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Yield and Quality Traits of Field-grown Sugar Beet (*Beta vulgaris* L.) in Response to Foliar Application of Micronutrients and Different Levels of Manure

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ABSTRACT

Sugar beet (*Beta vulgaris* L.) is an agricultural crop with a high sucrose content in the root. Its specific properties make it an essential crop for the sugar processing industry—the response of sugar beet cv. 'Sonja' to different rates of animal manure and foliar application of micronutrients was explored. Animal manure was applied at six rates, whereas micronutrients (Fe, Zn, B, and Mn) were foliar applied at five levels and no micronutrients (control). The evaluated traits included gross sugar percentage, Na, K, and N contents of tubers, alkalinity, sugar extraction coefficient, root yield, pure sugar percentage, and molasses. The results showed that the maximum gross sugar of 18.59% and pure sugar of 16.22% were obtained in plots treated with 40 t ha^{-1} manure that was subjected to the foliar application of B. Also, foliar application of micronutrients (Mn, Zn, and B) under 40 t ha^{-1} manure by reducing the amount of Na and amino-N content of the sugar beet roots improved the quantitative and qualitative characteristics. The application of manure enhanced root yield, white sugar yield, and sugar yield by 31, 35, and 38%, respectively, compared to the no-manure treatment. The highest root yield of 63.96 t ha^{-1}, white sugar yield of 11.24 t ha^{-1} and sugar yield of 9.28 t ha^{-1} was obtained from Mn application. The results revealed that the foliar application of micronutrients accompanied by animal manure application could maintain soil fertility and improve the quantitative and qualitative traits of sugar beet.

HIGHLIGHTS

- Sugar beet is an essential crop agricultural crop cultivated mainly for its high sucrose content root.
- Animal manure and foliar application of micronutrients improved both soil fertility and improved the quantitative and qualitative traits of sugar beet.
- The highest gross and pure sugar contents were obtained in plots treated with 40 t ha^{-1} of manure and that were subjected to foliar application.

Keywords: Sugar beet, gross sugar percentage, sugar extraction coefficient, yield, molasses

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Most parts of Iran have an arid and semi-arid climate. In these regions, fewer crop residuals are returned to soils due to their low vegetation biomass. Consequently, the soils in these regions are poor in organic matter. An excellent way to improve soil fertility in arid and semi-arid regions is to apply organic fertilizers to help accomplish production stability (Tarkalson *et al*. 2018; Maitra and Gitari 2020). Organic fertilizers are safe products and appropriate natural resources to protect and restore soil fertility so that they supply soil organic matter and nutrient requirements of plants (Rahimi *et al*. 2019; Faridvand *et al*. 2021).

Furthermore, most soils in Iran have undesirable physical and chemical properties due to the lack or shortage of organic matter. This is partially responsible for the inadequate growth of plants and their low yields (Abou-Hussein *et al*. 2003; Abdel-Lateef, 2018). Another limiting factor is the undesirable soil structure in these regions. The soils are crusted or agglomerated by water absorption or loss, which may induce seed dormancy, hindering their growth. Hence, it is imperative to apply organic fertilizers, including manure, to increase or at least maintain soil fertility and enhance yields (Rahimi *et al.* 2019, 2021; Habib, 2021). Manures not only increase soil organic matter but also improve soil water retention and biological properties such as microbial biomass, soil respiration, and the activity of such enzymes as acid phosphatase, protease, and dehydrogenase. In addition, soils that are applied with manure have more active and more affluent microbial communities and exhibit higher P, K, Ca, Mg, and N availability than soils treated with inorganic fertilizers (Jabeen *et al*. 2018; Dlamini *et al.* 2020). By reducing soil alkalinity and helping preserve soil moisture, organic fertilizers are effectively involved in extending the root system and thereby increasing the uptake of water and nutrients by plants (Azizi *et al*. 2010; Nyawade *et al*. 2021; Seleiman *et al*. 2021).

Foliar application of micronutrients is one of the fastest ways to meet fertilizer demand. The advantages of this method do not confine to saving in fertilizer use and its positive economic aspect, but the environment is protected against chemical contamination too, which is very important for the accomplishment of sustainable agriculture (Hassanpouraghdam *et al*. 2020). Not only should nutrients be in forms that can readily be available to plants, but there should also be a balance in their quantities (Abd El-Mageed *et al*. 2021; Mugo *et al*. 2021). The arable lands of Iran are suffering from a severe shortage of micronutrients, mainly Fe and Zn, for different reasons such as their high lime content, bicarbonate content of irrigation water, low organic matter content, and excessive application of phosphate-containing fertilizers (Mekdad and Shaaban, 2020). Given these limiting factors of soils in Iran, foliar application of micronutrients is preferred to their soil incorporation for rapidly coping with the shortage of nutrients (Armin and Asgharipour, 2012; Hefny and Said, 2021).

Micronutrients are applied to plants in very low dosages, but they are crucial in improving their growth and production. These elements are key for cell differentiation, cell growth, and cell wall integrity and induce resistance to pests and diseases in most cases (Zewail *et al.* 2020). The deficiency of these elements may sometimes limit the uptake of other nutrients and plant growth (Abbas *et al*. 2014). Fe is involved in cytochrome structure, redox operation, and chlorophyll synthesis. Zn is an essential element for vital enzymes and growth regulators. Zn deficiency may impair plant yield by adversely influencing auxin biosynthesis (Bybordi and Mamedov, 2010). The low solubility of these elements in limy pH, bicarbonate content of irrigation water, and high P application are prevailing. In some crops, plant needs vary with the environmental conditions. Soil nutrient contents may not suffice to meet crop needs. Indeed, most trace elements, including Fe and Mn, are quickly fixed in soils with alkaline pH, and some, like Ca, Mg, and Mn, are not readily transferred to leaves (Mekdad and Rady, 2016).

Therefore, the foliar application of these elements can contribute to solving these problems. Foliar application of nutrients can increase crop yield and quality and reduce the need for soil incorporation of fertilizers, so a significant increase has been reported in sugar beet root yield as the result of the foliar application of nutrients (Mekdad and Shaaban, 2020). Sugar beet (*Beta vulgaris* L.) is an important crop whose production should be developed since it is one of the significant sources of sugar. Various factors are influential in the quantity and quality of sugar beet root yield, including cultivar, planting arrangement, climate type, appropriate sowing time, soil fertility, and plant feeding, especially fertilization type, dosage, and timing. Sugar is the main product of sugar beet and is a significant source to meet the energy demand of people. Some byproducts of sugar beet are molasses and pulp, which are widely used to feed animals (Asadi, 2006). Western Azerbaijan province is one of the leading sugar beet-producing regions of Iran that accounts for 60 percent of the sugar in the country, along with Khorasan province.

The present study aimed to explore the impact of the foliar application of selected micronutrients (Fe, Zn, B, and Mn) and manure on quantitative and qualitative traits of sugar beet under the climatic conditions of Naqadeh, Iran.

MATERIALS AND METHODS

Experiment Design: The study was carried out as a factorial experiment based on a Randomized Complete Block Design with three replications in the research farm of Naqadeh Sugar Factory (Long. 45°24′ E., Lat. 36°57′ N., Alt. 1328 m) in the 2012-2013 growing season. Before the initiation of the experiment, the soil was randomly sampled to determine its physicochemical properties. The results are presented in Table 1.

Six rates of cow manure (0, 10, 20, 30, 40, and 50 t ha^{-1}) constituted the first factor, and five rates of foliar application of micronutrients (Fe, Zn, B, and Mn) and no foliar application constituted the second factor. Some chemical parameters of the cow manure were measured before use (Table 2). The experimental plots were in the form of ridge and furrow. They were composed of eight 4-m-long planting rows with an inter-row spacing of 50 cm and on-row spacing of 25 cm. After the plots were prepared, the seeds were sown by wet planting on ridges in early April of 2013. The seeds, which were supplied by the Naqadeh Sugar Factory, were for cv. 'Sonja' with 98% viability and 99% purity. The application of manure commenced in mid-February of 2013 as per the experimental design. Foliar application of micronutrients was performed at the 6-8-leaf and 10-12-leaf stages in the early morning. As per the recommendation of the manufacturing company (Kavian Toos Mashhad), the micronutrients were applied at the rates of 1, 1, and 2 L ha^{-1} and 3 kg ha^{-1} for Fe, Zn, B, and Mn, respectively.

The thinning operation was performed at the 2-4-leaf stage. The weeds were controlled manually throughout the growing period. The first irrigation was performed immediately after sowing, and the subsequent irrigations were carried out at 7-day intervals.

Determination of sugar beet root qualitative traits: The plants were harvested in mid-November after removing the marginal effect. Then, a 15-kg sample from each plot was sent to a laboratory to determine their sugar, N, K, and Na contents. After the roots were detached from the shoots and were thoroughly rinsed, they were placed in a sampling device to prepare root pulp. Then, the roots were decomposed, and their qualitative traits were measured with a breathalyzer (the model D-2016) and a flame-photometer (Reinefeld *et al*. 1974). Molasses percentage was calculated by Eq. (1) (Dutton and Bowler, 1984).

$$\%MS = 0.17K + 0.13Na + 0.215\ (\alpha - \text{amino} - N) \quad \ldots(1)$$

MS represents molasses, K denotes potassium, Na shows sodium, and α-amino-N represents nitrogen. K, Na, and α-amino-N contents of sugar beet roots were in meq per 100 g of the root. Pure sugar percentage, or extractable sugar percentage, was calculated by gross sugar percent minus molasses percentage as represented by Eq. (2) (Asadi, 2006):

$$\%WSC = \%SC - \%MS \quad \ldots(2)$$

WSC is the white sugar content, SC is sugar content, and MS is molasses content.

The gross sugar percentage (sugar content) is composed of extractable sugar content and the sugar content of molasses. To measure the quality parameters of the roots, root pulp and lead subacetate were mixed with the ratio of 26 g pulp + 177.7 cm^3 lead subacetate with an automatic mixer. Then, it was infiltrated through a filter paper (Whatman 42), its extract was separated, and it was determined by polarimetry (Clarke *et al*. 1991).

The alkalinity coefficient of the samples was calculated based on the Polak Equation by Eq. (3) (Asadi, 2006).

Table 1: Some of the physicochemical properties of the soil from the study site

EC	pH	Texture	Clay	Silt	Sand	CCE	SP	N	OC	Mn	B	Zn	Fe	K	P
dSm^{-1}			%							mg kg^{-1}					
7.81	0.72	Clay loam	39	43	18	23	55	0.06	0.7	11.5	0.3	1	9.1	397	9.1

$$\text{Alkalinity} = \frac{\text{Potassium} + \text{Sodium}}{\text{Nitrogen}} \quad \ldots(3)$$

The Na and K contents of the root pulp sample were recorded by a flame photometer. Also, the α-amino-N content was measured by a Cooper reagent and a betalyzer (Flavy and Vukou, 1977).

Data Processing: Data were analyzed by the SAS 9.1 software package, and means were compared by Duncan's multiple range test at the $P < 0.05$ level.

RESULTS

Root yield: According to the results of variance analysis, the impact of different amounts of animal manure and foliar application of micronutrients was significant ($P < 0.01$) on root yield (Table 3). Means comparison indicated that the highest root yield of 69.71 t ha^{-1} was obtained from the application of 50 t ha^{-1} animal manure. In contrast, the control (without the application of animal manure) exhibited a root yield of 47.98 t ha^{-1} (Table 4).

According to the results of means comparison, the maximum root yield of sugar beet (63.96 t ha^{-1}) was observed in plants treated with Mn, which did not differ significantly from the application of Zn. The lowest root yield of 50.56 t ha^{-1} was obtained from the control treatment (Table 5).

Gross sugar percentage: The analysis of data variance showed that the interaction of animal manure application and foliar application of micronutrients caused significant differences in gross sugar percentage ($P < 0.01$) (Table 3). According to the results, gross sugar percentage was increased with the increase in the application of animal manure amounts in plants treated with micronutrients, so that the highest gross sugar percentage of 18.59 was observed in plants sprayed with B that were treated with 40 t ha^{-1} manure and the lowest was 16.06 percentage observed in the control (without the application of animal manure) plants but not sprayed with micronutrients (Table 6).

Pure sugar percentage: The interaction between animal manure application and foliar application of micronutrients was significant for pure sugar percentage (Table 3). T=he highest pure sugar percentage of 16.22 was observed in plants sprayed with B that were treated with 40 t ha^{-1} animal manure, and the lowest was 12.58 percent was related to the plants treated in the control plants (not treated with animal manure and micronutrients) (Table 6).

White sugar yield: Different amounts of animal manure and micronutrients influenced white sugar yield significantly ($P < 0.01$) (Table 3). The highest white sugar yield of 12.16 t ha^{-1} was obtained from the application of 50 t ha^{-1} animal manure. The animal manure amounts of 30 and 40 t ha^{-1} did not differ significantly in the white sugar yield. The lowest white sugar yield of 7.91 t ha^{-1} was obtained from the control (Table 4). In the treatment of foliar application with micronutrients, the maximum white sugar yield of 11.24 t ha^{-1} was obtained from Mn-treated plants, which the lowest white sugar yield of 8.73 t ha^{-1} was found in control plants (Table 5).

Sugar yield: According to the results of variance analysis (Table 3), different levels of animal manure and micronutrients influenced sugar yield significantly ($P < 0.01$). The means comparison revealed that the application of animal manure increased sugar yield so that the highest and lowest sugar yield of 10.20 and 6.35 t ha^{-1} was obtained from the treatment of 50 t ha^{-1} animal manure and control plant (no animal manure), respectively (Table 4). In the treatment of foliar application with micronutrients, the maximum sugar yield of 9.28 t ha^{-1} was obtained from Mn-treated plants, which did not differ significantly from the application of Zn. The lowest sugar yield of 7.15 t ha^{-1} was observed in control plants (Table 5).

Alkalinity index: Alkalinity was significantly ($P<0.01$) influenced by simple effects of animal manure and foliar application of micronutrients (Table 3). So the highest alkalinity index of 3.68

Table 2: Some chemical properties of manure used in this study

EC	pH	Mn	B	Zn	Fe	K	P	N	OC
dSm^{-1}				mg kg^{-1}				%	
8.94	7.57	98.76	1.87	67.84	380.23	1.1	1.14	1.69	38.43

Table 3: Analysis of variance for some quality and quantity characteristics of sugar beet as affected by animal manure application and foliar application of micronutrients

Source of variation	df	Root yield	Gross sugar	Pure sugar	White sugar yield	Sugar yield	Alkalinity	Molasses	The extraction coefficient	α-amino-N	K^+	Na^+
Replication	2	42.93	0.43	1.01	2.40	2.42	0.67	0.12	6.79	0.03	0.26	0.13
Manure (M)	5	888.97**	2.64**	5. 26**	35.07**	29.17**	4.81**	0.51**	32.05**	1.07*	19.72**	1.01*
Foliar (F)	4	537.77**	1.88**	2.04**	16.40**	11.98**	6.18**	0.11^{ns}	6.13*	0.41^{ns}	2.65**	0.19^{ns}
M * F	20	19.68^{ns}	0.24**	0.40*	0.63^{ns}	0.48**	1.54^{ns}	0.16**	5.56**	0.40^{ns}	0.26^{ns}	0.50^{ns}
Error	58	12.15	0.009	0.07	0.39	0.28	1.29	0.06	2.21	0.41	0.23	0.35
C.V (%)		5.91	0.55	1.90	6.12	6.22	31.86	8.61	1.80	29.99	11.92	27.89

**, ** and ns, Significant at 5% and 1% levels of probability, non-significant, respectively.*

Table 4: Mean comparisons of the effect of animal manure application on some quality and quantity characteristics of sugar beet

Manure	Root yield (Ton ha^{-1})	White sugar yield (Ton ha^{-1})	Sugar yield (Ton ha^{-1})	Alkalinity (%)	α-amino-N (meq)	Potassium (meq)	Sodium root (meq)
0	47.98±4.19	7.91±0.81	6.35±0.72	2.14±1.16	1.67±0.61	2.04±0.51	1.74±0.32
10	55.42±3.98	9.34±0.78	7.62±0.66	3.18±1.07	1.75±0.51	3.73±0.47	1.84±0.31
20	58.79±2.77	9.93±0.52	8.18±0.42	3.46±0.82	1.75±0.39	4.03±0.50	1.91±0.47
30	65.51±3.08	11.29±0.45	9.40±0.50	3.68±0.93	2.03±0.38	4.29±0.31	1.89±0.54
40	62.15±2.51	11.00±0.60	9.23±0.41	3.61±1.18	2.22±0.51	4.73±0.35	2.21±0.58
50	69.71±2.84	12.16±0.54	10.20±0.47	3.40±1.25	2.27±0.55	5.43±0.51	2.46±0.54

The means with common letters have no significant difference according to Duncan's multiple range test (P≤0.05).

was observed in the treatment of 50 t ha^{-1} animal manure. However, it did not show a significant difference with other amounts of animal manure application. But the lowest one (2.14%) was obtained for the plants not treated with animal manure (Table 4). According to the comparison of the means, the maximum Alkalinity index of 3.93% was obtained from sprayed plants with Mn, which did not differ significantly from the foliar spraying of Zn and B. The lowest alkalinity index of 2.39% was observed in non-sprayed plants (control) (Table 5).

Molasses: Molasses was influenced by the interaction effect between the foliar application of micronutrients and animal manure application (Table 3). the foliar application of micronutrients caused a decrease in molasses by increasing the application of animal manure amounts. The highest molasses content was 3.48% (Table 6), which was observed in the control plants (not treated with animal manure and micronutrients). The lowest one (2.37%) was observed in sprayed plants with B that were treated with 40 t ha^{-1} animal manure (Table 6).

Sugar extraction coefficient: The interaction effect of experimental treatments (micronutrients × animal manure) on the sugar extract coefficient was significant (Table 3). The highest coefficient of sugar extract (87.24%) was related to the treatment of 40 t ha^{-1} animal manure that was sprayed with B. While the lowest one (78.30%) was obtained from the control plants (not treated with animal manure and micronutrients) (Table 6).

Nitrogen: The simple effect of the different amounts of animal manure was significant ($P < 0.01$) for the α-amino-N content of the sugar beetroots (Table 3). Means comparison revealed that the increase in

Table 5: Mean comparisons of the effect of foliar application of micronutrients on some quality and quantity characteristics of sugar beet

Micronutrients	Root yield (Ton ha^{-1})	White sugar yield (Ton ha^{-1})	Sugar yield (Ton ha^{-1})	Alkalinity	Potassium (meq)
B	56.81±4.31	10.18±0.83	8.48±0.72	3.41±0.96	4.14±0.35
Fe	60.07±3.49	10.39±0.66	8.61± 0.56	2.98±0.94	4.02±0.27
Zn	63.22±2.99	10.81±0.51	8.96±0.35	3.51±1.14	4.15±0.38
Mn	63.96±2.67	11.24±0.50	9.28±0.44	3.93±1.23	4.47±0.54
Control	50.56±2.71	8.73±0.46	7.15±0.43	2.39±0.56	3.42±0.36

The means with common letters have no significant difference according to Duncan's multiple range test (P≤0.05).

Table 6: Mean comparisons of some quality and quantity characteristics of sugar beet as affected by animal manure application and foliar application of micronutrients

Manure	Micronutrients	The percentage of gross sugar	The percentage pure sugar	Molasses (%)	The extraction coefficient (%)
	B	17.78±0.11	14.34±0.20	3.44±0.09	80.62±1.22
	Fe	17.12±0.14	13.89±0.19	3.22±0.18	81.24±0.57
0	Zn	16.68±0.21	13.47±0.34	3.21±0.08	80.73±0.64
	Mn	16.44±0.08	13.18±0.11	3.26±0.13	80.15±0.64
	Control	16.06±0.06	12.58±0.02	3.48±0.04	78.30±0.16
	B	17.56±0.11	14.27±0.20	3.29±0.09	81.24±0.64
	Fe	17.07±0.02	14.05±0.32	3.01±0.31	82.34±1.80
10	Zn	17.15±0.02	13.76±0.04	3.29±0.03	80.50±0.19
	Mn	17.21±0.05	14.29±0.50	2.92±0.52	83.00±2.99
	Control	16.89±0.02	13.59±0.11	3.39±0.13	80.24±0.73
	B	17.55±0.10	14.80±0.36	2.74±0.28	84.34±1.01
	Fe	17.28±0.12	14.30±0.27	2.98±0.38	82.75±2.08
20	Zn	16.95±0.11	13.79±0.24	3.11±0.08	81.94±0.87
	Mn	17.33±0.04	14.18±0.12	3.14±0.08	81.94±0.51
	Control	16.85±0.11	13.74±0.15	3.15±0.13	81.15±0.52
	B	17.91±0.37	14.74±0.52	3.17±0.27	82.28±1.65
	Fe	17.07±0.07	14.37±0.12	2.70±0.40	84.17±2.36
30	Zn	17.50±0.20	14.82±0.18	2.68±0.05	81.52±0.91
	Mn	17.98±0.18	14.75±0.61	3.23±0.49	82.02±2.80
	Control	17.06±0.16	14.22±0.44	2.84±0.17	81.39±0.23
	B	18.59±0.09	16.22±0.22	2.37±0.28	87.24±1.44
	Fe	17.92±0.21	14.87±0.42	3.05±0.22	82.94±1.39
40	Zn	17.83±0.07	14.98±0.16	2.85±0.14	83.98±0.74
	Mn	18.04±0.13	14.83±0.43	3.21±0.40	82.19±3.46
	Control	17.57±0.17	14.64±0.66	2.93±0.61	83.29±2.21
	B	18.00±0.37	14.99±0.42	3.00±0.06	83.29±0.95
	Fe	17.66±0.17	14.53±0.26	3.01±0.17	82.59±0.64
50	Zn	17.42±0.07	14.69±0.20	2.72±0.42	84.34±2.45
	Mn	18.09±0.17	15.41±0.07	2.68±0.11	85.17±0.47
	Control	17.30±0.160	14.29±0.48	3.13±0.14	82.27±0.89

The means with common letters have no significant difference according to Duncan's multiple range test (P≤0.05).

the animal manure amounts was accompanied by the increased content of α-amino-N in the roots so that the maximum N accumulation was 2.27 meq per 100 g observed in plants treated with 50 t ha-1 animal manure, but the lowest one (1.67 meq per 100 g) was observed in plants not treated with animal manure (Table 4).

Potassium: The analysis of variance showed that K accumulation in the roots was influenced by animal manure and micronutrients (Table 3). The highest

K (5.43 meq per 100 g) was obtained from the application of 50 t ha^{-1} animal manure. The lowest K (2.04 meq per 100 g) was observed from control plants (Table 4). According to the mean comparison of micronutrient foliar, the maximum K of 4.47 meq per 100 g was obtained from sprayed plants with Mn. The lowest K of 3.42 meq per 100 g was related to the control plants (Table 5).

Sodium: The Na content of sugar beet roots was only influenced by the simple effects of the application of animal manure treatment (Table 3). Given the results of the comparison of the mean, the maximum Na accumulation rate of 2.46 meq per 100 g was observed in the roots of plants treated with 50 t ha^{-1} animal manure, which did not differ significantly from the application of 40 t ha^{-1}. In contrast, the minimum Na accumulation of 1.7 meq per 100 g was found in the application of animal manure (Table 4).

DISCUSSION

It has been shown that the application of animal manure contributes to the gradual release of N to sugar beets so that N is supplied to the plants during the growth period by the decomposition and mineralization of the manure and improves root yield (Zengin *et al*. 2009; Nadeeka and Seran, 2020). Furthermore, it has been reported that the application of animal manure can enhance the growth and yield of sugar beets by stimulating germination and increasing the uptake of water and nutrients (Jabeen *et al*. 2018). The improving impact of Mn and Zn on root yield can be attributed to the impact of these nutrients on increasing enzymatic activity and enhancing the productivity of metabolic activities. The impact of Mn, Zn, and Fe application on the improvement of chlorophyll content, dry matter, and net photosynthesis of sugar beets has been reported by other researchers (Gharib and El-Henawy, 2011; Mekdad and El-Sherif, 2016). The foliar application improves the potential of leaves to absorb Zn and Mn and contributes to increasing pigments and photosynthesis capacity of the plants (Mekdad and El-Sherif, 2016). This can be effective in yield improvement.

It has been reported that the application of animal manure increased gross sugar percentage and its difference was significant with the control plants not treated with manure (Maharjan and Hergert, 2019). Probably due to the gradual release of nutrients in manure-treated plots and its uptake by sugar beet plants in periods that their need for this nutrient is increased (Lehrsch *et al*. 2014); this, in turn, increases sugar percentage. On the other hand, it seems that animal manure application stimulates vegetative growth in the late vegetative period. This increases sugar association resulting in the enhancement of gross sugar content (Nadeeka and Seran, 2020). In the micronutrient treatments, the B-containing fertilizers might have been able to activate some enzymatic systems and metabolic activities, which increased the generation of energy and carbohydrates and developed leaf area, eventually leading to the higher sugar content beets (Zewail *et al*. 2020). Mekdad and Shaaban (2020) reported that micronutrients played a critical role in the metabolism of carbohydrates, the regulation of cell metabolism, and the mobilization of sugar compounds, which improved sugar percentage.

Increased nutrient uptake in different treatments of animal manure and foliar application of micronutrients might be responsible for the enhancement of pure sugar percentage because it has been established that there is a positive correlation between nutrient uptake and its sugar content (Lehrsch *et al*. 2014; Zewail *et al*. 2020). It has been reported that the increase in animal manure rate increases nutrient uptake, finally resulting in the enhancement of pure sugar percentage of sugar beets (Maharjan and Hergert, 2019). Boron plays a significant role in vital activities of plants, e.g., cell division in system tissues, the formation of leaf and flower buds, the metabolism and translocation of sugars and hydrocarbon-containing compounds, the regulation of water, and its conductivity in plants (Armin and Asgharipour, 2012). Thus, this may increase photosynthesis capacity, and the allocation of more assimilates to the metabolism of sugar synthesis in plants like sugar beets (Shiemshi, 2007; Zewail *et al*. 2020; Nasar *et al*. 2021).

By the gradual release of nutrients and the improvement of aeration, the application of decayed animal manure improves some physical and chemical properties of soil, including its texture, and allows the penetration and further growth of roots and better uptake of nutrients by them (Lehrsch *et al*. 2014; Maharjan and Hergert, 2019). It has been reported that animal manures can enhance the solubility and absorbability of micro and macronutrients in soils (Lehrsch *et al*. 2014).

The impact of Mn and Zn in improving white sugar yield can be attributed to their influence on increasing enzymatic activity resulting increase in the productivity of metabolic activities (El-Mageed *et al*. 2021). As a result, this improves white sugar yield owing to the increase in root growth and yield. Since sugar yield is a function of root yield and pure sugar percentage, the application of manure increases sugar yield by enhancing root yield (Maharjan and Hergert, 2019). Accordingly, the application of Zn- and Mn-containing fertilizers is likely to activate some enzymatic systems and metabolic activities, thereby increasing the production of energy and carbohydrates and leaf area, which eventually lead to higher sugar yield (El-Mageed *et al.* 2021).

Since the alkalinity index is Na and K quantity divided by α-amino-N, it is influenced by N content negatively and by K content positively (Asadi, 2006). Zengin *et al.* (2009) reported that the application of animal manure was related to the increase in α-amino-N of the roots so that the lowest α-amino-N content and alkalinity index were obtained from the plants not treated with animal manure. Zewail *et al.* (2020) state that micronutrients are involved in regulating plant water content and increasing sugar content. Also, the presence of Zn in auxin contributes to vegetative growth, photosynthesis, and assimilation significantly. In addition, the Fe content of chlorophyll increases the sugar content of roots by influencing photosynthesis rate, CO_2 fixation, and the synthesis of starch and sugar and their storage in the roots (El-Mageed *et al*. 2021).

It has been reported that exposure to macronutrients and micronutrient deficiency results in the decline of photosynthesis pigments and leaf chlorophyll content (Amin *et al.* 2013). Accordingly, the decline of nutrient consumption due to the lack of foliar application entails the decline of photosynthesis rate, CO_2 fixation rate per leaf unit area, and consequently, the storage of starch and sugar in leaves and roots. In these conditions, the molasses content of roots or root pulp increases (El-Mageed *et al*. 2021).

The coefficient of sugar extraction depends on the Na, K, and N contents of roots. Thus, its escalation requires increasing root sugar content and decreasing the amounts of Na, K, and α-amino-N (versus sucrose percent) (Maharjan and Hergert, 2019). This implies a high potential of leaves for this nutrient uptake and its use in increasing pigments and plant photosynthesis. The foliar application of micronutrients extended the green cover area, so growth was improved, and water translocation to phloem was facilitated (Zewail *et al*. 2020). The application of Zn and Mn-containing fertilizers can enhance the generation of energy, the synthesis of proteins and carbohydrates, and the development of leaf areas by activating enzymatic systems and metabolic activities (El-Mageed *et al*. 2021). Micronutrients are involved in increasing sugar content by participating in enzymatic reactions, membrane integrity and performance, metabolism of different compounds, mobilization of sugars, synthesis of pyrimidine bases and flavonoids, cell division in meristem tissues, and regulation of water and its conductivity in cells (El-Mageed *et al*. 2021). In these conditions, the sucrose ratio was increased, resulting in a higher sugar extraction coefficient.

It has been reported that animal manure can increase the α-amino-N content of sugar beetroots (Maharjan and Hergert, 2019). It is noteworthy that as long as soils have high N content, higher rates of manure make soil N available for plants, increasing the N content of their roots (Nadeeka and Seran, 2020). Animal manure improves soil structure and aeration on the one hand and facilitates the growth and development of root systems by warming soils, possibly resulting in a higher likelihood of N uptake (Dlamini *et al*. 2020). Animal manure, by improving soil physicochemical structure facilitates the growth and development of root systems, thereby increasing nutrient uptake by plants (Maharjan and Hergert, 2019). Amin *et al*. (2013) reported that micronutrients affected the metabolism of carbohydrates, thereby increasing sugar, starch, and dry matter contents so that micronutrients application reduced the accumulation of nitrates in sugar beetroots in addition to enhancing their yield and improving their quality (Mekki, 2014). Maharjan and Hergert (2019) reported that excessive application of animal manure increased N, K, and Na contents, which may be associated with the high mineral contents of animal manure. Manures gradually release various nutrients and hinder their loss by leaching so that their uptake by plants is increased (Habib, 2021). This may be partially responsible for the increase in root impurities. Thus, the application of animal manure in low amounts may be considered a mechanism for improving root growth and the increased storage of sugars in sugar beetroots (Maharjan and Hergert, 2019; Mamyandi *et al*. 2012).

CONCLUSION

Overall, the results showed that the integrated application of animal manure and micronutrients in a sustainable agriculture systemcould improve the quantitative and qualitative traits of sugar beetroots. The maximum gross and pure sugar percentage were obtained from the treatment of 40 t ha^{-1} animal manure that was subjected to foliar application of B. In addition to the enhancement of root sugar yield with the increase in animal manure amounts, root yield was increased so that the final result was the increase in the economic value of sugar beet. Also, foliar application of micronutrients (Mn, Zn, and B) under 40 t ha^{-1} manure by reducing the amount of Na and N sugar beetroot improved the quantitative and qualitative characteristics. So that animal manure application and foliar application of micronutrients, along with the goals of sustainable agriculture, can offset nutrient deficiencies, maintain soil fertility and sustainable crop production, and finally, inhibit environmental pollution.

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