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CLIMATIC AND AGRONOMIC IMPACTS ON SUGAR BEET (*Beta vulgaris* L.) PRODUCTION

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SUMMARY

The use of suitable technologies helps crop cultivation under unfavorable and extreme weather conditions obtain the optimum yield by influencing irrigation, fertilization, sowing time, and crop density. The study aimed to determine the impact of adaptive technologies on sugar beet (*Beta vulgaris* L.) cultivation at the Kazakh Research Institute of Agriculture and Plant Growing, Almaty Region, Kazakhstan. The phenological observations on basic phases of sugar beet growth and development, and plant density were done according to the generally accepted methods. Moreover, the photosynthetic activity of crop productivity was studied through the accumulation of raw and dry biomass (weight method), area determination of the assimilation apparatus (die-cutting method), and the advent of photosynthetic active radiation. The influence of meteorological conditions was particularly noted on plots with moisture deficit. Maintaining such pre-irrigation soil moisture at 60% of LMC (Least Moisture Capacity) requires less watering with large irrigation rates (1020-1260 m^3 ha^{-1}) with inter-irrigation periods of 30–37 days. In 2016, three irrigations with the rate of 1220-1260 m^3 ha^{-1} were done. Maximum water consumption occurs from the end of July to the beginning of August. Consumption of spring reserves for soil moisture was 8%-10% higher at late harvesting than at early harvesting. During the crop season with high rainfall distributed uniformly over the vegetation period, spring soil moisture reserves consumption increased and their share in total water consumption increased 12% up to 20%, whereas, during dry seasons it decreased 6% up to 14%. The study noted that for producing the sugar beet yields ranging from 22.6 to 65.2 t ha^{-1}, the NPK should be applied at the rate of nitrogen (32 – 215 kg ha^{-1}), phosphorus (12–68 kg ha^{-1}), and potassium (50–380 kg ha^{-1}), It was also found necessary to apply fertilizers differentially depending on the level of applied technology for the planned beet yield.

Keywords: Crop productivity, production process, fertilizers, photosynthesis, automated agricultural technologies, sugar beet (*Beta vulgaris* L.)

Key findings: The present results can serve as a basis for the development of a technological model and algorithms for better management of the sugar beet production at each specific stage of plant growth and development for various strengthening levels.

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INTRODUCTION

Sugar beet (*Beta vulgaris* L.) is one of the most important crops in world agriculture and it requires significant growth in production (Ivanov, 2003; Phipps *et al*., 2003; Biancardi *et al*., 2005). Thanks to the owners who developed new technologies, the Western European countries have reached 120–130 t ha^{-1} of sugar beet yield and continually increasing while the average world yield ranged from 90 to 100 t ha^{-1} (Fischer *et al.*, 2002; Řezbová *et al*., 2013). In Kazakhstan, the suitable land area for agricultural production is 222.4 million ha. The large availability of land coupled with the recent technological developments make sugar beet a promising commodity for the country.

In Kazakhstan, the agricultural practices were developed to obtain a root crop productivity of about 80 t ha^{-1} , achieved through balanced management of all regulated factors such as optimal sowing time, antecedent soil water (70%-80%-60% of WHC), mineral nutrition (NPK @ 120-80-80) and crop density (80,000 plants ha^{-1}) (Ramazanova *et al*., 2011). However, deviations from the optimal growth conditions often occur under field conditions, resulting in variations during plant growth and development. Yet, these deviations mainly occurred due to the negative effects of extreme climatic conditions i.e., light frost, aridity, and a large amplitude in air temperature fluctuations, especially in the Southeastern region, the main growing zone of sugar beet. The sugar beet yield ranged from 35 to 40 t ha^{-1} under normal cultivation where the cultivation technologies or the genetic potential of the cultivated varieties are not fully exploited.

Previous studies have clearly shown that there is a significant effect of weather on crop yields and yield variability. However, the direction of these effects is not necessarily consistent and such effects may interact with the nutrient availability of the crop. Tilman (1982) demonstrated the theory of competition for resources, through which some of the basic patterns in plant morphology observed along ecological gradients on a geographical scale can be determined. For example, the low-temperature level may cause a decrease in the leaf expansion rates and hence, reduce light interception. This effect however, maybe partially or wholly offset by increasing the availability of nutrients (Tilman *et al*., 2011).

Long-term data have been used to estimate the degree of occurring inhibitory effects in crops. Sugar beet is sown in Kazakhstan in spring (after April 10) and grows throughout the summer. Light interception, irrigation, simulated drought, and patterns of light interception, as well as, evapotranspiration affected the performance of sugar beet (Konysbekov, 2007). At the beginning of growth, sugar beet plants absorb relatively small amounts of nitrogen (N), phosphorus (P), and potassium (K), resulting to phosphorus deficiency (Yu, 1992; Shpaar *et al*., 2003; Sulfab *et al*., 2017). During the period of intensive leaf growth, beetroot consumes a lot of N and K. For the formation of root crops, plants require moderate N and enhanced P and K nutrition (Mishura *et al*., 2011; Hosseinpour *et al*., 2013). For 10 tons of root crops with the appropriate amount of tops, sugar beet takes out an average of 60 kg of N, 26 kg of P, and 120 kg of K. Nitrogen fertilizers contribute to a significant increase in sugar beet root yield, however, excessive N is the main reason for decreasing the sugar content (Morkovkin and Yartsev, 2016).

For achieving the maximum potential yield in sugar beet, it is important to have available sufficient moisture a to meet the atmospheric demand so that transpiration and photosynthesis can occur without any stomatal limitation (Ober and Rajabi, 2010). Then again, these optimal conditions are often not met either because of the insufficient rainfall or the ability to irrigate the crop is restricted. Therefore, the best approach is to introduce a flexible and adaptive farming system to maximize the sugar beet yield.

Adaptive farming consists of managing agriculture practices by considering the changing weather conditions, the agrochemical characteristics of the area, and the local features within each field to obtain the inherent yields (Filin, 2014; Lysenko *et al.*, 2016). The lack of applied technologies on crop production method, based on "leveling" principles without considering the spatial and temporal variability of environmental factors that directly affect the agro-ecosystems and sustainable production needs to be addressed (Ganusevich, 2009). In this regard, the study aimed at understanding the impact of various farming technologies to analyze and develop an optimal model and algorithms for more efficient management and use of production factors for the development of different levels of intensification in sugar beet production.

MATERIALS AND METHODS

Experimental conditions

The multiple-factor experiments were conducted to optimize the main agricultural farming technologies to reach a certain level of sugar beet yield using a domestic hybrid 'Aksu' at the Kazakh Research Institute of Agriculture and Plant Growing, Almaty Region, Kazakhstan. According to the soil and climatic parameters, the Southeast Region of Kazakhstan is typical for irrigated cultivation. The meteorological data during 2012-2014 was provided by the Meteorological Station 'KazRIAPG' (Table 1). The impact on different nutrition levels, irrigation regimes, crop density, and timing of sowing and harvesting were modeled.

The variants including sowing period (early, late), harvesting period (early, late), moisture level (60% and 80% LMC [Least Moisture Capacity]), application of mineral fertilizers (NPK at the rate of 60-40-40 and 180-120-120 kg ha^{-1}), and control (without fertilizer), and the planting densities (40 and 120 thousand plants ha^{-1}) were tested. The yield performance of the sugar beet genotypes was observed between 2014 and 2016. Early sowing was made on April 6 and late sowing on May 6 after 30 days in 2014 and 2015. With the unusual cold weather in 2016, the early sowing was conducted on May 6 and the late sowing on June 9.

Table 1. Meteorological conditions during the sugar beet growth and development period.

Germination period	2014				2015				2016			
	Number of days	Sum t ^{0}C	Average daily t ^{0}C	Precipitation. mm	Number of days	Sum t ^{0}C	Average daily t ^{0}C	Precipitation. mm	Number of days	Sum t ^{0}C	Average daily t ^{0}C	Precipitation. mm
Early sowing												
Sowing-seedling	17	107	6.29	93.5	11	103	9.4	19.9	6	113.1	18.8	-
3 pairs of true leaves	31	391	12.6	135	27	404	14.9	54.7	22	399.8	18.4	12.9
Closing space between rows (early harvesting)	73	1449	19.8	18.0	86	1996	23.2	116	70	1558	22.3	63.3
Closing space between rows (late harvesting)	117	2017	17.2	29.3	130	2715	20.8	127	114	2253	19.7	79.9
Late sowing												
Sowing-seedling	8	107	12.5	15.4	7	109	15.6	30.7	5	104	20.8	-
3 pairs of true leaves	24	404	16.8	20.6	20	405	20.2	43.4	18	393	21.8	13.9
Closing space between rows (early harvesting)	53	1034	19.5	18.1	63	1438	22.8	99.3	43	951	22.1	17.4
Closing space between rows (late harvesting)	97	1600	16.3	29.3	107	2157	20.2	109	87	1646	18.92	34.0

Estimation of the indicators of the yield

The plant performance indicators were evaluated during the growing season according to the plant growth phases and the development in ontogenesis. Those indicators allowed us to study how sugar beet plants reacted to the changes in environmental conditions i.e., unregulated factors of productivity such as solar radiation, temperature, rainfall, and relative air humidity.

The crop productivity mainly depends on the energy resources of solar radiation and its photochemically active processes. The arrival of photosynthetic active radiation (PAR) was calculated by the formula using regional coefficients (Tooming and Gulyaev, 1967):

$$\Sigma Q_{PAR} : 0.41\Sigma S + 0.62\Sigma D$$

where
Q_{PAR} : is the arrival amount of photosynthetic active radiation on the examined surface, MJ/m^2;
ΣS : the sum of direct solar radiation, MJ m^{-2};
ΣD : the sum of diffuse solar radiation, MJ m^{-2}.

The irrigation depth was determined by the soil's moisture deficit (field capacity - FC) between the upper and lower limit of moisture.

Phenological observations and selection of plant samples were carried out depending on the intra-field variability during the growing season, beginning, and complete onset of phenophases. Photosynthesis is inseparable from the conditions of internal metabolism and interdependent with the environment. In this regard, the identification of photosynthetic activities in extreme and manufacturing situations reproduced in a multi-factorial experiment was studied in the sugar beet. A study of photosynthetic activity and crop productivity was done to determine the quantitative and qualitative parameters of sugar beet growth and development such as accumulation of raw and dry biomass, area of the assimilation apparatus, consumption level detection of the solar radiant energy (C_{PAR}), and coefficient establishment of crop business activity. At the same time, the determination of photosynthetic activity indicators and productivity of the crops agro-biocenosis was conducted according to the unified classical methodology of Nichiporovich (1969) i.e., accumulation of raw and dry biomass weight method and area determination of the assimilation apparatus by die cutting method. The utilization coefficient of PAR by crops was determined by the following formula:

$$C_{PAR} = M*q*100;$$

$$\Sigma QPAR$$

where
C_{PAR}: utilization coefficient of PAR (%);
M: the amount of dry biological yield (kg/m^2);
ΣQPAR: arrival amount of PAR for crops growth season (MJ/m^2);
q: the calorific value of one kg of dry matter (MJ kg^{-1}).

The sum of the average daily temperatures by months and phases of the growing season was determined according to Shashko (1985). Rainfall metering of the studied crops during the growing season to establish the next irrigation, the moisture content of a soil meter-deep layer was systematically determined.

Statistical analysis

The data compilation and analyses have been performed using the R software environment open-source (R Version 3.6.1) using the standard statistical packages (stats) for one-way (ANOVA), and multivariate analysis of variance (MANOVA). To assess the influence of factors such as sowing time, application of various fertilizer rates, soil moisture level, and sowing density on the yield of sugar beet, MANOVA was done. To analyze the dependence of water consumption coefficients on the timing of sowing and the degree of application of mineral fertilizers, the one-way ANOVA was used (Zar, 2010).

RESULTS

Effect of sowing times

The multifactor (four factors) analysis of variance revealed that the sowing times significantly ($P < 0.0001$) affected sugar beet yield (Figures 1 and 2, Table 2). The average yield for the early sowing period ranged from 44.7 to 59.6 t ha^{-1}. An increase in temperature above 20.5 °C during 2015 reduced the sugar beet root yield to 41.1 t ha^{-1}. The late sowing period of 2016 carried out in June sharply reduced the yield of root crops by almost half (23.6 t ha^{-1}), likely an outcome of the high average temperature and low rainfall during that year.

The sowing times also resulted in distinct meteorological conditions into which the sugar beet plants were exposed. At the early sowing period that the seeds germinated, the average daily air temperature was 9.4 °C (Table 1), acquiring a root yield of 59.6 t ha^{-1}, and hence, the said temperature was found to be the most favorable. In the late sowing, the optimal temperature was 12.5 °C and the period length with optimal temperatures was eight days to obtain a yield of 46.5 t ha^{-1} (Table 1). A high air temperature (20.8 °C) during the period of root crop growth at the early sowing period significantly slows down the crop growth. After 20 days, the leaves overlapped the space between rows and the yield decreased by 5.0 t ha^{-1}, and after 70

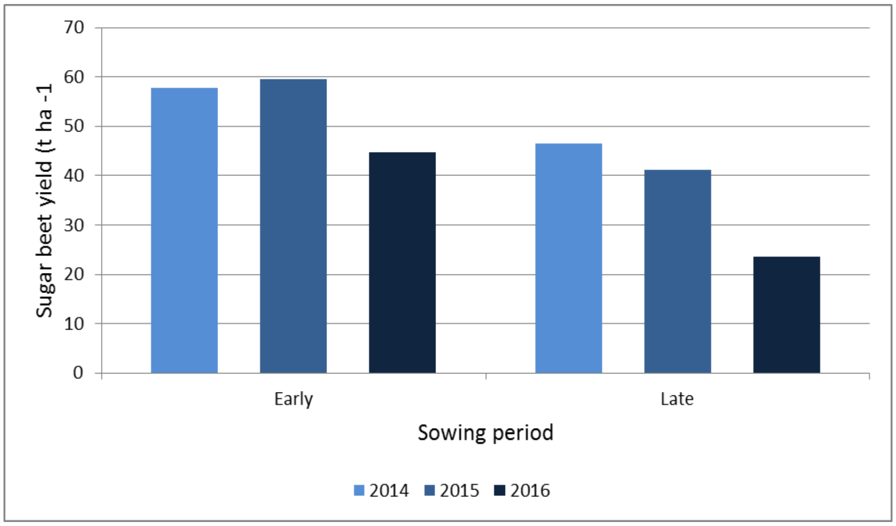

Figure 1. Influence of sowing time and period on sugar beet yield.

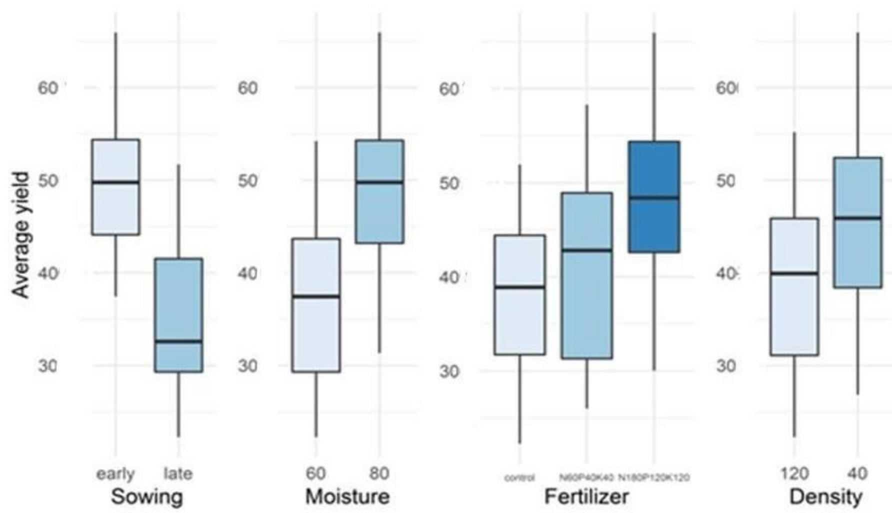

Figure 2. Results of four-factor ANOVA on sugar beet sowing time (early and late), fertilizer treatments (NPK @ 60-40-40 and 180-120-120 kg ha^{-1}) and control (with no fertilizer), plant density (40 and 120 thousand plants ha^{-1}), and soil moisture (60% and 80% of field capacity).

Table 2. Multivariate analysis of variance (MANOVA) for the sugar beet yield.

Factors	Sum of squares (S.S.)	Degree of freedom (d.f.)	F-value	Pr (>F)
Sowing	400463.00	1.0	661120.14	3.99e-43***
Moisture	233738.00	1.0	66653.79	5.86e-36***
Fertilizer	118747.00	2.0	66166.07	1.75e-26***
Density	77552.00	1.0	66216.92	1.54e-22***
Residuals	23596	66	-	-

***: 0.0001, **: 0.001, *: 0.01

days, by 3.0 t ha^{-1}, compared with the yield that accumulates at an air temperature of 17.5 °C, which was noted the optimal temperature for cultivating sugar beet.

The danger of a sharp decline in the sugar beet yield arises and was negatively affected by late cold weather during spring in May and early frosts in September. With the emergence of beet seedlings before April 25 and harvesting in the second day or week? of October, the average air temperature during 2014 and 2015 was 15.5 °C and 19.1 °C, respectively, and was found favorable for obtaining a high root yield in sugar beet. This also authenticated the advantage of early sowing for achieving high yields in sugar beet in Kazakhstan.

Rainfall also presented the highest variability during the different sugar beet growth phases and environments in terms of years. In 2014, rainfall during the sowing-seedling phase was 93.5 mm for the early sowing, and 15.4 mm for the late sowing (Table 1). Additionally, during the second growth phase of the plants with three pairs of true leaves, the differences between early and late sowing were even greater in 2014, with 6.55 times more rainfall for the plants sown earlier. However, for the following years (2015 and 2016), the rainfall levels became more similar. Therefore, it is necessary to have a weather forecast for the period of seedling emergence.

Effect of moisture level in the soil

The influence of meteorological conditions was especially and more clearly observed in plots with a moisture deficit. Maintaining such pre-irrigation soil moisture at a level of 60% from FC requires less irrigation with high irrigation rates (1020-1260 m^3 ha^{-1}) at irrigation intervals of 30-37 days. During 2016, it took three irrigations with a rate of 1220-1260 m^3 ha^{-1}. Maximum water consumption by crops occurred at the end of July and at the beginning of August. Consumption of spring soil moisture reserves at late harvesting is 8%-10% higher than early harvesting. The following pattern was established i.e., in years with a large amount of rainfall equally distributed throughout the growing season, the consumption of soil spring moisture reserves enhanced, and their share in the total water consumption increased to 12%-20%, and in dry years it decreased to 6%-14%. The analysis showed that the treatment with the most efficient water consumption (102 m^3 ha^{-1}) was the combination of excessive soil moisture, 1.5 times fertilizer rate, with an early sowing period, a late harvesting period, and a plant density of 40.000 crops ha^{-1}.

The study also revealed that late sowing resulted in more water consumption. An amount of 102-228 m³ of water was required to produce one ton of beetroot crops at the early sowing and from 116 to 405 m^3 at the late sowing (Table 3). Comparing the significance of the differences in water consumption values between the early and late sowing revealed that the differences were adequately significant (P < 0.0001) when compared to fertilizers (P < 0.05 (Figure 3a, Table 4), and the water consumption coefficients were lower at early sowing. Further, when adverse events occur affecting yield values, water consumption/soil moisture is the most impacted (P < 0.0001) among all other environmental factors (Figure 2, Table 2).

Table 3. Water consumption by sugar beet crops in interaction with different agricultural practices.

Sowing times	Harvesting times	Moisture levels (%) from FC	Degree of mineral fertilizers					
			Control		NPK (60-40-40 kg ha^{-1})		NPK (180-120-120 kg ha^{-1})	
			Crop density (000 Plants ha^{-1})					
			40	120	40	120	40	120
Early	Early	60	177	228	171	197	141	174
		80	149	163	125	141	108	126
	Late	60	153	174	138	157	120	144
		80	129	140	114	124	102	112
Late	Early	60	312	405	259	312	211	256
		80	226	262	194	213	167	193
	Late	60	218	259	191	220	163	195
		80	146	172	132	189	116	134

Table 4. One-way ANOVA for the consumption of soil moisture by sugar beet.

Factors	Sum of squares (S.S.)	Degree of freedom (d.f.)	F-value	Pr (>F)
Fertilizer	22636	2	3.30	0.046*
Residuals	154503	45	-	-
Sowing	55897	1	21.2	3.263e-05***
Residuals	121242	46	-	-

***: 0.001, **0.01, *: 0.05

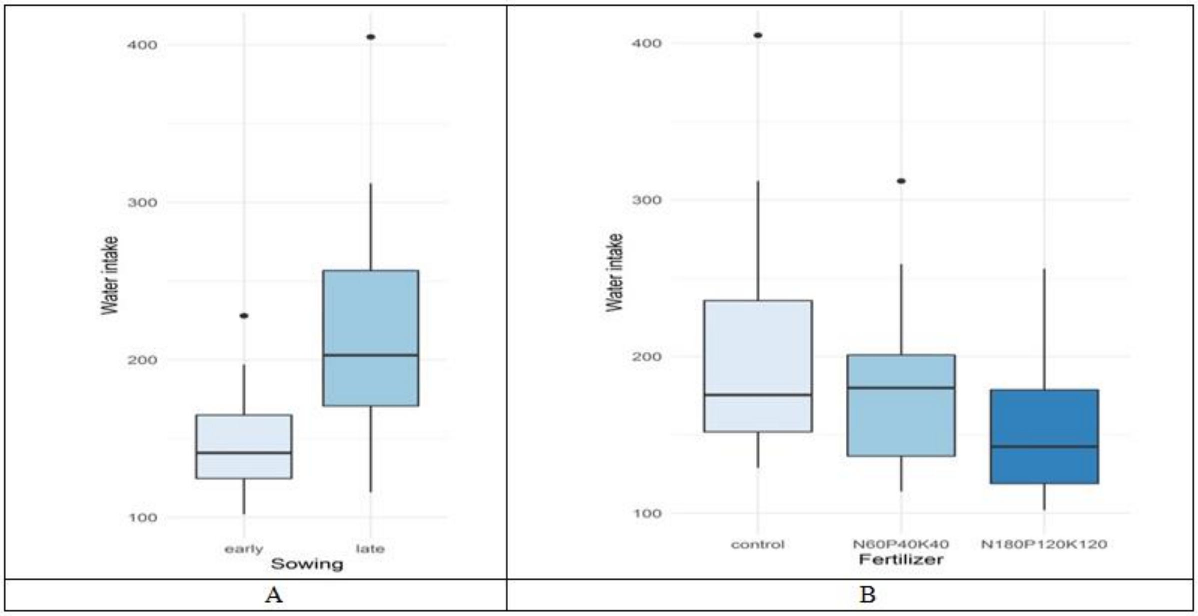

Figure 3. One-way ANOVA on the coefficients of water consumption depending on the sowing time and degree of mineral fertilizers.

Effect of fertilizer doses

Increase use of mineral fertilizers reduced water consumption (Figure 3b, Table 3). The analysis showed that 12%-15% less water intake of plants in soils applied with fertilizer than in soils without fertilizer (control) (P < 0.0001) between the coefficients of water consumption for different doses of mineral fertilizers (Figure 3b, Table 4). Multivariate analysis of variance revealed significant (P < 0.0001) differences in yield values by using different fertilizers (Table 2). Consequently, changes in mineral fertilization serve as a tool to adjust the water consumption for soil moisture in sugar beet crops.

In terms of soil nutrient uptake, the best and worst combinations were identified for both early and late harvesting (Table 5). Results revealed that the variant with a combination of all favorable factors of cultivation, the nutrients (N, P, and K) uptakes were 1.6, 1.3, and 1.9 times higher at the early harvesting period which yielded 52.0 t ha^{-1} than late harvesting (65.2 t ha^{-1}). The study further revealed that harvesting of every 100 sugar beet plants showed uptake of nitrogen (40-61 kg), phosphorus (15-20 kg), and potassium (54-75 kg) from the soil. Comparing the results of nutrient uptake at the highest (65.2 t ha^{-1}) and the lowest (15.6 t ha^{-1}) yields, and at maximum tuber yield, the uptake of N, P, and K was 1.44, 1.80, and 1.50 times higher than that with the low tuber yield.

Effects of plant density

The sugar beet yield mainly depends on the leaf size and area. According to the study, sugar beet plants showed the maximum leaf area per hectare from late July to early August (30.8-49.9 000 m^2 ha^{-1}). With the late sowing period, the growing season is shortened, which leads to a decrease in the leaf area (23.9-45.9 000 m^2 ha^{-1}), and r 9%-25% less than at an early sowing date. The treatment with mineral

Table 5. Uptake and consumption of nitrogen (N), phosphorus (P), and potassium (K) by sugar beet.

Early / late harvesting	Yield (t ha^{-1})	Consumption per one ton of sugar beet			Nutrients uptake (kg ha^{-1})		
		N	P	K	N	P	K
Early harvesting	52.0	2.05	0.5	4.7	178	40	338
Late harvesting	65.2	0.83	0.35	1.86	113	31	175
Early harvesting	15.6	0.80	0.32	1.83	78	17	119
Late harvesting	22.6	0.41	0.22	2.90	59	15	118

fertilizers of $N_{60}P_{40}K_{40}$ has increased the leaf area by 3-5 000 m^2 ha^{-1} and the 1.5 rate of NPK (180-120-120 kg ha^{-1}) by 6-9 000 m^2 ha^{-1}. The leaf surface area has maximum values with thick sowing and 6-9 000 m^2 ha^{-1} higher than in the variants with a thinned plant density (40,000 plants ha^{-1}). The opposite pattern was obtained by considering the leaves area in terms of one plant. The assimilation surface of one plant in a thinned crop density was 2.2-2.5 times higher than the same in a thick one. This is explained by the fact that the feeding area of one plant in a thinned sowing was larger than in a thick one, which almost completely excludes competition for food, moisture, and light and contributes to developing a powerful plant's leaf surface.

With an increase in the assimilating surface, the photo potential values increased and reaches a maximum value. The results of research on physiological indicators of sugar beet hybrid "Aksu" showed that increasing assimilating surface value of photo potential increases and reaches the maximum value of 0.59 million m^2 ha^{-1} days in the second half of July, then there was a gradual decrease. The favorable combination of factors (early sowing date, late harvesting date, excessive moisture background, 1.5 rate of fertilizers, and plant density of 120,000 plants ha^{-1}) contributed to the accumulation of up to 21.0 t ha^{-1} of dry biomass of sugar beet. Accumulation of dry matter per plant in thinned sowing was on average 2.6-2.8 times higher in the experiment, and the productivity of photosynthesis was 0.4-0.6 g m^{-2} day higher than with a thick crop. Hence, a favorable combination of different factors could contribute to the accumulation of sugar beet dry biomass.

Furthermore, to achieve a sugar beet root yield of 70-80 t ha^{-1} in Kazakhstan, it is necessary to apply the NPK at the rate of 180-120-120 kg ha^{-1}, for the formation of powerful biomass (20.4 t ha^{-1}), a photosynthetic apparatus of considerable size (53,200 m^2 ha^{-1}), working actively (5.3 g m^{-2} day^{-1}) functioning against a high absorption degree of the incoming energy of photosynthetic active radiation (C_{PAR} 2.0%) and maintaining the optimal level of soil moisture at 70%-80%-60%. With planting density (40,000 plants ha^{-1}), early sowing, and application of NPK at 180-120-120 kg ha^{-1}, the sugar beet root yields were 57.8, 59.6, and 44.7 t ha^{-1} during 2014, 2015, and 2016, respectively. It was established that for the formation of sugar beet yields ranging from 22.6 to 65.2 t ha^{-1}, the NPK should be applied at the rate of nitrogen (32-215 kg ha^{-1}), phosphorus (12-68 kg ha^{-1}), and potassium (50-380 kg ha^{-1}). It is also necessary to apply fertilizers differentially depending on the level of applied technology for the planned sugar beet yield.

DISCUSSION

Sugar beet (*Beta vulgaris* L.) is a key crop and plays a vital role in the economy of 52 countries in temperate zones, particularly in Central and South Europe (Stevanato *et al.*, 2019). However, in many regions, sugar beet production becomes increasingly challenging. It was reported that there is an increased requirement for water in Europe for cultivating beet (Shrestha *et al.,* 2010; Supit *et al.,* 2010). This demand will likely enhance more with climate change and global warming (Gornall *et al.,* 2010). Therefore, it is crucial to continue the application of adaptable technologies for sugar beet cultivation and its tolerance to a range of abiotic stresses. The current study contributed to this challenge by better understanding the impact of different agricultural practices on achieving more efficient water and nutrient use in different environmental conditions.

The response of sugar beet yield to water availability is well known (Jaggard *et al.,* 1998), and confirmed by the degree to which sugar beet crops wilt in the field. Previous studies of the factors determining sugar beet yield in temperate regions of the United Kingdom have emphasized the role of early season growth and the pattern of light interception during summer (Jaggard *et al.,* 1998). The analysis presented above indicates quite clearly that it was the combination of temperature and rainfall during July and August, that is, the hottest and driest part of the UK summer, and the most important weather variables determining sugar beet yields, and that this effect is consistent across all the seasons, and not just the hottest ones (Jaggard *et al.,* 2007).

The methodology for optimizing sugar beet yields was aimed at determining the degree of influence of fixed and random factors on plants by developing various economic and agro-technical measures. Based on the timely and accurate implementation, it is most likely to obtain an economically viable harvest. In this regard, it is necessary to group the data of field experiments according to their variability to obtain reliable conclusions and tangible results about the vital role of various factors that influenced the sugar beet yield. The average air temperature was taken during the growth season of sugar beet as one of the main factors of meteorological conditions characterizing their variability, significantly influencing the intensity of physiological processes, duration of root crops period, and soil moisture supply.

The present findings highlighted the importance of adjustable practices to circumvent the loss from unexpected changes in the weather. Interestingly, a significant effect of fertilizer use in reducing water intake was observed, suggesting the potential of mineral fertilization as a tool for more sustainable use of water. In the present era, sustainable use of water and fertilizers is becoming a priority in agriculture, particularly in water-scarce regions (Wang *et al.,* 2013). The present study contributes to this discussion by suggesting the positive impact of mineral fertilization in reducing the water demand of sugar-beet.

Early sowing periods are also crucial for getting the high sugar beet yield in Kazakhstan, especially when combined with adaptable farming. In agreement with the present findings, Mekdad *et al.* (2021) also reported that early sowing combined with adequate potassium and sulfur fertilization promoted the sugar beet yield and nutrient use efficiency in the dry saline soils of Egypt. Similarly, Fortune *et al.* (1999) findings revealed that early sowing increased the sugar beet leaf area and the beneficial effect of pesticides. The present results validated the past findings by confirming that early sowing also promotes more water use efficiency. Additionally, the early sowing in combination with flexible farming (e.g., late harvesting and irrigation) also contributed to achieving the higher yields in sugar beet.

The impact of temperature during April on yields did not always occur consistently significant throughout the analysis. The importance of the influence of early season growth on the final yield of sugar beet was stressed by Jaggard *et al*. (1998) arguing that final yields of sugar beet are strongly affected by the amount of light intercepted by the crop in early summer. The rationale is that the amount of light intercepted is then determined by the date of seedling emergence and the rate of canopy expansion. Both the date of emergence and the rate of canopy expansion can be positively influenced by warm spring temperatures. This idea was reinforced by detailed experiments on growth in sugar beet and other irrigated crops (Yu, 1992; Jaggard *et al*., 2007, 2009).

When choosing a sowing time, it must be considered that a single day delay in sowing leads to a loss of 0.5-0.6 t ha^{-1} in root crops yield, which cannot be compensated by a lengthy growing season via delayed harvesting (Tooming and Gulyaev, 1967). Besides, the present findings revealed that late sowing exposed the sugar beet plants to the worst meteorological conditions during the seedling phase, which is crucial for the final crop yield. In general, the sum of temperatures in this study site ranged between 103.1 °C to 113.1 °C. Although the sum of temperatures was approximately the same, the average daily temperature ranged from 6.29 °C to 20.78 ^{0}C during this period, and the duration varied from five to 17 days (Table 1). Thus, it is necessary to have a weather forecast for the period of seedling emergence since there is a high probability of cold weather in the foothill zone, precisely in late April to early May during early sowing. The weather forecast will help to decide the best set of accommodating farming tools to gain higher crop yields. With that, it is suggested to adopt the pliable farming technologies to cultivate sugar beet under unfavorable working and extreme meteorological conditions.

Planting date is considered among the most important factor for all field crops generally, and sugar beet especially. It has an active role in growth, yield, and root quality. The suitable date for sugar beet planting mainly depends on many factors such as the previous crop, weathering conditions, contract conditions with sugar factories, and cultivated cultivar. Rinaldi and Vonella (2005) and Rinaldi *et al*. (2006) reported that crop growth rate and relative growth rate did not show great differences according to the date of sowing. Net assimilation rate was higher in November and December sowing compared with October sowing, because October sowing presented the highest accumulation of dry matter compared with November and December sowing. Badawi (1985) reported that planting dates markedly affected leaf area index, biological plant weight, root weight, and foliage weight. Ghonema (1998) reported that planting dates markedly affected all growth characters under study, except foliage weight and root/top ratio in the second season.

Mineral fertilizers are used in spring in calculated doses for the planned yield, depending on the agrochemical characteristics of the soils. An important condition for the effective use of mineral fertilizers is their differentiated application, taking into account the planned harvest and the level of soil fertility. It was also reported that varied application of mineral fertilizers with biological products increases the sugar beet root yield by 5.6-7.5 t/ha relative to the control (Idris *et al*., 2021; Varga *et al*., 2021). Phosphorus and potash fertilizers are applied for pre-sowing cultivation and cohesive soils, yet autumn application of phosphorus and potassium is possible (Ramazanova *et al*., 2011). According to past findings, the introduction of mineral fertilizers ensures the formation of the planned yield, however, a double increase in mineral fertilizers does not give an effect, as well as, a decrease in the rate of mineral fertilizers (Morkovkin and Yartsev, 2016). With an increased dose of nitrogen fertilizers, the sugar content of sugar beet crops naturally decreased (Hosseinpour *et al*., 2013; Sulfab *et al*., 2017; Islamgulov *et al*., 2019).

The multi-factorial study allowed us to determine the relative importance of each tool for adjustable farming in the sugar beet yield. The factors that had the greatest impact on the sugar beet production process were a) sowing time (35.53%), b) harvesting time (18.15%), and c) irrigation schedule (15.6%). The Aksu hybrid's physiological processes were studied to form the planned yield levels of different sugar beet crops, which made it possible to establish the patterns of plant growth and development with a combination of optimal cultivation factors on light chestnut irrigated soils (Table 3).

In the Southeastern fields of Kazakhstan, beets are usually sown in spring (March-April) and harvested in autumn. However, past studies showed that autumn sugar beet has the advantage of prolongation of the growth period, early harvest, reduced irrigation requirements, and reduced risk of low blood sugar (Caliandro *et al*., 1989). These findings proposed to evaluate the effects of two sowing times (autumn and spring), two different levels of irrigation, and water application (optimal and reduced) on the sugar beet root yield and its composition. A special feature of sugar beet production is its high requirement for nutrients. The present findings provided the basis for developing a technological model and algorithms for better management of the sugar beet production at each specific stage of plant growth and development for different levels of intensification.

CONCLUSIONS

The timely and high-quality implementation of agricultural practices made it possible to form the planned yield with an optimal combination of regulated factors. Based on present findings, it can be concluded that for cultivation of sugar beet (*Beta vulgaris* L.), modern technologies should be differentiated and adaptable, taking into account frequently changing weather conditions, the content of nutrients in the soil, and production situations. The results obtained can serve as a basis for the development of a technological model for managing sugar beet production.

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