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Effect of Nitrogen and Boron Treatments on Harvest Index and Nitrogen Use Efficiency in Sugar Beet

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ABSTRACT

The use of optimum nitrogen (N) and boron (B) fertilizers is important for yield and quality in sugar beet production. Therefore, it is necessary to determine the rate of use and recycling parameters of the applied nutrients by the plants in order to optimize the yield and quality in production. This study aims is to examine the effect of different doses of N and B treatment on sugar harvest index (SHI), nitrogen harvest index (NHI), and N use efficiency parameters and to determine the economic optimum nitrogen rates (EONR) in sugar beet. The experiment was set up in a randomized block factorial design with three replications. Five doses of N (0, 90, 180, 270, and 360 kg N ha^{-1}) and four doses of B (0, 2, 4, and 6 kg B ha^{-1}) were applied in the study. According to the results of the research, the SHI decreased statistically significantly with the increase of dose of the N treatment, but the NHI was not affected by the N treatment. The physiological efficiency of N in taproot dry matter yield and physiological efficiency of N in sugar yield decreased statistically significantly ($p<0.01$) with the increase in the dose of N treatment. A similar case was observed in the parameters of nitrogen agronomic efficiency (NAgE) and nitrogen uptake efficiency (NUpE). The increase in B treatment doses statistically significantly ($p<0.01$) increased the NAgE in the first year. The EONR, calculated using the quadratic model, was found to be 240 kg N ha^{-1} on average of two years. As a result, the N use potential decreased with the increase of N doses applied to sugar beet. The use of EONR can be recommended for optimum yield and quality in the region.

Keywords: Sugar harvest index, Physiological efficiency of nitrogen, Nitrogen agronomic efficiency, Nitrogen uptake efficiency, Economic optimum nitrogen rates

1. Introduction

Nitrogen (N) is one of the most commonly applied nutritional elements in sugar beet production. In agricultural production, plants' N fertilizer use capacity varies between 30.2-53.2% and N losses can increase up to 70% as a result of excessive and incorrect treatments (Anas et al. 2020). The use of excessive N fertilizers increases the input cost of farmers and causes an increase in nitrate concentration in ground and surface waters and eutrophication in the coastal ecosystem, thus negatively affecting biodiversity (Smil 2011). On the other hand, N applied to sugar beet more than needed increases the taproot yield (Sulfab et al. 2017) and decreases the sugar yield (Cimrin 2001). Therefore, N fertilizer should be applied at the optimum dose without reducing the yield and quality of sugar beet. For this reason, it is recommended to calculate nitrogen use efficiency (NUE) and harvest index (HI) and to apply the optimum dose of fertilizer. The purpose of NUE parameters is to evaluate the performance of crop growing systems determine the losses of N applied to the soils and to provide optimum nutrients to the crops (Fixen et al. 2014). NUE parameters can also be expressed as the relationship between the ability of the cultivated plant to take up the available N from the soil and the dry matter production (Hirose 2012).

While there are many calculations of NUE in wheat, maize or other grains, these calculations are quite limit in sugar beet. N in beta beet crops is required for (i) canopy (Malnou et al. 2006) and (ii) sugar storage in root cells (Milford & Watson 1971). However, N is not a compound of sugar and is the main storage product of sugar beet (Hoffman et al. 2005). Therefore, the calculation of HI and NUE parameters in sugar beet is different from cereals (Laufer et al. 2016).

The first goal of sugar beet producers should be to obtain a high sugar yield. The sugar harvest index (SHI), which is also expressed as the ability of the plant to produce (Porker et al. 2020), is defined as the amount of sugar produced per one unit of dry matter (Laufer et al. 2016).

The nitrogen harvest index (NHI) in plants is an important feature that shows how efficiently the applied N is used. NHI in sugar beet is calculated similarly to grains. While NHI is calculated in grains by the ratio of the amount of N taken up by the grain to the total amount of N taken up (Fageria 2014), in sugar beet it is calculated by the ratio of the N taken up by the taproot of the sugar beet to the total amount of N taken up (Laufer et al. 2016).

In order to facilitate the NUE studies, Moll et al. (1982) divided the NUE into two components in the 1980s: (i) physiological NUE and (ii) N uptake efficiency. On the other hand, Fageria et al. (2008) asserted that the agronomic efficiency of N is also an important component in NUE calculations.

While physiological efficiency of nitrogen (NPE) is calculated in cereals as the grain yield per one unit of N taken up by the plant (Yilmaz 2015), it is calculated separately for the taproot dry matter yield and sugar yield in sugar beet. While the NPE in the taproot dry matter of sugar beet is the taproot dry matter yield obtained per one unit of N taken up by the plant (tap - root + leaf), the NPE in sugar yield is expressed as the sugar yield obtained per unit of N taken up by the plant (taproot + leaf) (Laufer et al. 2016). N uptake efficiency is calculated in corn plant by the ratio of the N taken up by the above-ground parts to the applied N dose (Buyuk 2016). Unlike the corn plant, significant amounts of N are taken up by both the taproot and the leaf in sugar beet; therefore, it has been suggested that it is more appropriate to formulate nitrogen uptake efficiency (NUpE) in sugar beet as the ratio of the total amount of N uptake (taproot + leaf) to the amount of N dose applied (Good et al. 2004).

N agronomic efficiency a feature that more closely reflects the direct impact of a unit of fertilizer applied on production, is associated with economic returns (Fixen et al. 2014). N agronomic efficiency is calculated in sugar beet as the taproot dry matter yield per unit of N fertilizer (Fageria et al. 2008).

In their study, Laufer et al. (2016) administered six different doses of N (0, 40, 80, 120, 160, and 200 kg N ha^{-1}) in six different locations (DE10, DE11, NL10, NL11, DK10, DK11) in Germany (DE), Netherlands (NL), and Denmark (DK) between 2010 and 2011 and determined the NHI and NUE. They reported that, with increasing doses of N treatment, SHI decreased up to 0.619, 0.617, 0.605, 0.601, 0.590, and 0.579 in these six locations, respectively. They also reported that while the N treatments did not have a statistically significant effect on NHI, the physiological efficiency of N in taproot dry matter yield (NPE_{TDMY}) decreased from 128.5 to 84.9 (18120 kg ha^{-1}, 22260 kg ha^{-1}) with increasing doses of N. Moreover, they asserted that the physiological efficiency of nitrogen in sugar yield (NPE_{SY}) decreased from 95.7 to 63.1 with increasing doses of N.

Increasing NUE must be achieved in agricultural production systems by maintaining yield and quality. While NUE can be increased by rational management of N fertilizer, it is limited by boron (B) deficiency. Using this synergistic relationship between N and B is an effective strategy to increase efficiency and improve NUE (Zhang et al. 2015; Wang et al. 2021). The use of B fertilizer in sugar beet directly affects the taproot yield because it increases the sugar ratio (Mekdad 2015), has a positive effect on the formation of healthy cell walls, and increases the indolacetic acid (IAA) (Marschner 2012). However, B has an important role in N_2 fixation and nitrate assimilation. Camacho-Cristobal et al. (2008) reported that nitrate uptake is low in both leaves and roots in areas where B is deficient.

Shivay et al. (2017) applied urea fertilizer to the wheat plant by coating it with borax containing 0.1%, 0.2%, 0.3%, 0.4%, and 0.5% B and reported that the nitrogen agronomic efficiency (NAgE) increased with the increase of B concentration, and the highest NAgE was obtained in the treatment containing 0.5% B. Also, Pooniya et al. (2018) reported that the yield and NUE of maize increased with the treatment of urea fertilizer by coating it with B.

Hellal et al. (2009) used soil applied N and foliar applied B fertilizers and examined their effect on the yield of sugar beet and the distribution and ratio of nutrients in taproots and shoots. They administered 3 different doses of N (60, 80, and 100 mg N kg^{-1}) and 4 different doses of B (0, 20, 50, and 100 mg B L^{-1}) and reported that the combined treatment of 100 mg N kg^{-1} + 50 mg B L^{-1} yielded the maximum taproot yield, maximum shoot yield, and maximum nutrient balance. In conclusion, they asserted that N, K, and Fe concentrations increased in taproots and shoots due to the positive interaction between N and B.

N fertilizers are the most commonly used fertilizers in sugar beet. Irrational and excessive use of N fertilizers increases the taproot yield of the sugar beet but decreases the sugar ratio, which is the most important quality character, and thus decreases the SHI and NUE. The main goal in sugar beet production is to increase sugar yield without compromising quality. For this reason, it is very important to determine the economic optimum N dose in order to prevent the use of the excessive amount of N fertilizer and to improve NUE parameters.

Although several different models are widely used to describe the response of the yield to the applied N fertilizer, it has been reported that the most suitable model for sugar beet is the Quadratic Model (Cerrato & Blackmer 1990; Sayili & Akca 2004). Rezvani et al. (2013) took into account the yield of sugar beet while determining economic optimum nitrogen rates (EONR), but Ilbas et al. (1996) took into account sugar yield and leaf yield in addition to sugar beet yield while determining EONR.

In the interviews made with the agricultural stakeholders and farmers in the region where the study was conducted, it was determined that they applied nitrogenous fertilizer (300-400 kg N ha^{-1}) to the sugar beet well above the needed, and the B content was generally found to be low in the region's soils. Therefore, it is necessary to investigate the use of N and B fertilizers for optimum yield and quality in the region. Researches on NUE parameters in sugar beet in Türkiye are also limited. Therefore, it is important to determine the NUE parameters and HI of N applied to sugar beet, which has a large share in agricultural production. The aim of this study is to determine the effect of the treatment of different doses of N and B fertilizers on NUE parameters and HI in sugar beet production and to develop a proposal about EONR.

2. Material and Methods

2.1. Study area

This research was carried out for two consecutive years (2017 and 2018) in the district of Elbistan, Kahramanmaras. Before the experiments, soil samples were taken from the study area, and their texture, pH, EC, lime, organic matter, available Ca, K, Mg, P, B, Cu, Fe, Zn, Mn, and N-min were determined. According to the results of physical and chemical analyzes, deficient P, Fe and Zn were applied homogeneously at the beginning of the experiment (2017). In 2018, only N and P fertilizers were applied. The experiment was set up in a randomized block factorial design with three replications. The fertilizers were applied to an area of 20 m^2 (2.50 m x 8 m), and 18 m^2 (2.25 m x 8 m) of this area was used to collect data due to the edge effect. The doses of N fertilizer (0, 90, 180, 270, 360 kg N ha^{-1}) were applied in two splits in 2017 and 2018, the first half was applied in the form of ammonium sulfate at planting and the other half in the form of urea before the first irrigation. The doses of B fertilizer (0, 2, 4, and 6 kg B ha^{-1}) were applied only in 2017. In order to distribute the B homogeneously in the parcels, it was dissolved in water and mixed with a rake after it was sprayed on the soil.

In the experiment, the seeds of the sugar beet variety "Aranka" were used, and sowing was done in the first half of April in both years. After the planting, singling and rarefying were performed, and 144 plants (8000 plants per da^{-1}) were left in each parcel. Irrigation was carried out with the treatment of the same amount of water to each parcel at the same time, taking into account the need for plants.

2.2. Sugar beet harvest and yield calculations

After completing the vegetation period and reaching technological maturity, sugar beets were harvested in October in both years. After removing the heads and leaves of the harvested beets, the beet taproots were counted and weighed, and the yield per hectare was calculated using the average taproot weight. The leaves of 10 randomly selected sugar beets were weighed, and the leaf yield per decare was calculated. The samples taken from the taproot and leaves were dried in an oven at 65 °C until they reached a constant weight in order to calculate the dry matter yield. Then, N concentrations of dry leaf and taproot samples were determined (Equation 2.1). For the amount of N removal up by sugar beet taproot and leaves and the sugar yield were calculated using the following Equation 2.2:

Nutrient removal (kg ha^{-1}) = Dry matter yield (kg ha^{-1}) x N concentration (%)/100 (2.1)

Sugar yield (kg ha^{-1}) = Sucrose concentration (%) x Taproot yield (kg ha^{-1})/100 (2.2)

2.3. Method

The texture class of the soils was identified using the bouyoucus hydrometer method reported by Gee & Bauder (1986), and pH and EC values were determined by pH and EC meter using the method reported by Demiralay (1993), Rhoades (1996). Organic matter content was determined using the modified Walkley-Black method (Nelson et al. 1996), total lime content using Scheibler calcimeter (Allison & Moodie 1965), and plant-available Ca, Mg, and K using the 1 N ammonium acetate (NH_4OAC, pH=7) method (Helmke & Sparks 1996). Plant-available phosphorus was determined using the 0.5 M $NaHCO_3$ method (Olsen & Sommers 1982), and extractable Fe, Cu, Zn, and Mn using the DTPA method (Lindsay & Norvell 1978). The available B in soils was determined using mannitol-$CaCl_2$ method

(Cartwright et al. 1983), the N concentration in the leaves using the Kjeldahl method reported by Bremner (1996), and the N-min concentration in the leaves using the method reported by Bremner (1965). The sugar content was determined by mixing the chopped sugar beet samples with 0.3% aluminum sulphate solution, then filtering and using a polarimeter (Kavas & Leblebici 2004).

2.4. Formulas for calculating the nitrogen use efficiency parameters

The formulas developed for the calculation of HI, NHI, and NUE parameters (NPE_{TDMY}, NPE_{SY}, NAgE, NUpE) in sugar beet are given in Table 1 (Good et al. 2004; Hoffmann 2006; Fageria 2008; Ciampiti & Vyn 2012).

Table 1- The terminology used to calculate harvest indices and NUE parameters in sugar beet

Used terminology	***Formula***
Harvest index (HI)	
Sugar harvest index	$HI_S = SY/PDMY$
Nitrogen harvest index	$NHI = TNU_p/PNU_P$
Nitrogen use efficiency (NUE)	
Physiological efficiency of nitrogen in taproot dry matter yield	$NPE_{TDMY} = TDMY/PNU_P$
Physiological efficiency of nitrogen in sugar yield	$NPE_{SY} = SY/PNU_P$
Nitrogen agronomic efficiency	$NAgE = (N_{fertilizedTDMY} - N_{unfertilizedTDMY})/N_{applied}$
Nitrogen uptake efficiency	$NUpE = PNU_P - N_{applied}$

S: Sugar, SY: Sugar yield, PDMY: Total (taproot + leaf) Dry matter yield, TNUp: N taken up by taproot (kg da^{-1}), PNUp: Total (taproot + leaf) N taken up (kg da^{-1}), TDMY: Taproot dry matter yield

2.5. Determination of critical dose of nitrogen and economical optimum nitrogen rates

In this study, the relationship between N fertilization and sugar yield was calculated with the quadratic, quadratic-plateau, linear-plateau models (Ceratto & Blackmar 1990) obtained from the Sigmaplot program. It was determined that the relationship between yield and fertilizer dose in determining the optimum economical N rates was best explained by the quadratic model (Equation 2.3).

The Quadratic Model Equation is given below;

$$Y = a+bX+cX^2 \qquad (2.3)$$

In this formula, Y: Sugar yield, X: Nitrogen dose, a: Inception coefficient, b: Linear coefficient, and c: Quadratic coefficient.

The critical dose of nitrogen (CD) is determined by setting the first derivative of the quadratic model equation to zero. This also refers to the N dose corresponding to the maximum yield (Dikici 2007). The EONR are calculated by equating the first derivative of the quadratic model formula with the fertilizer product price ratio (Equation 2.4).

$$EONR = (PR-b)/2c \qquad (2.4)$$

In this equation, PR refers to the fertilizer-product price ratio. In the study, only sugar yield values obtained from N fertilized plots were used to calculate the critical dose and the economic optimum dose of N (N_0B_0, $N_{90}B_0$, $N_{180}B_0$, $N_{270}B_0$, $N_{360}B_0$).

2.6. Statistical analysis

In the study, variance analysis was performed according to the randomized blocks factorial experiment design using the "JMP 13.2.0" package program. Tukey's multiple comparison test was used to determine the difference between treatments in statistically significant results (SASS 1999).

3. Results and Discussion

3.1. General characteristics of the soils of the experiment area

Some physical and chemical properties of soils were given in Table 2.

Table 2- Some physical and chemical properties of soils

Texture	*Sand*	*Loam*	*Clay*	*Lime*	*OM*	*pH*	*EC*
	%	*%*	*%*	*%*	*%*		*ds m^{-1}*
CL	31.4	31.8	36.7	33	2.15	7.97	2.15

OM: Organic matter EC: Electrical Conductivity CL: Clay Loam

The texture of the experimental area soil was clay loam. The soil pH value was 7.97, and it was slightly alkaline (Saglam 2012). The soil is very calcareous with a lime content of 32.7%, and its organic matter content is 2.15% (middle class) (Gucdemir 2006). According to the limit values reported by Alparslan et al. (1998), the soil's available phosphorus (P) was low, its potassium (K) and magnesium (Mg) contents were high, calcium content (Ca) was very high, manganese (Mn) and copper (Cu) contents were sufficient, and B, iron (Fe), and zinc (Zn) contents were deficient (Table 3).

Table 3- Some macro and micro nutrient contents of soils

Ca mg kg^{-1}	*K mg kg^{-1}*	*Mg mg kg^{-1}*	*P mg kg^{-1}*	*B mg kg^{-1}*	*Cu mg kg^{-1}*	*Fe mg kg^{-1}*	*Zn mg kg^{-1}*	*Mn mg kg^{-1}*	*N-min mg kg^{-1}*
7659	473	877	11	0.56	1.50	3.20	0.47	2.80	4.20

3.2. Harvest index

3.2.1. Sugar harvest index

SHI refers to the sugar produced per unit of dry matter amount (Table 4). The effect of N and B fertilizers applied at different doses on SHI is given in Table 5. With the increase of N fertilizer treatment doses, SHI decreased, and the differences between the treatment doses were found to be statistically significant ($p<0.01$). In the first year, the highest SHI (0.74) was found to be in the N_0 treatment, while the lowest SHI (0.65) was in the N_{27} treatment. In the second year, the highest SHI (0.72) was found to be in the N_0 treatment, while the lowest SHI (0.63) in the N_{18}, N_{27}, N_{36} treatments. While the B treatment did not cause a significant effect on SHI, the NxB interaction had a significant effect in the second year, and the highest SHI was found to be in the N_0xB_2 treatment. Laufer et al. (2016) reported that SHI decreased significantly with increasing N doses. In this study, SHI values did not change significantly with the increase of N treatment dose in both years, except for the control and 90 kg N ha^{-1} dose. Malnou et al. (2008) reported that the sugar forming capacity of the dry matter decreased with the increase in the amount of N applied to sugar beet. While the increase of N applied to sugar beet increases leaf and taproot yield (Mampa et al. 2017), it causes a decrease in sugar content (Cimrin 2001). McDonnell et al. (1966) stated that every 23 kg ha^{-1} N added to sugar beet causes a 0.1% decrease in sugar ratio.

Table 4- Effect of N and B fertilization on the dry matter yields and amounts of N removed in sugar beet sections in 2017 and 2018

	Dry matter yields						*Amounts of N removed in sugar beet sections*					
	Leaf (kg ha^{-1})		*Taproot (kg ha^{-1})*		*Total (kg ha^{-1})*		*Leaf (kg ha^{-1})*		*Taproot (kg ha^{-1})*		*Total (kg ha^{-1})*	
Treatments	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
N_0B_0	1803	1703	11150	11220	12953	12923	69.2	71.8	93.6	111	162	183
N_0B_2	1979	1462	11368	11657	13347	13119	80.9	58.6	114	93.0	195	151
N_0B_4	2171	1617	10696	12166	12868	13783	75.3	66.3	95.8	88.6	171	154
N_0B_6	2324	1785	11248	12690	13543	14476	74.2	67.2	109	99.4	185	160
$N_{90}B_0$	2089	1846	11985	13038	14075	14885	85.8	75.0	128	139	214	214
$N_{90}B_2$	2896	2152	13087	13538	15984	15690	78.0	84.9	124	119	219	204
$N_{90}B_4$	2526	1970	12873	13169	15399	15139	90.6	81.3	127	126	218	208
$N_{90}B_6$	2688	2079	13262	13939	15950	16018	96.9	84.0	154	148	258	232
$N_{180}B_0$	2663	2819	13250	14885	15913	17705	122	110	143	164	265	275
$N_{180}B_2$	2495	2216	12435	14352	14930	16569	115	91.5	145	168	260	260
$N_{180}B_4$	2365	2252	13620	14922	15985	17174	93.2	91.7	141	164	234	256
$N_{180}B_6$	2691	2236	16314	15802	19005	18039	100	89.7	158	178	258	268
$N_{270}B_0$	3265	2568	14567	14805	17833	17374	130	111	164	182	295	293
$N_{270}B_2$	2779	1971	15303	14946	18082	16917	112	86.1	175	181	289	267
$N_{270}B_4$	2703	2715	14513	14635	17217	17350	132	116	186	172	319	288
$N_{270}B_6$	2729	2364	14131	14423	16861	16788	82.0	103	170	177	278	280

Table 4. Continued

$N_{360}B_0$	3148	2506	14695	16840	17843	19347	123	105	215	188	339	294
$N_{360}B_2$	3250	3485	14895	15084	18145	18569	170	151	178	181	345	332
$N_{360}B_4$	3204	3147	15427	16394	18631	19542	134	126	180	206	314	332
$N_{360}B_6$	3339	3078	14898	15885	18238	18963	134	133	204	209	339	342
Minimum	1803	1462	10696	11220	12953	12923	69.2	58.6	93.6	88.6	162	151
Maximum	3339	3485	16314	16394	19005	19542	170	133	215	209	339	342
Mean	2655	2298	13486	14219	16140	16518	104	95.1	150	154	257	249

3.2.2. Nitrogen harvest index

According to the results of variance analysis applied N, B doses and NxB interaction did not have a statistically significant effect on the NHI of sugar beet (Table 5). In this study, NHI values were found to be between 0.51-0.63 ($N_{360}B_2$-$N_{360}B_0$) in 2017 and between 0.54-0.67 ($N_{360}B_2$-$N_{270}B_2$) in 2018. In a study on the N uptake of sugar beet, it was determined that 0.44 of the N absorbed by the plant was in the leaves and 0.56 in the taproot (Noshad et al. 2012). Ebmeyer & Hoffmann (2021), in their study on N uptake and use in sugar beet genotypes, determined that sugar beet leaf and root N contents were close to each other. Laufer et al. (2016) argued that N treatments did not have a significant effect on the NHI index in sugar beet, and this was du e to the ability of sugar beet to assimilate the existing N in the taproot and leaf parts.

Table 5- Effect of N and B fertilization on the DF (Degrees of freedom), p value and mean values of SHI (Sugar Harvest Index) and NHI (Nitrogen Harvest Index) for the years 2017 and 2018

	Treatments	***SHI***		***NHI***	
		2017	***2018***	***2017***	***2018***
	N_0B_0	0.68±0.079	0.67±0.098	0.57±0.020ab	0.60±0.028
	N_0B_2	0.77±0.013	0.78±0.042	0.58±0.036ab	0.61±0.050
	N_0B_4	0.75±0.043	0.70±0.038	0.56±0.011ab	0.57±0.034
	N_0B_6	0.75±0.052	0.74±0.070	0.59±0.026ab	0.58±0.072
	$N_{90}B_0$	0.78±0.088	0.72±0.018	0.60±0.050ab	0.67±0.070
	$N_{90}B_2$	0.66±0.090	0.66±0.037	0.56±0.031ab	0.58±0.088
	$N_{90}B_4$	0.73±0.059	0.72±0.008	0.58±0.013ab	0.60±0.011
	$N_{90}B_6$	0.68±0.066	0.67±0.033	0.59±0.040ab	0.63±0.021
	$N_{180}B_0$	0.67±0.024	0.61±0.023	0.53±0.076ab	0.59±0.015
	$N_{180}B_2$	0.70±0.026	0.64±0.057	0.56±0.075ab	0.64±0.063
	$N_{180}B_4$	0.64±0.010	0.63±0.014	0.60±0.010ab	0.64±0.029
	$N_{180}B_6$	0.67±0.050	0.64±0.022	0.61±0.028ab	0.66±0.049
	$N_{270}B_0$	0.63±0.043	0.63±0.037	0.55±0.020ab	0.62±0.016
	$N_{270}B_2$	0.64±0.030	0.63±0.011	0.60±0.032ab	0.67±0.017
	$N_{270}B_4$	0.66±0.025	0.62±0.066	0.58±0.031ab	0.59±0.024
	$N_{270}B_6$	0.67±0.006	0.65±0.049	0.61±0.011ab	0.63±0.058
	$N_{360}B_0$	0.65±0.023	0.56±0.046	0.63±0.023a	0.64±0.027
	$N_{360}B_2$	0.68±0.050	0.66±0.027	0.51±0.027b	0.54±0.033
	$N_{360}B_4$	0.68±0.037	0.63±0.017	0.57±0.055ab	0.62±0.047
	$N_{360}B_6$	0.71±0.050	0.66±0.058	0.60±0.038ab	0.61±0.046
Effect	***DF***	***p value***	***p value***	***p value***	***p value***
N	4	<0.01	<0.01	ns	ns
B	3	ns	ns	ns	ns
NxB	12	ns	ns	<0.05	ns

Means sharing the same letter, within a column, don’t differ significantly at p<0.01; p<0.05
ns: non-significant

3.3. Nitrogen use efficiency parameters

3.3.1. Physiological efficiency of nitrogen in taproot dry matter yield

The effect of N fertilizer applied to sugar beet on NPE_{TDMY} was found to be statistically significant ($p<0.01$) for both years (Table 6). The highest values were obtained in treatments where N was not applied in both years. This can be attributed to the more efficient use of N in the soil in the production of taproot dry matter. It has been reported that in plant production the treatment of N above the optimum dose decreases the benefits of N fertilizer, increases the nitrogen losses, and decreases N use rate (Karam 2002).

Although NPE_{TDMY} was high in the control group without N fertilizer treatment, taproot dry matter yield and sugar yield were low in sugar beet (Table 7). It can be asserted that with the increase in the amount of N , the taproot dry matter yield and sugar yield increase, but the physiological efficiency of N decreases (Laufer et al. 2016). The effect of B treatment on NPE_{TDMY} was not significant. The highest NPE_{TDMY} value of NxB interaction was found to be N_0xB_0 in the first year.

3.3.2. Physiological efficiency of nitrogen in sugar yield (NPE_{SY})

The effect of N and B fertilizers applied to sugar beet at different doses on NPE_{SY} is given in Table 6. Physiological efficiency of N in sugar yield decreased with the increase in N fertilizer treatment doses, and the differences between the treatment doses were found to be statistically significant ($p<0.01$). While B treatment and NxB interaction did not cause significant changes in NPE_{SY} in the first year, significant differences were observed in 2 kg B ha^{-1} treatment in the second year due to high sugar yield (Table 7). In the NxB interaction, the highest NPE_{SY} value was found to be 68.1 in the N_0xB_2 treatment, while the lowest was 36.7 in the $N_{360}xB_6$ treatment.

Table 6- Effect of N and B fertilization on the degrees of freedom (DF), *p*-value and mean values of physiological efficiency of nitrogen in taproot dry matter yield (NPE_{TDMY}) and physiological efficiency of nitrogen in sugar yield (NPE_{SY}) for the years 2017 and 2018

	Treatments	***NPE_{TDMY}***		***NPE_{SY}***	
		2017	***2018***	***2017***	***2018***
	N_0B_0	68.3±2.39a	61.0±1.97	54.3±5.41	47.5±6.30
	N_0B_2	58.0±2.05a-e	76.9±5.29	53.0±0.53	68.1±6.78
	N_0B_4	62.5±2.47a-c	78.4±3.05	56.4±1.20	62.3±4.74
	N_0B_6	60.8±6.47a-d	80.5±16.0	55.4±5.22	68.0±11.7
	$N_{90}B_0$	56.0±2.58b-f	60.8±3.00	52.0±9.53	46.6±1.72
	$N_{90}B_2$	59.7±4.83a-e	68.1±17.9	48.2±4.63	54.6±18.4
	$N_{90}B_4$	59.1±2.76a-e	63.6±7.19	51.9±6.03	50.8±9.54
	$N_{90}B_6$	51.4±4.12c-g	59.9±0.48	42.4±6.34	45.0±1.18
	$N_{180}B_0$	49.9±3.03d-g	54.0±1.87	40.5±2.59	39.7±1.23
	$N_{180}B_2$	48.3±7.15e-g	55.1±4.22	40.7±3.49	40.7±3.55
	$N_{180}B_4$	58.4±5.30a-e	58.8±9.40	44.4±4.14	43.2±5.04
	$N_{180}B_6$	63.3±4.16ab	59.3±6.14	49.7±4.23	43.5±6.10
	$N_{270}B_0$	49.3±1.49d-g	50.3±1.31	38.1±3.30	37.4±1.64
	$N_{270}B_2$	52.9±2.76b-g	55.7±2.11	40.1±2.85	40.3±1.67
	$N_{270}B_4$	45.6±2.40fg	50.7±2.15	35.8±1.05	37.5±4.97
	$N_{270}B_6$	50.8±2.67d-g	51.3±2.43	40.8±2.12	39.2±3.47
	$N_{360}B_0$	43.3±2.96g	57.1±2.44	34.3±1.76	37.0±2.02
	$N_{360}B_2$	43.1±2.60g	45.3±1.97	35.8±2.73	37.0±1.08
	$N_{360}B_4$	48.9±3.35e-g	49.5±4.83	40.2±0.76	37.4±3.48
	$N_{360}B_6$	43.9±1.09g	46.6±3.55	38.3±3.27	36.7±4.87
Effect	***DF***	***p value***	***p value***	***p value***	***p value***
N	4	<0.01	<0.01	<0.01	<0.01
B	3	ns	ns	ns	ns
NxB	12	<0.01	ns	ns	ns

Means sharing the same letter, within a column, don't differ significantly at p<0.01; p<0.05, ns: non-significant

NPE_{SY} at the N_0 dose was found to be approximately 12% lower in the first year than in the second year. The reason for this is due to the difference in the total amount of N taken up although there was no significant difference between the sugar yields in the N_0 doses in the two years (Table 7). Laufer et al. (2016) reported that NPE_{SY} decreased from 95.7 to 63.1 with the increase of N doses applied to sugar beet. The difference in this regard between the present study and the study of Laufer et al. (2016) is due to the difference in sugar and taproot dry matter yields. It has been reported that sugar beet, which takes up the N in the soil in the area where N treatment is not applied, uses the N more effectively in sugar production, while increasing the N treatment dose causes an increase in the vegetative part of the plant and a decrease in the physiological efficiency of N in sugar yield (Allison et al. 1996). Many researchers stated that B application increases the yield of sunflowers, chickpeas and beans (Ceyhan et al. 2007; 2008; Harmankaya et al. 2008).

Table 7- Effect of N and B fertilization on the sugar yield ($kg\ ha^{-1}$) for the years 2017 and 2018

Treatments	***Sugar yield***	
(kg ha^{-1})	***2017***	***2018***
N_0B_0	8820	8710
N_0B_2	10390	10340
N_0B_4	9660	9570
N_0B_6	10260	10790
$N_{90}B_0$	11000	10770
$N_{90}B_2$	10610	10480
$N_{90}B_4$	11280	11040
$N_{90}B_6$	10910	10770
$N_{180}B_0$	10750	10950
$N_{180}B_2$	10540	10590
$N_{180}B_4$	10370	10990
$N_{180}B_6$	12820	11560
$N_{270}B_0$	11250	11000
$N_{270}B_2$	11590	10810
$N_{270}B_4$	11430	10790
$N_{270}B_6$	11340	11030
$N_{360}B_0$	11670	10880
$N_{360}B_2$	12330	12340
$N_{360}B_4$	12670	12400
$N_{360}B_6$	12990	12470
Minimum	8820	8710
Maximum	12990	12470
Mean	11130	10910

3.3.3. Nitrogen agronomic efficiency (NAgE)

When the NAgE data of the sugar beet were analyzed, it was observed that the NAgE decreased statistically significantly ($p<0.01$) with the increase in N treatment in the first year (Table 8). However, with the increase of B treatment doses in the first year, the NAgE increased statistically significantly ($p<0.01$) up to 10.8, 12.3, 16.9, and 18.0, respectively. In the first year, the highest NAgE (28.3) was found to be in the $N_{180}xB_6$ treatment, while the lowest NAgE (5.92) in the $N_{180}xB_2$ treatment. It has been reported that the increase in NAgE value with the increase in B treatment doses is due to the positive effect of B fertilization applied to sugar beet on taproot yield (Durak & Ulubas 2017). NAgE is highly affected by environmental factors. Especially the residues of the previous year's agricultural products and the remaining mineral N in the soil can affect the NAgE value (Jacops et al. 2018). This can explain our result that NAgE was higher in the first year than in the second year and caused statistically significant differences. Atar et al. (2017) reported that NAgE decreased from 9.1 to 7.6 with the increase of N doses (75, 125 kg N ha^{-1}) in the 2011/2012 crop production year in their study which took into account the grain yield in wheat. It has been determined that N application to sugar beet increases yield, but application of more N than the plant needs reduces agronomic efficiency and decreases root quality parameters (Varga et al. 2022). In the study, in which the effect of N application doses (120, 240, 360 kg N ha^{-1}) on different wheat varieties was investigated, it was reported that NAgE value decreased significantly with the increase of N doses (Belete et al. 2018). Fixen et al. (2014) determined that NAgE value in corn, rice, and wheat varied between 15 and 30. Shivay et al. (2017) reported that when the urea fertilizer applied to the wheat plant was covered with B, it increased from 10.5 in the control group to 14.1 with the increase in the amount of B used in the NAgE coating.

3.3.4. Nitrogen uptake efficiency

It was observed that NUpE decreased significantly ($p<0.01$) with increasing N treatment doses in both years of the study. The effect of B treatment on NUpE was not significant. The highest NUpE value of NxB interaction was found to be $N_{90}xB_6$ in both years. The lowest NUpE value was obtained in the $N_{360}xB_4$ treatment in the first year and in the $N_{360}xB_0$ treatment in the second year (Table 8). The decrease in NUpE may be due to the increased N losses caused by increased N doses. In a similar study conducted in wheat, it was reported that the NUpE value decreased significantly with increasing doses of N (30, 60, 90, 120 kg N ha^{-1}) (Haile et al. 2012). Keeney and Olson (2009) suggested that NUpE value decreases with increasing N doses and that N fertilization should be done in splits, not all at once, in order to increase NUpE value. Buyuk (2006), in his study on maize, asserted that NUpE decreased from 5.8 to 2.1 with increasing N treatment doses.

3.4. Critical dose of nitrogen and economic optimum nitrogen rates

Table 8- Effect of N and B fertilization on the degrees of freedom (DF), P value and mean values of nitrogen agronomic efficiency (NAgE) and nitrogen uptake efficiency (NUpE) for the years 2017 and 2018

	Treatments	***NAgE***		***NUpE***	
		2017	***2018***	***2017***	***2018***
	N_0B_0	-	-	-	-
	N_0B_2	-	-	-	-
	N_0B_4	-	-	-	-
	N_0B_6	-	-	-	-
	$N_{90}B_0$	9.28±2.17de	20.1±13.7	2.38±0.26b	2.38±0.16
	$N_{90}B_2$	19.1±4.12a-d	20.8±20.3	2.43±0.06b	2.27±0.41
	$N_{90}B_4$	24.1±3.30ab	11.1±6.40	2.42±0.13b	2.31±0.19
	$N_{90}B_6$	22.7±9.06a-c	13.8±12.6	2.87±0.22a	2.58±0.08
	$N_{180}B_0$	11.6±6.05c-e	20.3±8.96	1.47±0.07c	1.52±0.04
	$N_{180}B_2$	5.92±1.39e	14.9±2.33	1.44±0.15cd	1.44±0.06
	$N_{180}B_4$	16.2±0.19b-e	15.3±9.89	1.30±0.11c-e	1.42±0.14
	$N_{180}B_6$	28.3±1.44a	17.2±4.14	1.43±0.10cd	1.49±0.18
	$N_{270}B_0$	12.6±0.61b-e	13.2±2.91	1.09±0.08d-f	1.08±0.05
	$N_{270}B_2$	14.5±1.23b-e	12.1±3.02	1.07±0.06ef	0.99±0.02
	$N_{270}B_4$	14.1±2.66b-e	9.14±4.15	1.18±0.04c-f	1.06±0.08
	$N_{270}B_6$	10.7±1.50de	6.42±1.74	1.03±0.07ef	1.04±0.03
	$N_{360}B_0$	9.84±4.97de	15.6±0.30	0.94±0.02ef	0.81±0.02
	$N_{360}B_2$	9.79±4.62de	9.51±1.40	0.96±0.08ef	0.92±0.02
	$N_{360}B_4$	13.1±3.66b-e	11.7±3.15	0.87±0.01f	0.92±0.07
	$N_{360}B_6$	10.2±2.10de	8.87±2.18	0.94±0.04ef	0.95±0.11
Effect	***DF***	***p value***	***p value***	***p value***	***p value***
N	4	<0.01	ns	<0.01	<0.01
B	3	<0.01	ns	ns	ns
NxB	12	<0.01	ns	<0.01	<0.01

Means sharing the same letter, within a column, don't differ significantly at p<0.01; p<0.05 ns: non-significant

For an accurate fertilizer dose recommendation, only the N doses used in the experiment are not sufficient, it is very important to determine the intermediate doses. The critical N dose, the intermediate dose at which maximum efficiency is obtained, should not be interpreted as an economic rate.

According to the quadratic model ($Y=8972.9+167.61x-2.724x^2$) for the N treatment doses and sugar yield data in first year, the highest sugar yield was obtained at the critical N dose of 11551 kg ha^{-1} and 307 kg ha^{-1}. According to the quadratic model ($Y=8911+192.82x-3.946x^2$) for the second year's data, the highest sugar yield was obtained at the critical N dose of 11260 kg ha^{-1} and 244 kg ha^{-1} (Table 9). The differences in critical N doses between the two years are due to sugar yield (Table 7).

Table 9- The coefficients of the quadratic equation (a, b, c) and the critical dose of nitrogen (CD), maximum yield, economic optimum nitrogen rates (EONR) calculated in 2017 and 2018

Quadratic Model	*a*	*b*	*c*	*CD (kg ha^{-1})*	*Max.Yield (kg ha^{-1})*	*EONR (kg ha^{-1})*	*R^2*
2017	8972.9	167.61	-2.724	307	11551	265	0.83
2018	8911	192.82	-3.946	244	11260	207	0.91

In both years, N doses applied to the experiment area were divided into two: half of them in the form of ammonium sulfate (21% N) and the remaining half in the form of urea (46% N). In determining the EONR, the price ratio was calculated by taking into account the price of 1 kg of pure N, based on ammonium sulfate (20.8%) + urea (46%) fertilizers, and the price of 1 kg of sugar determined by the purchase price of sugar beet (Table 10).

Table 10- Determination of price ratio with ammonium sulfate, urea fertilizers (Anonymous 2021) and sugar price (Anonymous 2020) in 2017 and 2018

Years	*A. sulfate (kg/$)*	*Urea (kg/$)*	*Nitrogen (kg/$)*	*Sugar (kg/$)*	*Nitrogen/sugar*
2017	0.95	0.69	0.82	0.36	2.26
2018	1.23	0.90	1.07	0.30	2.91

The EONR were determined as 265 kg ha^{-1} in 2017 and 207 kg ha^{-1} in 2018. The EONR differences in both years are due to the fact that the quadratic model used is very much affected by price changes. Dikici (2007) reported that EONR reached the lowest value because fertilizer prices increased too much compared to wheat prices. Ilbas et al. (1996) reported the EONR as 150 kg N ha^{-1} for the N fertilizer applied by dividing into two in order to provide the highest sugar yield. The reason why their low value was lower than ours was because their sugar yield was.

Marlander et al. (2003) stated that the amount of N fertilizer applied to sugar beet is closely related to soil mineralization. Although the N requirement of sugar beet is 200-250 kg ha^{-1} on average (Varga et al. 2022), some researchers have stated that the amount of N needed by sugar beet can be reduced by adding 100-150 kg N ha^{-1} to the soil through mineralization. In Greece, where sugar beet is widely grown, sugar beet yield (taproot and sugar yield) is maximized when N treatment dose is >200 kg N ha^{-1} (Tsialtas & Maslaris 2005). Neeteson and Wadman (1987) and Stevens et al. (2008), reported that the optimum dose of N is more than 200 kg N ha^{-1} in the Netherlands and USA. When interpreted considering the coefficient of determination in order to achieve maximum sugar yield in the soils of the region, the EONR to be applied in 2018 (R^2= 0.91) will be 207 kg N ha^{-1}, while sugar yield decreases with the N treatment dose exceeding 244 kg N ha^{-1}. Therefore, in the calculation made by combining the data of the two years, the economic optimum N dose was obtained in the treatment of approximately 240 kg N ha^{-1}. In studies carried out by different researchers, 200-250 kg ha^{-1} N application has been suggested for maximum efficiency in sugar beet (Armstrong & Milford 1985; Draycott 1993; Lopez-Bellido et al. 1994).

Considering the economic optimum N level, with the reduction of the amount N applied in fertilization, HI and NUE parameters improved and fertilizer cost decreased, contributing to both the farmer and the country's economy. Moreover, using economic optimum level of N rather than large amounts of N fertilizers decreases the negative effects of N fertilizers on the environment.

4. Conclusions

In this study, N and B fertilizers were applied to sugar beet grown as the main product in Kahramanmaras Elbistan in Türkiye, the effects of this treatment on SHI and NUE parameters (NPE_{TDMY}, NPE_{SY}, NAgE, NUpE) were examined, and critical dose of N and EONR were calculated. As a result of the research, SHI values decreased with increasing N treatment doses. N and B fertilizers had no significant effect on NHI. The NPE_{TDMY} and NPE_{SY} values of N utilization efficiency parameters decreased with increasing N fertilizer treatment doses. While the effect of N and B treatment on NAgE was found to be statistically significant in the first year, no significant effect was observed in the second year. While the NAgE value decreased with the increase of the N treatment doses, but it increased with the increase of the B treatment doses. The NUpE value decreased from 2.52 to 0.93 in the first year and from 2.38 to 0.90 in the second year with the increase in N treatment doses.

The EONR was 265 kg N ha^{-1} in 2017 and 207 kg N ha^{-1} in 2018. The EONR was obtained as 240 kg N ha^{-1} in the calculation made with the quadratic model by combining the two years' data. In the study, HI and NUE parameters, which are a reflection of the N taken up by the plant, decreased for per unit N applied in plant production. The HI and NUE parameters can also be evaluated as an indicator of the yield and quality relations of plant products. Therefore, it can be recommended to apply economical optimum N doses in terms of fertilizer economy, yield and quality in the research area.

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