ($p \leq 0.05$); V = 0.3497; T = 1.1059; T × V = 1.5640				V = 5.14; T = 16.28; T × V = 23.02			V = 17.4; T = 55.2; T × V = 78.1			V = 0.15; T = 0.48; T × V = 0.68			V = 0.15; T = 0.48; T × V = 0.68		

Means sharing same letter case (for main effects and interaction) for an organic amendment did not differ significantly at $p \leq 0.05$; G = varieties; OA = organic amendments.

Table 2. Influence of different organic amendments on leaf length, leaf weight, leaf yield and chlorophyll contents of sugar beet genotypes under diverse environmental conditions.

Experimental Treatments	Number of Leaves per Plant		Leaf Length (cm)		Leaf Weight (g per Plant)		Leaf Yield (t ha^{-1})		Chlorophyll Contents (SPAD Value)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Experimental Sites (ES)										
BZU Research Farm Layyah	36.1 A	41.8 A	35.1 A	39.4 A	260.0 A	270.3 A	18.7 A	20.1 A	54.6 A	55.9 A
Farmer Field Layyah	33.0 B	36.3 C	32.4 B	35.7 B	238.5 B	246.8 C	16.9 B	18.5 B	52.2 B	53.1 B
Farmer Field Bhakkar-A	32.7 B	37.3 B	29.4 C	35.2 C	237.2 B	251.2 B	16.0 B	18.5 B	51.8 C	53.1 B
Farmer Field Bhakkar-B	31.5 C	35.1 D	28.8 D	28.8 D	231.2 C	231.2 D	16.0 C	16.0 C	49.4 D	49.4 C
LSD ($p \leq 0.05$)	0.72	0.92	0.18	0.29	1.78	1.84	0.29	0.31	0.19	0.27
Organic Amendments (OA)										
Poultry Manure	38.6 A	43.0 A	34.8 A	37.9 A	268.3 A	276.2 A	18.4 A	19.6 A	52.4 A	53.3 A
Farm yard Manure	33.1 B	37.5 B	35.5 B	37.1 B	141.9 B	250.4 B	17.4 B	18.6 B	51.6 C	52.5 C
Compost	31.9 C	36.2 C	29.3 C	32.6 C	227.3 D	235.4 D	16.5 C	17.4 C	52.2 B	53.0 B
Biochar	29.7 D	33.8 D	28.1 D	31.4 D	229.4 C	237.5 C	16.3 C	17.5 C	51.9 B	52.9 B
LSD ($p \leq 0.05$)	0.72	0.92	0.18	0.29	1.78	1.84	0.29	0.31	0.19	0.27
Sugar Beet Genotypes (SG)										
California	33.5	37.9	31.6 A	34.9 A	245.2 A	253.3 A	17.4 A	18.5 A	52.3 A	53.2 A
Serenada	33.1	37.3	31.2 B	34.7 B	238.3 B	246.5 B	16.9 B	18.0 B	51.7 B	52.6 B
LSD ($p \leq 0.05$)	NS	NS	0.13	0.21	1.26	1.30	0.20	0.22	0.13	0.19
Interactions										
ES × OA	NS	NS	**	NS	NS	NS	NS	**	NS	NS
ES × SG	NS	NS	**	*	NS	NS	NS	NS	**	NS
OA × SG	*	NS	NS	NS	NS	NS	**	**	NS	NS
ES × OA × SG	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Means sharing same letter case (for main effects and interaction) for an organic amendment did not differ significantly at $p \leq 0.05$. * = significant at $p \leq 0.05$; ** = significant at $p \leq 0.01$; NS non-significant.

Table 3. Influence of different organic amendments on root length, root weight, root diameter, root top ratio and root yield of sugar beet genotypes under diverse environmental conditions.

Experimental Treatments	Root Length (cm)		Root Weight (g per Plant)		Root Diameter (cm)		Root Top Ratio		Root Yield (tha^{-1})	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Experimental Sites (ES)										
BZU Research Farm Layyah	22.7 A	23.6 A	990.8 A	1004.5 A	13.9 A	14.9 A	3.98 A	3.72 D	71.0 A	75.8 A
Farmer Field Layyah	20.3 C	21.3 B	947.9 B	959.0 B	12.8 B	13.9 B	3.95 A	3.89 B	67.7 B	70.2 C
Farmer Field Bhakkar-A	20.8 B	21.4 B	921.2 C	944.1 C	11.9 C	13.4 C	3.89 B	3.77 C	66.6 C	71.4 B
Farmer Field Bhakkar-B	20.3 C	20.3 C	912.9 D	913.0 D	11.6 D	11.6 D	3.80 C	3.96 A	62.4 D	62.4 D
LSD ($p \leq 0.05$)	0.15	0.25	2.38	2.78	0.13	0.20	0.02	0.02	0.85	0.85
Organic Amendments (OA)										
Poultry Manure	22.2 A	22.8 A	997.5 A	1009.4 A	13.5 A	14.4 A	3.72 D	3.66 D	70.9 A	73.9 A
Farm yard Manure	20.6 C	21.2 B	962.9 B	975.0 B	12.8 B	13.8 B	3.96 B	3.89 B	65.8 B	68.8 B
Compost	20.8 B	21.4 B	931.5 C	943.6 C	12.0 C	12.9 C	4.10 A	4.01 A	66.4 B	69.3 B
Biochar	20.7 BC	21.2 B	880.9 D	892.7 D	11.9 C	12.8 C	3.84 C	3.76 C	64.8 C	67.7 C
LSD ($p \leq 0.05$)	0.15	0.25	2.38	2.78	0.13	0.20	0.02	0.02	0.85	0.85
Sugar Beet Genotypes (SG)										
California	21.3 A	21.9 A	948.0 A	959.9 A	12.7 A	13.6 A	3.94 A	3.89 A	67.6 A	70.6 A
Serenada	20.8 B	21.3 B	938.4 B	950.4 B	12.4 B	13.3 B	3. 87 B	3.86 B	66.3 B	69.2 B
LSD ($p \leq 0.05$)	0.10	0.18	1.68	1.96	0.09	0.14	0.02	0.02	0.60	0.60
Interactions										
ES × OA	**	**	NS	NS	**	NS	*	NS	**	**
ES × SG	**	**	NS	NS	NS	NS	NS	NS	**	**
OA × SG	**	NS	**	*	NS	*	NS	NS	NS	NS
ES × OA × SG	**	*	NS	NS	NS	NS	NS	NS	NS	NS

Means sharing same letter case (for main effects and interaction) for an organic amendment did not differ significantly at $p \leq 0.05$. * = significant at $p \leq 0.05$; ** = significant at $p \leq 0.01$; NS non-significant.

Table 4. Influence of different organic amendments on sucrose percentage, sugar yield, Brix percentage and sugar recovery percentage of sugar beet genotypes under diverse environmental conditions.

Experimental Treatments	Sucrose Percentage		Sugar Yield (tha^{-1})		Brix Percentage		Sugar Recovery Percentage	
	2019	2020	2019	2020	2019	2020	2019	2020
Experimental Sites (ES)								
BZU Research Farm Layyah	14.1 A	14.9 A	9.7 A	11.3 A	19.2 A	20.0 A	13.3 B	12.3 B
Farmer Field Layyah	13.8 B	15.1 A	9.4 B	16.6 B	18.3 B	19.2 B	18.3 A	11.7 C
Farmer Field Bhakkar-A	12.0 C	13.3 B	8.0 C	9.5 C	17.1 C	18.2 C	12.5 C	12.3 B
Farmer Field Bhakkar-B	11.6 D	11.6 C	7.2 B	7.2 D	16.2 D	16.2 D	11.7 D	12.8 A
LSD ($p \leq 0.05$)	0.15	0.23	0.14	0.21	0.16	0.21	0.14	0.13
Organic Amendments (OA)								
Poultry Manure	13.8 A	14.7 A	9.6 A	10.9 A	18.6 A	19.3 A	14.8 A	12.9 A
Farm yard Manure	12.7 B	13.5 B	8.3 B	9.3 B	17.4 BC	18.1 B	13.6 BC	12.1 B
Compost	12.7 B	13.4 BC	8.4 B	9.3 B	17.5 B	18.2 B	13.7 B	12.2 B
Biochar	14.4 C	13.3 C	8.1 C	9.0 C	17.3 C	17.9 B	13.5 C	11.9 C
LSD ($p \leq 0.05$)	0.15	0.23	0.14	0.21	0.16	0.21	0.14	0.13
Sugar Beet Genotypes (SG)								
California	13.2 A	14.0 A	8.9 A	9.9 A	17.9 A	18.6 A	14.1 A	12.4 A
Serenada	12.6 B	13.5 B	8.3 B	9.4 B	17.5 B	18.2 B	13.8 B	12.1 B
LSD ($p \leq 0.05$)	0.10	0.16	0.10	0.14	0.11	0.14	0.10	0.09
Interactions								
ES × OA	**	**	**	**	**	**	**	**
ES × SG	**	**	NS	NS	**	**	NS	**
OA × SG	NS	NS	NS	NS	NS	NS	NS	NS
ES × OA × SG	NS	NS	NS	NS	NS	NS	NS	NS

Means sharing same letter case (for main effects and interaction) for an organic amendment did not differ significantly at $p \leq 0.05$. ** = significant at $p \leq 0.01$; NS non-significant.

Among the experimental sites, the highest number of leaves per plant, leaf length, leaf weight per plant, leaf yield, SPAD chlorophyll contents, root length, root weight per plant, root diameter, root top ratio, root yield, sugar percentage, sugar yield, and Brix percentage during both years were recorded at the BZU Research Farm Layyah site; this was statistically similar to the Farmer Field Layyah site for root-top ratio for the year 2019 and for sucrose percentage for the year 2020 (Tables 2–4). However, the root-top ratio during year 2020 was the highest at Farmer Field Bhakkar-B (Table 3). The sugar recovery percentage was highest for the Farmer Field Layyah site for the year 2019, and for the Farmer Field Bhakkar-B site during the year 2020 (Table 2).

Among the organic amendments, the highest number of leaves per plant, leaf length, leaf weight per plant, leaf yield, SPAD chlorophyll contents, root length, root weight per plant, root diameter, root yield, sugar percentage, sugar yield, Brix percentage and sugar recovery percentage were recorded with the application of poultry manure (20 t ha^{-1}) during both years (Tables 2–4), while the root-top ratio was highest with compost application during both years (Table 3). Furthermore, the highest leaf length, leaf weight per plant, leaf yield, SPAD chlorophyll contents, root length, root weight per plant, root diameter, root yield, sugar percentage, sugar yield, Brix percentage and sugar recovery percentage were recorded in genotype 'California' among the sugar beet genotypes during both years (Tables 2–4), while the root-top ratio was highest in genotype 'Serenada' during both years (Table 3).

Two-way interaction of experimental sites with organic amendments showed that the highest leaf length and root diameter during the year 2019, leaf yield and sugar during the year 2020, and root length and root yield during years 2019/2020 were recorded with the application of poultry manure at the BZU Research Farm Layyah during both years. Root-top ratio was highest with compost application at the Farmer Field Bhakkar-B during the year 2020. During 2019, the highest sugar yield was recorded with application of poultry manure at the Farmer Field Layyah site (Table 5). Sucrose percentage, Brix percentage and sugar recovery percentage was also highest with application of poultry manure at the BZU Research Farm Layyah sites during both years and was statistically similar to poultry manure application at the Farmer Field Layyah site for sucrose percentage during both years (Table 6).

Likewise, two-way interaction of experimental sites with the sugar beet genotypes showed that the highest leaf/root length, root yield and Brix percentage for years 2019 and 2020, chlorophyll contents during 2020, and sucrose percentage during 2019 were recorded in the sugar beet genotype 'California' when grown at the BZU Research Farm Layyah and that this was statistically similar with the genotype 'Serenada' for the year 2020 for Brix percentage at the same site, with the genotype 'California' at the Farmer Field Layyah site during 2019 for sucrose percentage, and with the genotype 'Serenada' at Farmer Field Layyah during 2019 for leaf length (Tables 7 and 8). During 2020, sucrose percentage was the highest in genotype 'California' when grown at Farmer Field Layyah (Table 8). Sugar recovery percentage was the highest in genotype 'California' at Farmer Field Bhakkar-B during the year 2020 (Table 8).

The interaction (organic amendments $\times$ sugar beet genotypes) showed that the highest number of leaves per plant and root length during year 2019, root diameter during year 2020, and leaf yield/root weight during year 2019/2020 were recorded with the application of poultry manure in genotype 'California' and that this was statistically similar to the genotype 'Serenada' in terms of poultry manure application for leaf yield and root diameter for the year 2020 (Table 9).

Table 5. Interactive effect of experimental sites and organic amendments on leaf length, leaf yield, root length, root diameter, root top ratio and root yield of sugar beet.

Experimental Sites	Organic Amendments	Leaf Length (cm)	Leaf Yield (t ha^{-1})	Root Length (cm)		Root Diameter (cm)	Root-Top Ratio	Root Yield (t ha^{-1})		Sugar Yield (t ha^{-1})	
		2019	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
BZU Research Farm Layyah	Poultry Manure	38.3 a	21.9 a	24.0 a	24.8 a	15.0 a	3.6 j	76.3 a	81.2 a	10.4 b	13.2 a
	Farm Yard Manure	37.0 b	20.7 b	22.1 c	23.1 bc	14.3 b	3.7 f–h	69.6 c	74.1 cd	9.5 c	10.9 c
	Compost	33.1 e	18.9 c	22.5 b	23.3 b	13.4 d	3.9 cd	69.6 c	74.4 cd	9.6 c	10.6 cd
	Biochar	31.9 f	18.9 c	22.2 bc	22.9 bc	13.3 de	3.7 g–i	68.7 c	73.5 d	9.3 cd	10.6 cd
Farmer Field Layyah	Poultry Manure	35.7 c	20.3 b	21.7 d	22.8 bc	13.8 c	3.8 fg	72.7 b	75.4 bc	10.9 a	12.4 b
	Farm Yard Manure	34.8 d	18.7 c	19.6 i	20.6 e–g	12.9 f	4.0 bc	66.1 de	68.5 fg	8.8 ef	9.9 e
	Compost	29.9 i	17.7 d	20.2 f–h	21.2 d	12.3 g	4.2 a	66.5 d	68.9 fg	9.1 de	10.4 d
	Biochar	29.0 j	17.6 d	19.9 h	20.5 fg	12.2 g	3.9 e	65.5 de	67.9 g	8.7 f	9.8 e
Farmer Field Bhakkar-A	Poultry Manure	32.7 e	20.3 b	22.2 bc	22.7 c	13.1 ef	3.6 ij	71.4 b	76.3 b	9.3 cd	10.8 c
	Farm Yard Manure	31.5 g	18.7 c	20.4 f	21.0 de	12.3 g	3.9 d	64.7 e–g	69.7 ef	7.6 gh	9.1 f
	Compost	27.5 k	17.5 d	20.4 f	20.9 d-f	11.3 i	4.1 b	66.4 d	71.1 d	7.8 g	9.3 f
	Biochar	26.1 m	17.4 d	20.3 fg	20.9 d-f	11.2 i	3.8 f	63.9 f–h	68.4 fg	7.4 hi	8.9 f
Farmer Field Bhakkar-B	Poultry Manure	32.3 f	15.8 e	20.8 e	20.8 d-f	12.2 gh	3.7 hi	63.1 gh	63.1 h	7.5 h	7.5 g
	Farm Yard Manure	30.9 h	16.3 e	20.2 f-h	20.2 g	11.9 h	4.0 bc	62.7 hi	62.8 h	7.4 hi	7.4 g
	Compost	26.7 l	15.7 e	20.1 gh	20.1 g	11.1 i	4.2 a	62.9 h	62.9 h	7.2 i	7.2 gh
	Biochar	25.3 n	16.3 e	20.3 fg	20.3 g	11.1 i	3.9 e	61.0 i	61.0 i	6.8 j	6.8 h
LSD ($p \leq 0.05$)		0.37	0.63	0.30	0.51	0.26	0.05	1.71	1.70	0.50	1.78

Means sharing same letter case (for main effects and interaction) for an organic amendment did not differ significantly at $p \leq 0.05$.

Table 6. Interactive effect of experimental sites and organic amendments on sucrose percentage, Brix percentage and recovery percentage of sugar beet.

Experimental Sites	Organic Amendments	Sucrose Percentage		Brix Percentage		Sugar Recovery Percentage	
		2019	2020	2019	2020	2019	2020
BZU Research Farm Layyah	Poultry Manure	15.1 a	16.2 a	20.3 a	21.2 a	19.4 a	13.3 a
	Farm Yard Manure	13.7 b	14.8 bc	18.8 c	19.5 cd	12.9 e	11.9 de
	Compost	13.8 b	14.3 d	18.9 c	19.8 c	13.0 e	12.1 d
	Biochar	13.6 bc	14.4 cd	18.7 c	19.6 cd	12.8 e	11.8 de
Farmer Field Layyah	Poultry Manure	15.1 a	16.4 a	19.4 b	20.4 b	14.3 c	11.9 de
	Farm Yard Manure	13.4 cd	14.5 cd	18.0 de	18.9 e	18.0 b	11.7 e
	Compost	13.7 b	15.1 b	17.9 de	18.9 e	17.9 b	11.7 ef
	Biochar	13.3 d	14.5 cd	17.7 e	18.7 e	17.7 b	11.4 f
Farmer Field Bhakkar-A	Poultry Manure	13.1 d	14.2 d	18.1 d	19.3 d	13.5 d	13.3 a
	Farm Yard Manure	11.7 e-g	13.0 e	16.7 fg	17.9 f	12.1 fg	11.9 de
	Compost	11.8 ef	13.1 e	16.8 f	17.8 f	12.3 f	12.1 d
	Biochar	11.6 fg	13.1 f	16.7 fg	17.7 f	12.0 f-h	11.8 de
Farmer Field Bhakkar-B	Poultry Manure	11.9 e	11.8 f	16.4 gh	16.4 g	11.9 g-i	13 b
	Farm Yard Manure	11.8 ef	11.9 f	15.9 i	15.9 h	11.7 hi	12.8 bc
	Compost	11.5 gh	11.5 fg	16.3 hi	16.3 gh	11.7 i	12.8 bc
	Biochar	11.2 gh	11.2 g	15.9 i	15.9 h	11.6 i	12.7 c
LSD ($p \leq 0.05$)		0.30	0.46	0.32	0.42	0.29	0.26

Means sharing same letter case (for main effects and interaction) for an organic amendment did not differ significantly at $p \leq 0.05$.

Table 7. Interactive effect of experimental sites and sugar beet genotypes on leaf length, root length, root yield and chlorophyll contents of sugar beet.

Experimental Sites	Sugar Beet Genotypes	Leaf Length (cm)		Root Length (cm)		Root Yield (t ha^{-1})		Chlorophyll Contents
		2019	2020	2019	2020	2019	2020	2020
BZU Research Farm Layyah	California	35.3 a	39.6 a	22.9 a	23.9 a	72.2 a	76.9 a	54.8 a
	Serenada	34.8 b	39.2 a	22.5 b	23.2 b	69.9 b	74.6 b	54.4 b
Farmer Field Layyah	California	32.7 c	35.7 b	20.6 d	21.8 c	68.9 b	71.3 cd	52.4 c
	Serenada	32.1 d	35.8 b	20.0 f	20.7 de	66.5 cd	69.0 e	52.1 d
Farmer Field Bhakkar-A	California	29.8 e	35.6 b	21.2 c	21.8 c	67.3 c	72.4 c	52.1 d
	Serenada	29.1 f	34.9 c	20.5 de	20.9 d	65.9 d	70.3 d	51.5 e
Farmer Field Bhakkar-B	California	28.8 g	28.8 d	20.3 e	20.3 f	61.8 f	61.8 g	49.9 f
	Serenada	28.8 g	28.8 d	20.4 e	20.4 ef	63.1 e	63.1 f	48.9 g
LSD ($p \leq 0.05$)		0.26	0.42	0.21	0.36	1.21	1.20	0.27

Means sharing same letter case (for main effects and interaction) for an organic amendment did not differ significantly at $p \leq 0.05$.

Table 8. Interactive effect of experimental sites and sugar beet genotypes on sucrose percentage, Brix percentage and recovery percentage of sugar beet.

Experimental Sites	Sugar Beet Genotypes	Sucrose Percentage		Brix Percentage		Sugar Recovery Percentage
		2019	2020	2019	2020	2020
BZU Research Farm Layyah	California	14.3 a	14.9 b	19.4 a	20.2 a	12.5 c
	Serenada	13.9 b	14.9 b	18.9 b	19.9 a	12.0 d
Farmer Field Layyah	California	14.1 a	15.3 a	18.4 c	19.4 b	11.8 e
	Serenada	13.5 c	14.8 b	18.1 d	19.0 c	11.5 f
Farmer Field Bhakkar-A	California	12.3 d	13.6 c	17.4 e	18.6 d	12.5 c
	Serenada	11.8 e	13.0 d	16.7 f	17.8 e	12.0 d
Farmer Field Bhakkar-B	California	12.1 d	12.1 e	16.2 g	16.2 f	12.9 a
	Serenada	11.1 f	11.1 f	16.1 g	16.1 f	12.7 b
LSD ($p \leq 0.05$)		0.21	0.33	0.22	0.29	0.18

Means sharing same letter case (for main effects and interaction) for an organic amendment did not differ significantly at $p \leq 0.05$.

Table 9. Interactive effect of organic amendments and sugar beet genotypes on number of leaves per plant, leaf yield, root length, root weight and root diameter of sugar beet at different experimental sites.

Organic Amendments	Sugarcane Genotypes	Number of Leaves per Plant	Leaf Yield (tha−1)		Root Length (cm)	Root Weight (g per Plant)		Root Diameter (cm)
		2019	2019	2020	2019	2019	2020	2020
Poultry Manure	California	39.1 a	13.6 a	19.7 a	22.5 a	999.9 a	1011.9 a	14.5 a
	Serenada	38.1 b	13.4 b	19.5 ab	21.8 b	994.9 b	1006.8 b	14.3 a
Farm Yard Manure	California	32.6 bc	13.0 c	19.1 b	20.9 c	969.7 c	981.9 c	13.9 b
	Serenada	33.5 b	12.7 d	18.0 c	20.2 e	956.0 d	968.1 d	13.6 c
Compost	California	32.4 cd	12.1 e	17.7 cd	20.9 c	936.8 e	948.5 e	12.9 d
	Serenada	31.6 d	111.9 f	17.2 e	20.7 d	926.2 f	938.7 f	12.9 d
Biochar	California	30.2 e	12.2 e	17.6 c-e	20.7 d	885.6 g	897.2 g	13.2 d
	Serenada	29.1 f	11.7 g	17.5 de	20.6 d	876.3 h	888.1 h	12.5 e
LSD ($p \leq 0.05$)		1.02	0.41	0.44	0.21	3.37	3.93	0.29

Means sharing same letter case (for main effects and interaction) for an organic amendment did not differ significantly at $p \leq 0.05$.

4. Discussion

In the first research work, significant differences were found among the different levels of organic amendment for improving sugar beet traits (plant height, leaf weight per plant, root weight per plant, sugar contents, and sugar recovery percentage). Among different levels of organic amendments, farmyard manure (40 t ha^{-1}), poultry manure (20 t ha^{-1}), biochar (20 t ha^{-1}) and compost (40 t ha^{-1}) showed maximum results for the studied sugar beet traits (Table 1). Our results clearly suggest that farmyard manure (40 t ha^{-1}), poultry manure (20 t ha^{-1}), biochar (20 t ha^{-1}) and compost (40 t ha^{-1}) are promising doses of the studied organic amendments for the improvement of sugar beet traits and were considered as the optimized doses of studied organic amendments for the further exploration of their effects at different experimental sites using the same sugar beet genotypes.

Over the following two years of research work, we found that sugar beet crops at the BZU Research Farm Layyah showed the highest growth, yield and quality traits as compared with the other experimental sites during both years of field experimentation (2019 and 2020) (Tables 2–4). It is noteworthy to mention here that the weather and soil conditions were observed to be uniform for all experimental sites during both years of field experimentation as shown in Figure 1. Improvements in the studied sugar beet traits at the BZU Research Farm Layyah might be attributed to better crop management practices and excellent crop care at this site as the crop was being efficiently managed by a skilled staff.

This study shows that the organic amendments significantly impacted the sugar beet growth, root yield, sugar yield and quality traits of both sugar beet genotypes under diverse environmental conditions. Among the organic amendments, poultry manure showed great potential for improving growth, yield and quality traits of sugar beet crop. Application of poultry manure at 20 t ha^{-1} showed highest growth, yield and quality traits of sugar beet crop (Tables 2–4). Improvements in the growth traits of sugar beet crop might closely, though indirectly, associated with improved soil structure and also due to the direct association with the enhanced availability of micro- and macro-nutrients which resulted in improved growth because the balanced application of N, P and K have a strong positive relationship with sugar beet root and sugar yield [42–45]. Indeed, the nutrients within the poultry manure are slowly released making them durable and thus available to plants for a longer time without leaching [46], ensuring an improved crop growth, as observed in this study. Similarly, improved yield of sugar beet traits was associated with increasing trend in growth traits as observed in this research work. Our results are in agreement with the results that show higher growth and yield traits with the soil amendment of poultry manure. This is due to an increased mobility of micro (Fe, Mn, Cu, B and Zn)- and macro-nutrients (N, P, K, Ca and Mg) after decomposition of poultry manure [47,48]. Our results present proof of a study that has shown higher growth traits of cotton with the application of poultry manure due to an improvement in soil-available nitrogen, potassium and phosphorus contents and soil organic matter [7].

Poultry manure is an excellent organic amendment that also improves soil porosity and favors increased retention of soil moisture and the root growth of field crops [49–51]. Hence, the higher root yield of sugar beet traits during both years of field research work (2019 and 2020) was closely related with the increased retention of soil moisture and root growth. Furthermore, application of poultry manure at 20 t ha^{-1} also incurred the highest root weight $plant^{-1}$, root length and root diameter during both years with these traits also correlated with improved root growth and development due to better total soil porosity and improved water availability [47,50,52]. Moreover, poultry manure improves a fertilizer's use efficiency by decreasing the leaching losses of nutrients. This reduction in leaching losses might in turn be behind the improved yield traits associated with the soil incorporation of 20 t ha^{-1} poultry manure during both years of experimentation [44,49,51,53]. A previous study reported a 46% increase in the root yield of carrot due to an improvement in soil water contents, soil porosity, aggregate stability and increased soil micronutrients via application of poultry manure [22]), which supported our hypothesis. Additionally, a previous study has observed longer and bigger roots of radish with poultry manure application due to an improvement in soil organic matter and nutrient contents [54], which is also a confirmation of our studied results. This indicates that the improvement in sugar beet growth, root yield and quality in our study might be attributed to an improved availability of macro- and micro-nutrients and improved soil physical environment. During both years of experimentation (2019 and 2020), sugar beet showed the highest Brix percentage, sucrose and recovery percentage with the application of poultry manure at 20 t ha^{-1} (Table 4). In our study, higher growth traits of sugar beet crop led to a linear increase in canopy development and assimilate portioning and, ultimately, to higher quality traits [52].

Among the sugar beet genotypes, a better root yield and sugar quality was observed in the genotype 'California' than for the genotype 'Serenada'. Better root yield in the 'California' genotype was the outcome of better leaf and root growth. Moreover, differences in morphological and yield parameters, stay-green (chlorophyll contents) and quality traits (sugar percentage, Brix percentage and sugar recovery percentage) might be due to differences in the genetic makeup of these genotypes [55,56] which resulted in different root yield in both genotypes. Many previous studies have also documented variation in root yield among the sugar beet genotypes under different soil and climatic conditions [55–57].

In our study, interactive effect of experimental sites with organic amendments indicated that application of poultry manure at 20 t ha^{-1} showed higher growth, yield and quality traits of sugar beet when grown on BZU Research Farm Layyah and were also satisfactory at Farmer Field Layyah (Tables 5 and 6). Furthermore, the interactive effect of experimental sites with sugar beet genotypes revealed that the 'California' genotype produced higher growth, higher yield and higher quality traits of sugar beet at the BZU Research Farm Layyah (Tables 7 and 8) which suggests that the BZU Research Farm Layyah is a better place for the sugar beet genotype 'California'. During both years of experimentation, the interactive effect of organic amendments with genotypes and experimental sites demonstrated that the sugar beet genotype 'California' produced a higher leaf yield, root length, root weight, and root diameter with the application of poultry manure at the BZU Research Farm Layyah (Table 9).

5. Conclusions

Different organic amendments significantly improved the root and sugar yield of sugar beet genotypes. The performance of the genotype 'California' was superior to the genotype 'Serenada'. In conclusion, growing the genotype 'California' in sandy loam soils with an application of poultry manure (20 t ha^{-1}) might be a pragmatic option to improve the yield and quality of sugar beet. Further studies are needed to explore the positive effects of poultry manure to further validate the results of the current study under different changing climate scenarios.

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