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Response of *Beta vulgaris* L. to nitrogen and micronutrients in dry environment

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ABSTRACT

Soils in dry environments, including Egypt, have low fertility and poor structure. To enhance soil fertility and crop performance, management technologies such as plant nutrition and suitable cultivars are needed for such environments. To investigate the yield performance under such conditions, two field trials were conducted using two *Beta vulgaris* cultivars (Amina – V_1; BTS 301 – V_2), two nitrogen levels (N_1 – 200; N_2 – 350 kg N/ha) and two micronutrient mixtures (M_1 – Fe + Zn + Mn; M_2 – tap water). Results indicated that growth and yields and their qualities were positively ($P \leq 0.05$ and/or $P \leq 0.01$) affected by all factors singly or in various interactions. The best yield performance was obtained with the trilateral interaction application of $V_2 \times N_2 \times M_1$. Correlation analysis revealed presence of highly significant *r* values between white sugar yield and root yield.

Keywords: arid and semi-arid regions; sugar beet; sugar quality; sustainability

Sugar is a strategic commodity for daily consumption and many industries worldwide. In terms of strategic importance, it comes right after wheat or rice in all countries all over the world.

In arid and semi-arid environments including Egypt, limited rainfall and low soil fertility have reduced crop productivity, particularly sugar cane crop that produces about 63% of sugar production worldwide, requiring high water availability (20 000–24 000 m^3 irrigation water/ha) and high soil fertility (Singh et al. 2008). Proper soil and water management, and selection of suitable cultivars affect crop productivity and soil sustainability (Benlhabib et al. 2014). Therefore, sugar beet as a limited water requirement crop (4200–5500 m^3 irrigation water/ha) is required for dry regions due to its ability to grow and produce well in the reclaimed-dry areas. Crop management technologies such as fertilization policy are also required to enhance crop production and sustain soil fertility under climate change effects.

Sugar beet (*Beta vulgaris* L.) is a second source of sugar production in many countries, including Egypt. The Egyptian agricultural policy encourages increase of sugar beet cultivated area to increase sugar production to meet the industry requirements of the recently-established factories and to minimize the gap between production and consumption. Selection of promising cultivars and application of suitable nitrogen (N) and micronutrients are important strategies for sugar beet production.

Nitrogen is the primary essential mineral nutrient that plays a significant role in growth and yield and its quality in sugar crops (Sreewarome et al. 2007). It also enhances soil water consumption (Wang et al. 2015). On the other hand, the increased N levels were found to increase the impurities (i.e., K, Na and α-amino N) and sugar loss (Mekdad 2015). Therefore, N fertilization should be managed well to produce high root tonnage with high sucrose and purity levels. Micronutrients (i.e., Fe, Mn and Zn) are very important to increase crop yield and quality. To avoid the deficiency symptoms on dry soils limited in organic matter (< 2%), the balanced and efficient use of micronutrients could be conducted to improve crop yield and quality (Mousavi et al. 2007) because they often act as co-factors to activate enzymes and participate in many important processes, including sugar translocation (Yarnia et al. 2008).

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The main objective of this study was to analyse a typical management of sugar beet cultivation under dry region conditions (Egypt). Several sustainable cropping techniques such as N soil fertilization and foliar application of Fe, Mn and Zn mixture were assessed to improve growth and yields and their qualities in two multigerm cultivars of *Beta vulgaris* L. over two seasons.

MATERIAL AND METHODS

In two seasons (2013/14 and 2014/15), two field experiments were conducted on the Experimental Farm, Faculty of Agriculture, Fayoum University, Egypt. The experimental soil (Southeast Fayoum; 29°17'N, 30°53'E) was sandy loam with organic matter of 0.78%, electical conductivity of 5.33 dS/m and pH of 7.87.

Healthy seeds of two multigerm sugar beet cultivars (Amina – V_1; BTS 301 – V_2) were obtained from the Crop Research Institute, Agricultural Research Center, Egypt, and were sown on 9 September 2013 and on 11 September 2014. After sterilization using 1% (v/v) sodium hypochlorite, seeds were sown in hills spaced 20 cm apart, rows spaced 60 cm apart in 3.0 m × 3.5 m plots. Thinning was done to produce one plant per hill (about 80 000 plants/ha). During soil preparation and plant growth, soil was supplemented with 70 P units as calcium super phosphate (31 kg P) and 57.5 K units as potassium sulphate (41 kg K) per hectare as recommended by the Ministry of Agriculture and Land Reclamation. Treatments were arranged in split-split plots in randomized complete block design, with three replicates. The cultivars (V_1 and V_2) were the main plots. Ammonium nitrate (33.5% N) at levels of 200 (N_1) and 350 (N_2) kg N/ha were the sub-treatments. It was applied in three equal doses (at 4–6 leaf stage, before the 2nd irrigation, and before the 3rd irrigation). A micronutrients mixture (M_1 – Fe + Zn + Mn (100 ppm)) and tap water (M_2) were the sub-sub plots. Micronutrients (Sigma-Aldrich Co., Taufkirchen, Germany) were applied, with 0.1% (v/v) Tween-20 as a surfactant, in two foliar sprays to run-off at a concentration of 100 ppm calculated from Zn-, Mn- and Fe-sulphate.

At harvest, a random sample of five guarded plants in each sub-subplot was taken and plants were separated into tops and roots. Leaf area index (LAI) was calculated: LAI = unit leaf area per plant (dm^2)/plant ground area (dm^2), and root lengths, diameters and weights were measured using a meter scale and digital balance. Plants of all ridges from each sub-subplot were harvested to measure root and biological yields. Harvest index was calculated as follows: HI = root yield (t/ha)/[root yield (t/ha) + top yield (t/ha)].

White sugar yield was calculated by multiplying root yield by white sugar %, and loss sugar yield was calculated by multiplying root yield by loss sugar %. Juice sugar contents and the non-sugar K, Na and α-amino N (expressed as a meq/100 g of root) were determined by Automatic Sugar Polarimetre according to McGinnus (1971). White sugar contents were calculated by linking the K, Na and α-amino N (expressed as a meq/100 g of root) according to Harvey and Dotton (1993).

All obtained data were statistically analysed by the technique of ANOVA for the split-split plot design using MSTAT-C (Michogen, USA), and *LSD* at 5% and 1% levels of probability was used to test the differences between treatment means.

RESULTS

Single effect of cultivars, N levels or micronutrients. Data in Tables 1 and 2 show that cv. BTS 301 significantly ($P \leq 0.05$) exceeded cv. Amina for growth and productivity over two seasons. However, top fresh weight and K content differed only in the second season. On the other hand, the two cultivars had no significant differences regarding the contents of Na, α-amino N and purity in both seasons. Tables 1 and 2 also reveal that except for harvest index and purity, all parameters of growth and yields and their quality were significantly ($P \leq 0.01$) increased by the application of 350 kg N/ha (N_2) compared to N_1 over two seasons. In addition, foliar spray with the micronutrient mixture (M_1) had significant ($P \leq 0.01$) positive effects on sugar beet yield components and quality traits (Tables 1 and 2). The M_1 (Fe + Zn + Mn) significantly exceeded the M_2 (control; tap water) in leaf area index, root length and diameter, root and top fresh weights, root and white sugar yields and purity over both seasons. However, it caused a significant decrease in harvest index and impurities (Na, K, and α-amino-N contents).

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Table 1. Effects of cultivars, nitrogen levels, and foliar spray with micronutrients and their interactions on sugar beet growth and yields in two seasons

Treatment		Leaf area index	Root length	Root diameter	Root fresh weight	Top fresh weight	Root yield	Biological yield
			(cm)		(kg/plant)		(t/ha)	
2013/2014								
Cultivar (V)	Amina (V_1)	3.98	28.64	14.57	1.45	0.83	78.39	94.1
	BTS 301 (V_2)	6.98	31.32	16.30	1.86	1.13	96.5	124.1
	$LSD_{0.05}$	1.31*	1.41*	0.61**	0.13**	NS	13.0*	11.8*
Nitrogen (kg N/ha) (N)	200 (N_1)	4.50	28.29	14.99	1.55	0.83	83.9	101.9
	350 (N_2)	6.46	31.67	15.88	1.76	1.13	91.0	116.4
	$LSD_{0.05}$	0.51**	1.61**	0.39**	0.13*	0.21**	2.6**	3.1**
Micronutrient (M)	Fe + Zn + Mn (M_1)	6.37	33.88	16.18	1.79	1.06	93.5	117.1
	control (M_2)	4.60	26.08	14.68	1.52	0.91	81.4	101.1
	$LSD_{0.05}$	0.25**	1.16**	0.29**	0.07**	0.04**	3.6**	4.3**
Interaction	V × N	ns	ns	ns	ns	ns	ns	ns
	V × M	**	ns	ns	ns	ns	ns	ns
	N × M	**	ns	ns	ns	ns	ns	ns
	V × N × M	ns	ns	ns	ns	ns	ns	ns
2014/2015								
Cultivar	Amina	3.96	28.32	14.41	1.44	0.70	77.4	93.0
	BTS 301	6.63	31.61	16.23	1.87	1.29	95.4	123.2
	$LSD_{0.05}$	0.27**	2.15*	1.02*	0.07**	0.31*	11.1*	14.5*
Nitrogen (kg N/ha)	200	4.24	28.38	14.84	1.53	0.84	82.7	100.1
	350	6.36	31.55	15.80	1.77	1.15	90.1	116.0
	$LSD_{0.05}$	0.41**	0.94**	0.2**	0.16*	0.11**	4.9*	5.4**
Micronutrient	Fe + Zn + Mn	6.25	33.80	16.02	1.78	1.13	93.0	116.8
	control	4.35	26.13	14.63	1.53	0.86	79.9	99.4
	$LSD_{0.05}$	0.19**	1.20**	0.39**	0.07**	0.11**	3.3**	4.1**
Interaction	V × N	ns	ns	ns	ns	ns	ns	ns
	V × M	**	ns	ns	*	ns	ns	ns
	N × M	**	ns	ns	ns	ns	ns	ns
	V × N × M	ns	ns	ns	ns	ns	ns	ns

*$P < 0.05$; **$P < 0.01$; ns – non-significant

Effect of different bilateral interactions. Data in Tables 1 and 2 show that white sugar yield and purity were significantly affected by the interaction application of cultivars and N levels in both seasons. The best results were obtained by the interaction application of V_2 (cv. BTS 301) with N_2 level (350 kg N/ha). The interaction application of cultivars and micronutrient mixture significantly affected leaf area index and white sugar yield in both seasons, while it significantly affected purity in the first season and root fresh weight in the second one (Tables 1 and 2). The best results were obtained by the interaction application of V_2 with M_1 (Fe + Zn + Mn). Data in Tables 1 and 2 also reveal that the in-

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Table 2. Effects of cultivars, nitrogen levels, and foliar spray with micronutrients and their interactions on harvest index, sugar beet yield, impurities and purity in two seasons

Treatment		Harvest index	White sugar yield (t/ha)	Loss sugar yield (t/ha)	α-Amino N (%)	Na (%)	K (%)	Purity (%)
2013/2014								
Cultivars (V)	Amina (V_1)	0.84	13.6	1.76	1.23	2.14	3.25	86.4
	BTS 301 (V_2)	0.79	16.7	2.19	1.01	1.90	3.61	85.6
	$LSD_{0.05}$	0.02**	3.7*	ns	ns	0.31**	ns	1.4*
Nitrogen (kg N/ha) (N)	200 (N_1)	0.83	12.6	1.53	0.95	1.30	2.92	88.7
	350 (N_2)	0.79	15.4	2.43	1.30	2.74	3.94	85.6
	$LSD_{0.05}$	0.02**	0.9**	0.04**	0.29*	ns	0.13**	0.9**
Micronutrients (M)	Fe + Zn + Mn (M_1)	0.81	16.1	1.91	1.04	1.73	3.04	89.3
	Control (M_2)	0.83	11.9	2.05	1.20	2.31	3.82	85.3
	$LSD_{0.05}$	0.01*	0.8**	0.04**	0.14*	0.15**	0.15**	0.2**
Interactions	V × N	ns	*	ns	ns	ns	ns	**
	V × M	ns	**	ns	ns	ns	ns	*
	N × M	*	**	ns	ns	**	*	**
	V × N × M	**	ns	ns	ns	ns	ns	ns
2014/2015								
Cultivars	Amina	0.84	11.6	1.73	1.16	2.14	3.22	86.3
	BTS 301	0.78	15.9	2.18	1.07	1.92	3.60	88.4
	$LSD_{0.05}$	0.02**	2.9*	ns	ns	ns	ns	0.9*
Nitrogen (kg N/ha)	200	0.82	12.8	1.48	0.83	1.31	2.83	88.5
	350	0.79	15.7	2.43	1.40	2.75	3.99	85.8
	$LSD_{0.05}$	0.02**	0.9**	0.09**	0.12**	0.33**	0.20**	0.8**
Micronutrients	Fe + Zn + Mn	0.80	16.6	1.89	0.98	1.73	3.03	89.7
	control	0.82	11.9	2.02	1.25	2.33	3.79	85.6
	$LSD_{0.05}$	ns	0.7**	0.04*	0.10**	0.24**	0.13**	0.5**
Interactions	V × N	ns	*	ns	ns	ns	ns	*
	V × M	ns	**	ns	ns	ns	ns	ns
	N × M	ns	**	ns	*	**	**	**
	V × N × M	*	ns	ns	ns	ns	ns	ns

*P < 0.05; **P < 0.01; ns – non-significant

teraction application of N levels and micronutrient mixture significantly affected leaf area index, harvest index, white sugar yield and purity in both seasons. The best results were obtained by the interaction application of N_2 and M_1.

Effect of trilateral interaction. Data in Tables 1 and 2 show significant differences in harvest index in both seasons. The best results of harvest index and sugar yields were obtained by the trilateral interaction application of V_2 (cv. BTS 301), N_2 level (350 kg N/ha) and M_1 (Fe + Zn + Mn).

Correlation analysis. The correlation coefficients in Table 3 between white sugar yield and each of root yield, root weight, root length and

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Table 3. A matrix of simple correlation coefficient between gross sugar yield and other important traits estimated in 2013/14 season

Parameter		Year	1	2	3	4	5
1	white sugar yield	2013/14	1				
		2014/15	1				
2	root yield	2013/14	0.959**	1			
		2014/15	0.964**	1			
3	root weight	2013/14	0.864**	0.874**	1		
		2014/15	0.826**	0.845**	1		
4	root length	2013/14	0.686**	0.674**	0.702**	1	
		2014/15	0.764**	0.747**	0.714**	1	
5	root diameter	2013/14	0.869**	0.894**	0.846**	0.833**	1
		2014/15	0.859**	0.888**	0.840**	0.839**	1

**$P < 0.01$

root diameter were computed in order to throw the light on the relationship of effectual traits interest. Positive and highly significant ($P \leq 0.01$) correlation coefficients were obtained between white sugar yield and each of root yield, root weight, root length and root diameter in both season, respectively. It was noted that white sugar yield showed the highest positive correlation with root yield followed by root weight, indicating their economic importance. Results in Table 4 show that root yield in both seasons was significantly ($P \leq 0.01$) contributed to variations in white sugar yield.

DISCUSSION

Low soil fertility and low available water are found to limit agricultural productivity in dry regions, including Egypt. These factors are not suitable for sugar cane due to its high requirements of water and soil fertility. Therefore, sugar beet can be used, as an alternative to sugar cane, for cultivation under dry region conditions. There are two suitable sugar beet cultivars (BTS 301 and Amina) for dry region conditions. They may be effectively used under these conditions using a suitable fertilization program. Our study indicated that a soil fertilization regime of 350 kg N/ha plus foliar spray of 100 ppm-micronutrient mixture of Fe + Mn + Zn enabled sugar beet plants to perform well. The cv. BTS 301 performed growth and yields much better than cv. Amina at all N levels and micronutrients on a tested soil. Accompanying with the increased photosynthetic efficiency (Neamatollahi et al. 2013), the superiority of cv. BTS 301 in root yields might be due to its high records of mean root dimensions and weights (Table 1), reflecting high white sugar yields over both seasons (Table 2). Therefore, BTS 301 is a favourable cultivar for selecting output with high yield potential for sugar beet breeding and cultivar development programme. The final yield differences between cvs. BTS 301 and Amina were associated closely with the growth traits measured (i.e., leaf area index, root length and diameter, and root and top fresh weights; Table 1).

Away from dry regions, studies have shown that up to 60% of applied N fertilizer is not taken up by

Table 4. Correlation coefficient (r), coefficient of determination (R^2) and standard error of the estimates (SEE) for predicting white sugar yield in 2013/14 and 2014/15 seasons

Season	r	R^2	SEE	Significance	Fitted equation
2013/14	0.959	0.920	0.506	***	white sugar yield = –5.693 + 0.315 root yield
2014/15	0.964	0.929	0.489	***	white sugar yield = –5.631 + 0.320 root yield

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plant roots due to leaching of nitrate, volatilization of ammonia and denitrification including emission of N_2O (Weier 1998, Thorburn et al. 2005). However, in the dry region of this study, we think that the loss of N is much lower due to low available water that limited loss by leaching. Sugar beet root and biological yields were increased with N_2 level (Table 1). The increase of root and white sugar yields as a result of N_2 level application may be due to the importance of N for plant nutrition, enhancing leaf initiation and increasing leaf chlorophyll concentration, which reflected in the increase of fresh root weights and sugar yields (Stevens et al. 2011, Salami and Saadat 2013, Mekdad 2015). Zhao et al. (2014) reported on sugar cane that a decrease in source (leaves) to sink (stalks) ratio increased leaf photosynthetic rate, reflecting in sugar yields. The higher root yield of cv. BTS 301 compared to cv. Amina was probably associated with its greater sink (roots) capacity that led to greater root yield and smaller impurities (Tables 1 and 2). The non-sucrose components most relevant for technical quality of sugar beet are K, Na and α-amino N that are regarded as impurities because they interfere with sugar extraction. There were significant differences in these impurities due to N-application in both seasons (Table 2). The N level of 350 kg/ha gave the highest impurities, but purity % found to increase by the application of this N rate. Some reports indicated that excess N fertilizer may decrease sugar %, lowering the recoverable sugar and increasing the impurities such as proteins, α-amino N and Na contents (Tsialtas and Maslaris 2005, Manderscheid et al. 2010, Mekdad 2015).

Micronutrients are important to plant growth and productivity that are the macronutrients in the soils. They play many complex roles in plant nutrition and plant production. A 100 ppm-micronutrient mixture of Fe + Mn + Zn was effective at increasing growth and yields of cv. BTS 301 above the cv. Amina (Tables 1 and 2). This improvement may be attributed to the important roles played by micronutrients as co-enzymes in plant metabolism, positively reflecting in growth and sugar yield. Mekki (2014) and Gobarah and Mekki (2005) reported that foliar application of micronutrients significantly increased growth, recoverable sugar yield and purity. Regarding the interaction applications, Masri and Hamza (2015) found that growth, white sugar yield and purity significantly affected by the interaction application of micronutrients and sugar beet cultivars. Our results show that the interaction application of cv. BTS 301, 350 kg N/ha and a 100 ppm-mixture of Fe + Zn + Mn showed the best yield performance (Table 2). This integrated application can offer a promising technology to improve sugar beet yield performance and yield quality under dry region conditions.

A prerequisite to maintain high sugar beet productivity under the conditions of dry regions is to determine whether it is possible to select high yielding cultivars under low soil fertility and low water available. Our results report that cv. BTS 301 had the ability to perform well in these adverse conditions if fertilized with 350 kg N/ha and a micronutrient mixture of Fe + Zn + Mn. In addition, multigerm sugar beet used for breeding in countries of dry regions must have considerable genetic variation for high water and nitrogen use efficiencies, which will be required for sustainable production of sugar beet in the future. Therefore, our next strategy for developing the cv. BTS 301 with improved water and nitrogen efficiencies is a step necessary to achieve sustainable sugar beet yield performance under the conditions of dry regions.

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