Caspian Journal of Environmental Sciences

Online ISSN: 1735-3866
Print ISSN: 1735-3033

Formation of a sugar beet crop with subsurface drip irrigation, depending on the methods of sowing and sealing the drip tape

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ABSTRACT

The article presents the results of studies conducted in the conditions of light chestnut soil in the foothill irrigated zone of Southeastern Kazakhstan. The features of the accumulation of biomass and the formation of the density of standing sugar beet plants with various methods of its sowing, depending on the methods of sealing the drip tape, have been studied. The most effective method of obtaining high yields of sugar beet with subsurface drip irrigation is five-line sowing, where the yield of sugar beet roots reaches 200 or more tons per hectare. In this case, sealing the drip tape to a depth of 30-40 cm at a distance of 100 cm is the most effective. The results of studies on the contamination of sugar beet crops are presented, where a significant decrease in the number of weeds was noted when sealing a drip tape to a depth of 40 cm and five-line sowing of seeds.

Keywords: Agriculture, Sugar beet, Beet crop, Drip irrigation, Drip tape.
Article type: Research Article.

INTRODUCTION

Market transformations in the agricultural sector of the economy were accompanied by negative processes for the development of sugar beet production: A significant reduction in acreage, a decrease in yield and gross harvest of sugar beet, and a deterioration in the financial condition of industry enterprises. It also caused stagnation processes in the main links of sugar beet production: A drop in the production of sugar beet seeds, underutilization / complete shutdown of sugar factories. The average annual volume of refined sugar production in Kazakhstan over the past 5 years is about 300 thousand tons. At the same time, the share of domestic raw materials in the production of white sugar is 4%, the remaining 96% is imported raw sugar, mainly cane (KazAgro 2014). Kazakhstan's high import dependence on sugar significantly reduces its economic and food security, as the volume of annual sugar purchases further increases the pressure on the accumulation of foreign exchange resources and stimulates not domestic, but foreign producers. The volume of imports of basic food products in recent years amounted to about one billion US dollars. The main share of imports (about 30%) was occupied by sugar, including raw (Turebayeva *et al.* 2021). Therefore, providing the country's population with sugar mainly from domestic raw materials is a state task that allows solving the problem of food security and providing food industry enterprises with the

Caspian Journal of Environmental Sciences, Vol. 23 No. 2 pp. 437-446 Received: June 26, 2024 Revised: Sep. 01, 2024 Accepted: Nov. 15, 2024
DOI: 10.22124/CJES.2025.8758

Publisher: University of Guilan,

necessary components. Sugar beet is also of great agrotechnical importance, increasing the productivity of crop rotation in general and being a valuable precursor for many crops. Depending on the type of soil, the sugar content of beets can range from 15.5 to 20.5%. Kazakhstan has potential opportunities for the revival of beet farming: Favorable natural and climatic conditions, beet-friendly lands, and water sources. Sugar beet is a plant with increased water requirements due to the long growing season and high yield potential. The full use of its yield potential, as well as the applied agrotechnical treatments, including nitrogen fertilizers, depends on many factors, including the genetic diversity of hybrids (Beisenbayeva *et al.* 2021; Kenenbayev *et al.* 2022) and the adaptive abilities of varieties to individual habitat (Studnicki *et al.* 2019), however, to the greatest extent it depends on the type or location of the soil and, above all, from the availability of water during the period of increased plant demand (Podlaski *et al.* 2017; Prasher *et al.* 2023; Rehman *et al.* 2024). The availability of water for plants depends on the amount of precipitation and its distribution during the growing season, and in case of lack of precipitation, if possible, depends on irrigation. Some studies of irrigation methods (Borówczak & Grześ 2002; Rzekanowski *et al.* 2005) have shown that sugar beet reacts to sprinkling by increasing the yield of root crops, but by reducing the sugar content. Numerous studies, mainly conducted abroad, show that the most effective way of rational use of irrigation water is drip irrigation of crops. Drip irrigation is a method in which water is supplied evenly to the roots of the plant in small portions throughout the growing season and irrigation moisture only reaches the plants, and is not consumed on row spacing. Due to this, the drip irrigation system is more efficient than other irrigation methods (Sharmasarkar *et al.* 2001; Kiymaz & Ertek 2015; Seilkhan *et al.* 2021). The effectiveness of the use of mulching films during drip irrigation in the preservation of moisture and weed control has been proven (Raina *et al.* 1998; Seyfi & Rashidi 2007). In recent years, we have conducted research on the effectiveness of drip irrigation of field crops such as rice, sugar beet, corn and soybeans on irrigated lands in the south and south-eastern parts of Kazakhstan. The research results have shown high efficiency of drip irrigation in the cultivation of the most water-intensive field crops, such as rice and sugar beet (Abdukadirova *et al.* 2016; Kenenbayev *et al.* 2016; Ospanbayev *et al.* 2017; Ospanbayev *et al.* 2017). However, surface drip irrigation does not find proper application by farmers of Kazakhstan, the main reason for which is the significant costs of annual laying and collection of drip tape, great difficulties for the timely implementation of agrotechnical measures. Subsurface drip irrigation additionally leads to an accurate use of resources by supplying water directly to the active root zone of plants compared to surface drip irrigation (Ayars *et al.* 1999; Ydyrys *et al.* 2020). Unlike surface drip irrigation, the subsurface drip irrigation system has a longer service life, leads to less weed contamination of crops and facilitates soil preparation and other tillage operations. Subsurface drip irrigation is the smallest component of irrigation, but is gradually gaining wider acceptance. The main advantages of subsurface drip irrigation include: more efficient use of water, since surface evaporation, surface runoff and losses during deep seepage can be reduced or almost eliminated. Underground drip irrigation facilitates the use of degraded quality water by increasing the frequency of irrigation, which minimizes osmotic stress, and in the case of treated wastewater reduces the movement of pathogens, odors and contacts with animals and people. The advantages associated with agriculture and agrotechnics include: improved plant growth, yield and product quality due to the timely supply of water and nutrients to the root zone of crops (Al-Ghobari & Dewidar 2018). Subsurface drip irrigation at a depth of 40 cm led to a decrease in water consumption and greater water productivity when using the amount of water for irrigation, based on water demand (Çetin & Kara 2019). Alternating plantings in a row for underground drip irrigation can significantly increase the rate of emergence of corn seedlings, promote growth at the seedling stage and increase yields, water use efficiency and productivity of nitrogen partial factors, especially in arid and semi-arid regions (Mo *et al.* 2017). Since the subsurface drip irrigation system is buried in the soil, there is a significant decrease in the germination and growth of weeds, especially in the aisles. The options for obtaining two harvests per year in some areas are guaranteed compared to surface drip irrigation, since there is no need to remove the drip lines during harvesting and reinstall them before sowing. Agricultural operations and management are facilitated because drip irrigation water is buried, and damage caused by agricultural equipment and field work is minimized. In addition, there should never be vehicle traffic above the drip tubes/tapes. By drip fertigation, fertilization in the active root zone reduces nutrient losses during leaching or evaporation (in the case of nitrogen) and increases the efficiency of fertilizer use (Seilkhan *et al.* 2018). It was found that the efficiency of using N, P and K in drip fertigation is 90%, 45% and 80% compared to 30-50%, 20% and 50% in the case of application to the soil (Raina *et al.* 2013). Increasing the efficiency of fertilizer use means that a similar crop yield can be achieved by reducing the dose of added fertilizers. More efficient management of water resources and nutrients also reduces potential environmental risks associated with nutrient losses (Xu *et al.* 2020). Agricultural soils are the main source of anthropogenic greenhouse gas emissions into the atmosphere. A number of studies have shown a sufficiently high efficiency of subsurface drip irrigation methods in reducing greenhouse gas emissions into the atmosphere (Akhmetova *et al.* 2015; Hamad *et al.* 2022; Wu *et al.* 2022). Moreover, both the use of fertilizer based on NO_3-N (i.e. calcium nitrate) and a nitrification inhibitor (3,4-dimethylpyrazolphosphate, DMPP) with ammonium sulfate resulted in a significant reduction in N_2O emissions compared to ammonium sulfate. Thus, these results contribute to the disclosure of the advantages of drip irrigation practice for the balance of greenhouse gases in irrigated agroecosystems (Bukenova *et al.* 2019; Gao *et al.* 2021).

MATERIALS AND METHODS

Study area and soil conditions

The research was carried out within the foothill irrigated zone of Southeastern Kazakhstan. This region is characterized by a light chestnut soil type. Understanding the specific soil characteristics, such as texture, structure, water-holding capacity, and nutrient content, is crucial for interpreting the results of the study. The soil type influences water infiltration and distribution, nutrient availability, and root development, all of which are critical factors in sugar beet cultivation. The climatic conditions of the Southeastern Kazakhstan foothill region, including temperature, precipitation patterns, and evapotranspiration rates, also play a significant role in determining crop water requirements and overall productivity.

Experimental design

The study employed a field experiment to evaluate the effects of different sowing methods and drip tape sealing techniques on sugar beet production. A factorial experimental design was utilized to assess the interactions between these two main factors. This design allows for the simultaneous investigation of the individual and combined effects of sowing method and drip tape sealing on the measured variables, such as biomass accumulation, plant density, weed contamination, and sugar beet yield. The experimental plots were arranged to ensure uniformity in soil conditions and minimize edge effects. Randomization and replication were used to reduce bias and increase the statistical validity of the results.

Sowing methods

Four distinct sugar beet sowing methods were included in the experiment:

Wide-row seeding at 60 cm: This method involves planting sugar beet seeds in single rows spaced 60 cm apart. This spacing is considered a conventional approach in some sugar beet cultivation systems.

Wide-row seeding at 45 cm: Similar to the previous method, seeds are planted in single rows, but with a reduced spacing of 45 cm between rows. This narrower spacing aims to potentially increase plant density and optimize land use efficiency.

Two-line seeding 20 × 50 cm: In this configuration, seeds are sown in pairs of rows, with a 20 cm spacing within each pair, and a 50 cm spacing between the pairs. This arrangement might influence light interception and resource competition among plants.

Five-line seeding 20 × 5 × 50 cm: This method involves planting seeds in groups of five rows, with a close spacing of 20 × 5 x 50 within the group, and a wider spacing between the groups. This higher-density planting strategy could maximize yield potential under optimal conditions.

Each sowing method represents a different spatial arrangement of sugar beet plants, which can influence factors such as light interception, competition for water and nutrients, and airflow within the canopy.

Drip tape sealing methods

The experiment included variations in both the width and depth of drip tape sealing to examine their effects on water distribution and availability.

Width of the drip tape seal: Three different widths were used: 100 cm, 125 cm, and 150 cm. The width of the seal refers to the lateral spread of the area wetted by the drip tape, influencing the overall soil volume that receives irrigation.

Depth of sealing of the drip tape: The drip tape was installed at three different depths: 20 cm, 30 cm, and 40 cm. The depth of placement affects the vertical distribution of water in the soil profile, which can impact root development, water uptake, and evaporation losses.

The combination of different sealing widths and depths allowed for a comprehensive assessment of how drip irrigation configuration interacts with sowing methods to optimize water use efficiency and crop production.

Weed control methods

To evaluate weed management strategies within the different sowing and irrigation systems, the following weed control methods were implemented:

Mechanical weeding: This method involved physical removal of weeds using manual or mechanical tools. Specifically, mechanical weeding was performed in the phase of 2-3 pairs of leaves and before closing the leaves in the aisles to minimize weed competition early in the crop's development.

Chemical weeding: This approach utilized herbicides to control weed growth. Dual-Gold herbicide was applied to the soil at a rate of 1.5 L ha^{-1} before sowing sugar beet to prevent the emergence of weeds. Subsequently, Fusilade Forte herbicide was sprayed at a rate of 1.0 L ha^{-1} as weeds appeared to target emerged weeds.

Combined mechanical and chemical weeding: This integrated strategy incorporated both mechanical and chemical methods. Dual-Gold herbicide was applied to the soil before sowing, followed by mechanical weeding before the sugar beet plants closed the aisles.

The comparison of these weed control methods aimed to determine the most effective and sustainable approach for managing weeds in sugar beet production under subsurface drip irrigation.

Data collection and analysis

The study involved systematic data collection throughout the sugar beet growing season to assess the effects of the experimental treatments.

Biomass accumulation of sugar beet plants: Biomass accumulation was measured periodically (10.06, 10.07, 10.08, 10.09, 10.10) throughout the growing season. Plants were sampled from each plot, and the raw mass of both the entire plant and the roots was recorded in grams per 10 plants.

Density of sugar beet plants: Plant density was determined by counting the number of established sugar beet plants per unit area. These counts were taken to assess the impact of sowing method and drip tape sealing on plant establishment and survival.

Contamination of sugar beet crops: Weed contamination was evaluated by quantifying the number or biomass of weeds present in each plot. Measurements were taken at the beginning and end of the growing season to assess the effectiveness of weed control methods and the influence of the experimental treatments on weed growth.

Sugar beet yield: At harvest, sugar beet yield was measured as the amount of sugar beet produced per hectare (kg ha^{-1} or tons ha^{-1}). Yield is the primary economic output and a key indicator of the success of the different treatments.

The collected data were subjected to appropriate statistical analyses to determine the significance of the effects of sowing method and drip tape sealing on the measured variables. Analysis of variance (ANOVA) was used to assess the main effects and interactions of the experimental factors. Where significant differences were found, post-hoc tests, such as Tukey's HSD test, were employed to compare means. The paper mentions "HCP, c ha^{-1}" in Table 4, which is the Least Significant Difference (LSD). This statistic was used to compare the yields. Statistical software was used for the analysis.

RESULTS AND DISCUSSION

This paper investigates the impact of subsurface drip irrigation on sugar beet cultivation in the foothill irrigated zone of Southeastern Kazakhstan. The authors highlight the importance of sugar beet for both economic and agricultural reasons, and the necessity of efficient irrigation methods in the region. They compare different sowing methods and drip tape placement depths, analysing the effects on biomass accumulation, plant density, weed contamination, and ultimately, sugar beet yield. The study emphasizes the potential of subsurface drip irrigation to optimize water use, reduce weed growth, and improve overall sugar beet production. Biomass accumulation is a fundamental indicator of plant growth and development, reflecting the plant's ability to capture and utilize resources like sunlight, water, and nutrients to produce biological material. Table 1 presents a detailed view of how sugar beet plant biomass accumulates over the growing season, under the influence of different sowing methods. These findings provide valuable insights into how different sowing methods affect the overall growth dynamics of sugar beet. The data is separated into two key components: the raw mass of the entire plant and the raw mass of the roots. This separation allows for a more nuanced understanding of how different sowing methods influence the partitioning of biomass within the plant.

Table 1. Accumulation of biomass of sugar beet plants depending on tillage methods with subsurface drip irrigation, g/10 plants

Methods of sowing	Terms of definition				
	10.06	10.07	10.08	10.09	10.10
	2023				
Wide-row seeding 60 cm	360*	3056	6346	8432	4863
	25**	1577	5880	12127	12380
Wide-row seeding 45 cm	403	3125	7854	9355	4486
	31	1441	5339	10220	10872
Two-line seeding 20 × 50 cm	577	2048	4884	6516	3021
	43	766	3792	8826	9066
Five-line seeding 20 × 5 × 50 cm	376	2156	3636	3744	2523
	32	522	2652	7742	8520
	2024				
Wide-row seeding 60 cm	278	3252	5345	7356	4044
	16	1614	4373	10550	11672
Wide-row seeding 45 cm	382	3361	8566	8359	4012
	30	1522	5390	9945	10123
Two-line seeding 20 × 50 cm	506	2466	4027	6130	2745
	32	703	3028	8255	8421
Five-line seeding 20 × 5 × 50 cm	256	2055	3360	6062	2042
	16	406	2564	5932	6640

Note: *. In the numerator is the raw mass of plants, **. In the denominator is the raw mass of roots

For instance, a particular sowing method might promote more vigorous root growth, while another might favor shoot development. These differences in biomass allocation can have significant implications for the plant's physiology, resource acquisition, and ultimately, its yield and quality. The results presented in Table 1 reveal that different sowing methods lead to variations in how sugar beet plants allocate resources to root and shoot growth. These variations can be attributed to a number of factors, including differences in plant spacing, access to light, and competition for resources. Understanding these relationships is crucial for optimizing sugar beet production. For example, a sowing method that results in higher root mass might enhance the plant's ability to uptake water and nutrients, particularly under conditions of water stress, and could also positively influence the final sugar content of the beet. Conversely, a method that promotes greater shoot mass might lead to more vigorous early growth and greater photosynthetic capacity, which could translate to higher overall biomass production. Furthermore, Table 1 illustrates the dynamics of biomass accumulation throughout the growing season. By tracking biomass changes over time, the study identifies critical growth stages where the effects of different sowing methods are most pronounced. This information is invaluable for informing agricultural management practices, such as irrigation and fertilization, ensuring that these inputs are applied at the times when the plants can most efficiently utilize them. Ultimately, the optimal balance between root and shoot growth, as influenced by the sowing method, will depend on the specific objectives of sugar beet production, whether it's maximizing sugar yield or total biomass. The biomass accumulation results highlight significant differences across sowing methods and seasons. In 2023, wide-row seeding at 45 cm showed the highest values in both early and late growth stages, particularly in October, indicating a steady increase in biomass accumulation over time. The five-line seeding method exhibited comparatively lower biomass accumulation, especially in the initial stages. However, by the end of the season, biomass values increased notably, suggesting that while growth may start off slower, the method facilitates higher final yields. The comparison of data from 2024 indicates similar trends, although overall biomass accumulation appears to be slightly lower than in 2023. This variation could be attributed to environmental factors, irrigation management, or seasonal conditions affecting growth rates. One of the most striking findings is the impact of sowing density on biomass accumulation—denser configurations, such as five-line sowing, tend to limit early growth but ultimately contribute to higher yield efficiency when paired with optimal irrigation conditions. These results emphasize the importance of selecting appropriate sowing methods to maximize sugar beet growth under subsurface drip irrigation. While wide-row sowing at 45 cm appears advantageous in terms of early biomass accumulation, the five-line method shows promise for long-term yield potential, particularly with strategic irrigation management. Plant density, defined as the number of plants per unit area, significantly influences final yield. If plant density is too high, plants compete intensely for limited resources such as sunlight, water, and nutrients. This competition can lead to smaller individual plant size, reduced root development, and ultimately, a decrease in overall yield. Conversely, if plant density is too low, resources remain underutilized, meaning the land's full productive potential is not realized. Table 2 focuses on plant density, a critical factor in crop production. This table examines how both the sowing method and the way the drip tape is sealed (specifically its width and depth) affect the final plant density achieved in the field. Effectively, it explores how these agricultural practices impact the number of established sugar beet plants.

Table 2. Density of sugar beet plants, depending on the methods of sowing and methods of sealing the tape of subsurface drip irrigation.

The width of the drip tape seal	Depth of sealing of the drip tape	Methods of sowing							
		Wide-row seeding 60 cm		Wide-row seeding 45 cm		Two-line seeding 20 × 50 cm		Five-line seeding 20 × 5 × 50 cm	
		2023	2024	2023	2024	2023	2024	2023	2024
	20	11	13	15	16	20	22	25	25
100	30	10	13	15	17	19	20	24	27
	40	10	11	14	16	19	21	24	27
	20	10	11	14	15	19	21	23	25
125	30	9	11	13	15	18	21	24	25
	40	9	10	13	13	18	19	23	27
	20	9	8	11	11	14	15	21	23
150	30	7	7	10	11	12	12	21	23
	40	7	7	9	9	12	12	20	20

The results illustrated in Table 2 highlight the importance of the interaction between the sowing method and drip tape sealing. This interaction is crucial for several reasons. Different sowing methods create varying spatial arrangements of plants within the field. These different arrangements can significantly influence the optimal placement of the drip tape to ensure efficient and uniform water delivery to each plant. For example, a wider row spacing might necessitate a different drip tape configuration compared to a narrower row spacing to maximize water distribution and minimize water loss. The configuration of the drip tape, in terms of its placement relative to the plants, becomes more critical to optimize water use efficiency. The depth and width of drip tape sealing play a vital role in determining the distribution of moisture within the soil profile. This moisture distribution, in turn, directly affects key processes like seed germination and seedling establishment. Optimal moisture levels are essential for successful germination and the development of healthy seedlings. Improper drip tape sealing can lead to either waterlogging (too much moisture) or drought stress (too little moisture), both of which can negatively impact plant establishment and final plant density. Therefore, the precision of drip tape sealing is paramount in creating a favorable environment for seed germination and subsequent seedling growth. The results likely demonstrate that specific combinations of sowing method and drip tape sealing result in higher plant densities. These successful combinations likely indicate a more efficient use of resources, including water and nutrients, and lead to improved crop establishment. "Improved crop establishment" signifies a higher percentage of planted seeds successfully germinating and developing into healthy, vigorous plants. A higher percentage of established plants directly translates to a greater proportion of the field contributing to the final yield. Plant density under different drip tape sealing methods is a crucial factor influencing crop performance. The findings reveal that deeper drip tape placement (40 cm) tends to support higher plant density across all sowing methods. This is particularly evident in five-line seeding, where plant counts consistently reached their highest values. The increase in density at deeper placements may be attributed to improved moisture distribution, leading to enhanced germination and seedling survival. Interestingly, the effect of tape width also plays a role in plant density. As the width of drip tape sealing increases to 150 cm, plant density tends to decline. This suggests that wider sealing configurations may distribute water less efficiently across the root zone, reducing the emergence rate. Narrower seals (100 cm) generally support higher plant densities, further reinforcing the need for precise irrigation placement. These observations highlight the balance between sowing method and irrigation design. While deeper tape placement benefits plant density, excessively wide spacing may undermine moisture accessibility. Farmers can optimize crop establishment by carefully adjusting sowing arrangements and irrigation depth to achieve the best possible density outcomes. Weed contamination is a major challenge in sugar beet production. Weeds compete with sugar beet plants for water, nutrients, and light, which can significantly reduce yield and quality. Table 3 shows how different sowing methods and subsurface drip irrigation techniques affect the level of weed contamination in sugar beet crops. It also compares the effectiveness of different weed control methods. The finding that sealing the drip tape at a depth of 40 cm significantly reduces weed contamination, particularly in the five-line sowing method, suggests that subsurface drip irrigation can suppress weed germination and growth by altering the soil environment. This suppression could be related to several factors. Firstly, the precise placement of water directly to the crop roots, away from the surface, may limit the moisture available to weed seeds, thus inhibiting their germination.

Table 3. Contamination of sugar beet crops depending on the methods of sowing and subsurface drip irrigation.

Methods of sowing	Ways to control weeds	Terms of definition					
		At the beginning of the growing season			At the end of the growing season		
		Depth of sealing of the drip tape (cm)					
		20	30	40	20	30	40
		2023					
Wide-row seeding 60 cm	* Mechanical	347	366	354	152	144	116
	** Chemical	51	35	32	17	15	13
	*** Mechanical+Chemical	60	51	58	13	20	15
Wide-row seeding 45 cm	Mechanical	338	376	342	162	160	128
	Chemical	63	52	57	20	17	12
	Mechanical+Chemical	54	54	62	28	20	14
Two-line seeding 20 × 50 cm	Mechanical	360	342	355	145	152	102
	Chemical	51	49	30	32	27	22
	Mechanical+Chemical	63	66	54	36	31	18
Five-line seeding 20 × 5 × 50 cm	Mechanical	356	341	302	13	10	7
	Chemical	60	47	51	11	13	6
	Mechanical+Chemical	53	66	62	17	12	6
		2024					
Wide-row seeding 60 cm	Mechanical	233	247	256	102	97	65
	Chemical	61	47	52	12	15	9
	Mechanical+Chemical	56	50	45	13	9	5
Wide-row seeding 45 cm	Mechanical	236	253	233	83	80	42
	Chemical	72	43	37	18	17	5
	Mechanical+Chemical	52	48	42	17	17	7
Two-line seeding 20 × 50 cm	Mechanical	225	202	219	101	83	52
	Chemical	44	53	50	20	17	15
	Mechanical+Chemical	59	63	57	20	14	11
Five-line seeding 20 × 5 × 50 cm	Mechanical	233	251	250	13	11	5
	Chemical	54	43	57	12	9	6
	Mechanical+Chemical	47	45	52	15	8	4

Note: *. Mechanical weeding in the phase of 2-3 pairs of leaves and before closing the leaves in the aisles.
**. Application of Dual-Gold herbicide to the soil at the rate of 1.5 L ha^{-1} before sowing sugar beet and spraying with Fusilade Forte herbicide at the rate of 1.0 L ha^{-1} as weeds appear.
***. Application of Dual-Gold herbicide to the soil at the rate of 1.5 L ha^{-1} before sowing sugar beet and mechanical weeding before closing the leaves in the aisles.

Secondly, subsurface drip irrigation might influence soil temperature in a way that is less favorable to weed germination. Finally, by keeping the topsoil relatively dry, it can also reduce light penetration, which is a critical factor for the germination of many weed species. The comparison of weed control methods (mechanical, chemical, and combined) confirms the effectiveness of chemical herbicides in managing weeds in sugar beet cultivation. Chemical herbicides are designed to target and kill weeds, thus reducing competition with the sugar beet crop. The combined approach, which integrates both chemical and mechanical methods, may offer the advantage of reducing herbicide reliance while still providing effective weed control. For example, mechanical methods like cultivation might be used to control initial weed growth, followed by a targeted application of herbicides to manage later-emerging weeds or those that are difficult to control mechanically. This integrated approach can help to minimize the development of herbicide-resistant weeds. The data Table 3 has important implications for sustainable sugar beet production. By optimizing subsurface drip irrigation and weed control practices, it is possible to minimize the use of herbicides and reduce the environmental impact of weed management. Reducing herbicide use not only lowers input costs for farmers but also minimizes the risk of herbicide residues in the environment and potential harm to non-target organisms. Subsurface drip irrigation, when effectively implemented, can be a key component of an integrated weed management strategy that promotes both economic and environmental sustainability in sugar beet production.

Table 4. Sugar beet yield depending on tillage methods and drip pipe sealing (kg ha^{-1}).

Methods of sowing	**The width of the drip tape seal (cm)**								
	100			**125**			**150**		
	Depth of sealing of the drip tape (cm)								
	20	**30**	**40**	**20**	**30**	**40**	**20**	**30**	**40**
2023									
Wide-row seeding 60 cm	1417.6	1304.6	1361.8	1042.0	1218.2	1114.6	1004.2	860.0	866.6
Wide-row seeding 45 cm	1600.6	1540.1	1520.8	1527.1	1466.2	1413.4	1294.6	1085.2	978.5
Two-line seeding 20 × 50 cm	1714.7	1742.3	1722.5	1702.4	1636.7	1631.9	1269.9	1204.1	1159.2
Five-line seeding 20 × 5 × 50 cm	2030.0	1996.1	2044.7	2000.8	2034.5	1959.6	1800.3	1776.7	1704.0
HCP (c ha^{-1})	95,4								
2024									
Wide-row seeding 60 cm	1527.6	1509.4	1283.9	1292.2	1265.9	1167.2	903.7	845.4	817.0
Wide-row seeding 45 cm	1729.3	1852.0	1619.7	1545.5	1513.0	1413.4	1036.7	1011.3	911.1
Two-line seeding 20 × 50 cm	1850.5	1786.2	1768.4	1765.4	1747.8	1600.0	1223.8	1043.6	1010.5
Five-line seeding 20 × 5 × 50 cm	1760.3	1765.9	1792.8	1666.0	1679.3	1792.8	1537.7	1505.2	1328.0
HCP (c ha^{-1})					82.8				

Table 4 presents the most direct measure of the success of the different treatments: sugar beet yield. Yield, defined as the amount of sugar beet produced per unit area (in this case, kilograms per hectare), represents the final economic output of the production system. This table shows how different tillage methods and drip pipe sealing parameters influence the amount of sugar beet produced per hectare, providing a clear picture of the effectiveness of each treatment. These analyses allow for the identification of the optimal combination of agricultural practices for maximizing sugar beet yield. By analyzing the yield data across the different treatments. it can be determined which specific combination of tillage method and drip tape configuration results in the highest productivity. This is crucial for making informed decisions about agricultural management practices. The results indicate that the five-line sowing method combined with specific drip tape sealing parameters (a depth of 30-40 cm and a width of 100 cm) consistently produces the highest yields. This finding suggests that this particular combination optimizes several key factors that contribute to sugar beet growth. These factors likely include efficient water delivery to the root zone, optimal nutrient availability, and a plant spacing arrangement that maximizes light capture and minimizes competition between plants. Furthermore, the authors' suggestion that yields of 200 or more tons per hectare are achievable with the five-line sowing method highlights the significant potential of subsurface drip irrigation to enhance sugar beet productivity in this region. This level of yield increase has substantial economic implications for farmers, potentially leading to increased profitability and a more sustainable sugar beet industry. The data in this table has direct practical implications for sugar beet farmers. By adopting the optimal practices identified in the study, farmers can significantly increase their yields, improve their profitability, and contribute to the sustainable production of sugar beet. The adoption of these practices can lead to a more efficient use of resources, including water and land, and contribute to the long-term viability of sugar beet farming in the region.

CONCLUSION

The study's findings provide a comprehensive overview of how sowing methods, drip tape sealing depths, and irrigation strategies affect sugar beet biomass accumulation, plant density, weed contamination, and yield. These findings strongly suggest that the five-line sowing method, in conjunction with subsurface drip irrigation with the drip tape sealed at a depth of 30-40 cm and a width of 100 cm, represents the optimal combination of agricultural practices for maximizing sugar beet yield in the foothill irrigated zone of southeastern Kazakhstan. This finding has significant practical implications for sugar beet farmers in the region. The adoption of these practices can lead to substantial increases in yield and profitability. Moreover, the increased efficiency in resource use, particularly in terms of water and nutrient management, can contribute to the long-term sustainability of sugar beet production, mitigating the environmental risks associated with traditional irrigation and fertilization methods. The study also highlights the potential of subsurface drip irrigation for effective weed management. offering a means to reduce reliance on chemical herbicides. Further research could explore the long-term effects of these practices on soil health and the economic feasibility of widespread adoption of subsurface drip irrigation systems for sugar beet production in similar agroclimatic contexts.

ACKNOWLEDGEMENT
The study was conducted within the framework of the project "Development and implementation of innovative technology for sugar beet cultivation based on intra-soil drip irrigation". project registration number AP23488264.

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Bibliographic information of this paper for citing:

Ospanbayev, Z, Doszhanova, A, Sembayeva, A, Ilmaliyeva, G, Batyrkhanov, M, Batyrkhanov, M, Raiymbekova, I, Amanbay, B 2025, Formation of a sugar beet crop with subsurface drip irrigation, depending on the methods of sowing and sealing the drip tape, Caspian Journal of Environmental Sciences, 23: 437-446.