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НАЦИОНАЛЬНАЯ АКАДЕМИЯ НАУК РЕСПУБЛИКИ КАЗАХСТАН ПРИ ПРЕЗИДЕНТЕ РЕСПУБЛИКИ КАЗАХСТАН

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ВОДНЫЕ, ЗЕМЕЛЬНЫЕ И ЛЕСНЫЕ РЕСУРСЫ

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A. Doszhanova[1], Zh. Ospanbayev[1,2], A. Sembayeva[1,2*], Sh. Abdukhaimova[1]
[1]Kazakh National Agrarian Research University, Almaty, Kazakhstan;
[2]Kazakh Research Institute of Agriculture and Plant Growing, Almaty, Kazakhstan.
E-mail: sembaeva.a84@mail.ru

STUDY OF SUGAR BEET SOWING METHODS UNDER SUBSURFACE DRIP IRRIGATION

Doszhanova A., candidate of Agricultural Sciences, Associate Professor, Kazakh National Agrarian Research University, Almaty, 050010, Kazakhstan
E-mail: ainurdoszhanova@mail.ru, https://orcid.org/0000-0002-9157-1022;
Ospanbayev Zh., doctor of Agricultural Sciences, Professor, Kazakh Research Institute of Agriculture and Plant Growing, Almaty region, 040909, Kazakhstan
E-mail: zhumagali@mail.ru, https://orcid.org/0000-0002-6570-8339;
Sembayeva A., PhD, Kazakh Research Institute of Agriculture and Plant Growing, Almaty region, 040909, Kazakhstan
E-mail: sembaeva.a84@mail.ru, https://orcid.org/0000-0001-5808-0080;
Abdukhaimova Sh., doctoral student, Kazakh National Agrarian Research University, Almaty, 050010, Kazakhstan
E-mail: shyrynkul.abdukhaimov@bk.ru, https://orcid.org/0009-0000-3085-8700.

Abstract. The article presents the results of studies on the formation of sugar beet yield under subsurface drip irrigation in the conditions of light chestnut soils of the foothill irrigated zone of southeastern Kazakhstan. The conducted studies established that sugar beet yield directly depended on the sowing method, as well as the width and depth of drip tape placement. According to the research results, the highest yield indicators were obtained under the five-row sowing method (20×5×50 cm), and wide-row sowing with 45 cm row spacing when the drip tape was placed at a depth of 30–40 cm and the distance between tapes was maintained at 100 cm. Under these conditions, root yield reached 200 c/ha and higher. The use of a 100 cm drip tape placement width ensured high yields across all sowing methods. Increasing the placement width to 150 cm resulted in a significant decrease in yield. Particularly low yield indicators were observed under the 60 cm wide-row sowing method. In addition, under optimal drip tape placement parameters and sowing methods, a significant reduction in weed infestation of crops was observed. It was proven that, in order to increase sugar beet yield under subsurface drip irrigation conditions, it is effective to place the drip tape at a width of 100 cm and a depth of 20–30 cm, as well as to apply five-row sowing or wide-row sowing with 45 cm row spacing.

Keywords: sugar beet, sowing methods, subsurface drip irrigation, weed infestation, yield

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А. Досжанова[1], Ж. Оспанбаев[1,2], А. Сембаева[1,2], Ш. Абдухаимова[1]*

[1]Қазақ ұлттық аграрлық зерттеу университеті КЕАҚ, Алматы, Қазақстан;
[2] Қазақ егіншілік және өсімдік шаруашылығы ғылыми зерттеу институты ЖШС, Алмалыбақ, Қазақстан.
E-mail: sembaeva.a84@mail.ru

ЖЕРАСТЫ ТАМШЫЛАТЫП СУАРУ ЖАҒДАЙЫНДА ҚАНТ ҚЫЗЫЛШАСЫНЫҢ СЕБУ ТӘСІЛДЕРІН ЗЕРТТЕУ

Досжанова А., ауылшаруашылығы ғылымдарының кандидаты, қауымдастырылған профессор, Қазақ ұлттық аграрлық зерттеу университеті, Алматы, 050010, Қазақстан
E-mail: ainurdoszhanova@mail.ru, https://orcid.org/0000-0002-9157-1022;
Оспанбаев Ж., ауылшаруашылығы ғылымдарының докторы, профессор, Қазақ егіншілік және өсімдік шаруашылығы ғылыми-зерттеу институты, Алмалыбақ, 040909, Қазақстан
E-mail: zhumagali@mail.ru, https://orcid.org/0000-0002-6570-8339;
Сембаева А., PhD докторы, Қазақ егіншілік және өсімдік шаруашылығы ғылыми-зерттеу институты, Алмалыбақ, 040909, Қазақстан
E-mail: sembaeva.a84@mail.ru, https://orcid.org/0000-0001-5808-0080;
Абдухаимова Ш., Қазақ ұлттық аграрлық зерттеу университетінің Агробиология факультетінің докторанты, Алматы, 050010, Қазақстан
E-mail: shyrynkul.abdukhaimov@bk.ru, https://orcid.org/0009-0000-3085-8700.

Аннотация. Мақалада Қазақстанның оңтүстік-шығысындағы тау бөктерінің суармалы аймағындағы ашық қоңыр топырақ жағдайында жер асты тамшылатып суару кезінде қант қызылшасының өнімінің қалыптасуын зерттеу нәтижелері келтірілген. Жүргізілген зерттеулер нәтижесінде қант қызылшасының өнімділігі себу тәсіліне, тамшылату лентасын көму ені мен тереңдігіне тікелей тәуелді екені анықталды. Әртүрлі себу тәсілдері мен тамшылату лентасын көму тереңдігінің өсімдіктердің биомассасының жиналуына, өсімдік жиілігінің қалыптасуына және өнімділігіне тікелей әсер ететіндігі зерттелді. Зерттеу нәтижелері бойынша ең жоғары өнімділік көрсеткіштері тамшылату лентасын 30–40 см тереңдікке көму және ленталар арасындағы арақашықтықты 100 см сақтау жағдайында бес қатарлы себу тәсілінде (20×5×50 см) және кеңқатарлы 45 см себу нұсқасында байқалды. Бұл жағдайда тамыржемістердің өнімділігі 200 ц/га және одан жоғары деңгейге жетті. Тамшылату лентасын көму енін 100 см деңгейінде қолдану барлық себу тәсілдерінде жоғары өнім қалыптастыруға мүмкіндік берді. Ал көму енін 150 см-ге дейін ұлғайту өнімділіктің айтарлықтай төмендеуіне әкелді. Әсіресе кеңқатарлы 60 см себу нұсқасында өнім мөлшері ең төмен деңгейде болды. Сонымен қатар, тамшылату лентасын көму параметрлері мен себу тәсілдерінің оңтайлы нұсқаларында егістіктің арамшөптермен ластануының айтарлықтай төмендегені байқалды. Алынған нәтижелер жер асты тамшылатып суару жағдайында қант қызылшасының өнімділігін арттыруда агротехникалық шаралардың маңыздылығын көрсетеді. Жер асты тамшылатып суару жағдайында қант қызылшасын өсіруде өнімділікті арттыру үшін тамшылату лентасын 100 см енде және 20–30 см тереңдікте орналастыру, сондай-ақ бес қатарлы немесе кеңқатарлы 45 см себу тәсілдерін қолдану тиімді екені дәлелденді.

Түйін сөздер: қант қызылшасы, себу тәсілдері, жер асты тамшылатып суару, арамшөптермен ластану, өнімділік

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А. Досжанова[1], Ж. Оспанбаев[1,2], А. Сембаева[1,2], Ш. Абдухаимова[1]*

[1]Казахский национальный аграрный исследовательский университет, Алматы, Казахстан;
Казахский научно-исследовательский институт земледелия и растениеводства, Алмалыбак, Казахстан.

E-mail: sembaeva.a84@mail.ru

ИЗУЧЕНИЯ СПОСОБОВ ПОСЕВА САХАРНОЙ СВЕКЛЫ ПРИ ПОДПОЧВЕННОМ КАПЕЛЬНОМ ОРОШЕНИИ

Досжанова А., кандидат сельскохозяйственных наук, ассоциированный профессор, Казахский национальный аграрный исследовательский университет, Алматы, 050010, Казахстан
E-mail: ainurdoszhanova@mail.ru, https://orcid.org/0000-0002-9157-1022;
Оспанбаев Ж., доктор сельскохозяйственных наук, профессор, Казахский научно-исследовательский институт земледелия и растениеводства, Алмалыбак, 040909, Казахстан
E-mail: zhumagali@mail.ru, https://orcid.org/0000-0002-6570-8339;
Сембаева А., PhD доктор, Казахский научно-исследовательский институт земледелия и растениеводства, Алмалыбак, 040909, Казахстан
E-mail: sembaeva.a84@mail.ru, https://orcid.org/0000-0001-5808-0080;
Абдухаимова Ш., докторант факультета агробиологии Казахского национального аграрного исследовательского университета, Алматы, 050010, Казахстан
E-mail: shyrynkul.abdukhaimov@bk.ru, https://orcid.org/0009-0000-3085-8700.

Аннотация. В статье представлены результаты исследований формирования урожая сахарной свеклы при подпочвенном капельном орошении в условиях светло-каштановых почв предгорной орошаемой зоны юго-востока Казахстана. В результате проведённых исследований установлено, что урожайность сахарной свеклы напрямую зависела от способа посева, ширины и глубины заделки капельной ленты. Изучено влияние различных способов посева и глубины заделки капельной ленты на накопление биомассы растений, формирование густоты стояния и урожайность культуры. По результатам исследований наиболее высокие показатели урожайности были получены при пятистрочном способе посева (20×5×50 см) и широкорядном посеве с междурядьем 45 см при заделке капельной ленты на глубину 30–40 см и расстоянии между лентами 100 см. В этих условиях урожайность корнеплодов достигала 200 ц/га и более. Применение ширины заделки капельной ленты 100 см обеспечивало формирование высокой урожайности при всех способах посева. Увеличение ширины заделки до 150 см приводило к значительному снижению урожайности. Особенно низкие показатели урожая отмечены при широкорядном посеве 60 см. Кроме того, при оптимальных параметрах заделки капельной ленты и способах посева наблюдалось существенное снижение засорённости посевов сорными растениями. Полученные результаты свидетельствуют о важности агротехнических мероприятий для повышения урожайности сахарной свеклы в условиях подпочвенного капельного орошения. Доказано, что для повышения урожайности сахарной свеклы в условиях подпочвенного капельного орошения эффективным является размещение капельной ленты на ширине 100 см и глубине 20–30 см, а также применение пятистрочного или широкорядного способа посева с междурядьем 45 см.

Ключевые слова: сахарная свекла, способы посева, подпочвенное капельное орошение, засоренность посевов, урожайность

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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, 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: 20].

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: 747–758]. 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 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 [Kenenbayev et al., 2022: 149–155; Beisenbayeva et al. 2021: 526–535] and the adaptive abilities of varieties to individual habitat [Studnicki, 2019: 514–521], but 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 [Rehman, 2024: 1298–1307; Prasher, 2023: 1164477; Żarski, 2020: 166–0172]. 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 have shown [Borówczak et al., 2002: 204–213; Rzekanowski, 2005: 287–300] 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 of irrigation 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 [Kiymaz, 2015: 225–234; Raina, 1998: 562–567; Cassel Sharmasarkar, 2001: 241–251]. The effectiveness of the use of mulching films during drip irrigation in the preservation of moisture and weed control has been proven [Seyfi, 2007; 15–20; Ospanbaev, 2024: 113–128].

In recent years, we have conducted research on the effectiveness of drip irrigation of field crops on irrigated lands in the south and south-east of Kazakhstan, including rice, sugar beet, corn, and soybeans. 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 [Ospanbaev, 2017: 1581–1603; Abdukadirova, 2016: 751–759; Kenenbayev, 2016: 917–924]. 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, 1999: 1–27; Ydyrys, 2020]. Unlike surface drip irrigation, the subsurface drip irrigation system has a longer service life, leading to less weed contamination of crops, and facilitates soil preparation and other tillage operations.

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.

Materials and methods.

The study was conducted in the foothill irrigated zone of Southern Kazakhstan in the fields of «Zhyly-bulak-Merke» LLP, located in the Merken district of Zhambyl region, which belongs to a very arid foothill agro-climatic zone. The sum of the effective temperatures reaches 3400–3800 °C, and the annual precipitation ranges from 300 to 450 mm. Warm-season precipitation slightly exceeds that of the cold season, with approximately 40 % of the annual precipitation occurring in spring. Nevertheless, arid conditions prevail during most of the warm season. The area experiences 120–140 days annually with relative humidity below 30 %, including approximately 90–95 days characterized by dry winds of varying intensity. However, dry weather prevails throughout most of the warm season. The region experiences 120–140 days per year with relative humidity below 30%, including approximately 90–95 days characterized by dry winds of varying intensity. The frost-free period lasts, on average, 145–160 days. A stable snow cover usually forms during the first half of December and persists for 60–90 days. Thaw periods occur frequently, accounting for 54–57 days per year. In terms of agricultural specialization, this zone is well suited for the cultivation of agricultural crops under irrigated conditions. This region is characterized by light chestnut soils. Understanding the specific characteristics of the soil, such as texture, structure, water retention capacity, and nutrient content, is crucial for interpreting the results of the study. The type of soil affects the penetration and distribution of moisture, the availability of nutrients, and root development - all these are important factors in the cultivation of sugar beet. The climatic conditions of the Southeastern foothill region of Kazakhstan, including temperature, precipitation patterns, and total evaporation, also play an important role in determining crop water requirements and overall productivity. During the study, a field experiment was conducted to evaluate the effect of various methods of sowing and sealing with drip tape on sugar beet yields. A factorial experimental plan was used to evaluate the interaction between these two main factors. This design makes it possible to simultaneously investigate the individual and combined effects of the seeding and drip tape sealing method on measured parameters such as biomass accumulation, plant density, weed infestation, and sugar beet yield. The experimental plots were arranged in such a way as to ensure uniformity of soil conditions and minimize side effects. Randomization and repetition were used to reduce bias and increase the statistical reliability 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. These 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 the 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.

The data indicate that the most intensive biomass accumulation occurred from July to September. In 2023, the highest aboveground biomass of plants was observed in the wide-row sowing with 45 cm row spacing, reaching 9355 g/10 plants on 10 September, while the root mass reached 10220 g/10 plants. Similar trends were observed in 2024, where the maximum biomass accumulation was also recorded in the wide-row sowing with 45 cm row spacing (8359 g/10 plants of plant mass and 9945 g/10 plants of root mass).

Lower biomass accumulation was noted in the five-line sowing (20×5×50 cm) and two-line sowing (20×50 cm) treatments. Nevertheless, in all treatments, a gradual increase in plant and root biomass was observed throughout the growing season, reaching maximum values by October.

Thus, the results show that row spacing and sowing method significantly influence the growth dynamics and biomass accumulation of sugar beet plants under subsurface drip irrigation conditions.

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* 25**	3056 1577	6346 5880	8432 12127	4863 12380
Wide-row seeding 45 cm	403 31	3125 1441	7854 5339	9355 10220	4486 10872
Two-line seeding 20x50 cm	577 43	2048 766	4884 3792	6516 8826	3021 9066
Five-line seeding 20x5x50 cm	376 32	2156 522	3636 2652	3744 7742	2523 8520
2024					
Wide-row seeding 60 cm	278 16	3252 1614	5345 4373	7356 10550	4044 11672
Wide-row seeding 45 cm	382 30	3361 1522	8566 5390	8359 9945	4012 10123
Two-line seeding 20x50 cm	506 32	2466 703	4027 3028	6130 8255	2745 8421
Five-line seeding 20x5x50 cm	256 16	2055 406	3360 2564	6062 5932	2042 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.

The results of a two-year field experiment (2023–2024) on sugar beet plant density depending on sowing methods (wide-row 60 cm, wide-row 45 cm, two-line 20×50 cm, and five-line 20×5×50 cm) and subsurface drip irrigation parameters, including drip tape sealing width (100, 125, and 150 cm) and sealing depth (20, 30, and 40 cm) (Table 2).

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. The data clearly show how irrigation layout and planting pattern influence the formation of plant stand density under irrigated conditions.

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 20x50 cm		Five-line seeding 20x5x50 cm	
		2023	2024	2023	2024	2023	2024	2023	2024
100	20	11	13	15	16	20	22	25	25
	30	10	13	15	17	19	20	24	27
	40	10	11	14	16	19	21	24	27
125	20	10	11	14	15	19	21	23	25
	30	9	11	13	15	18	21	24	25
	40	9	10	13	13	18	19	23	27
150	20	9	8	11	11	14	15	21	23
	30	7	7	10	11	12	12	21	23
	40	7	7	9	9	12	12	20	20

In 2023, the highest plant density was consistently recorded under the five-line sowing system (20×5×50 cm) across all irrigation treatments. At a drip tape width of 100 cm, plant density ranged from 24 to 27 plants per unit area, depending on depth, with the maximum value observed at 30–40 cm sealing depth. Even at increased widths of 125 cm, the five-line system maintained relatively high density (23–27 plants), demonstrating strong stability. However, at 150 cm width, a noticeable reduction occurred, with values decreasing to 20–23 plants, indicating that wider spacing between drip lines reduces uniform emergence and plant establishment.

The two-line sowing system (20×50 cm) in 2023 showed moderate plant density. At 100 cm width, values ranged from 19 to 20 plants, while at 125 cm width, density slightly decreased to 18–19 plants. At the largest width of 150 cm, plant density dropped further to 12–14 plants, confirming reduced seedling establishment under less optimal moisture distribution.

The wide-row sowing at 45 cm demonstrated lower plant density compared to more intensive sowing systems. At 100 cm width, density ranged from 14 to 15 plants, while at 125 cm, it decreased slightly to 13–14 plants, and at 150 cm width, it further declined to 9–11 plants, showing a clear negative effect of increased drip spacing.

The lowest plant density in 2023 was observed under wide-row sowing at 60 cm, especially under wider drip tape spacing. At 100 cm width, the density was 10–11 plants, while at 125 cm width, it decreased to 9–10 plants, and at 150 cm width, it reached the minimum values of 7–9 plants.

In 2024, a generally similar pattern was observed, although slight improvements in plant density occurred in several treatments, indicating better field emergence conditions in the second year.

The five-line sowing system again showed the highest and most stable plant density. At 100 cm width, values ranged from 25 to 27 plants, which was the maximum observed in the experiment. Even at 125 cm width, density remained high (23–27 plants), while at 150 cm width, a reduction was observed but still remained relatively stable (20–23 plants).

The two-line sowing system in 2024 also showed improved or stable performance compared to 2023. At 100 cm width, plant density reached 20–22 plants, while at 125 cm width, it remained at 19–21 plants. However, at 150 cm width, density decreased to 12–15 plants, confirming sensitivity to irrigation spacing.

The wide-row sowing at 45 cm in 2024 showed moderate density levels, ranging from 15–16 plants at 100 cm width, decreasing to 13–15 plants at 125 cm, and further to 9–11 plants at 150 cm width.

The lowest plant density in 2024 was again recorded under wide-row sowing at 60 cm, where values ranged from 11–13 plants at 100 cm width, decreasing to 7–11 plants at 125 cm width, and reaching the minimum of 7–8 plants at 150 cm width.

Overall, the results clearly demonstrate that plant density is strongly influenced by both sowing method and drip tape placement parameters. The most favorable conditions for plant establishment were observed at a drip tape width of 100 cm, which ensured more uniform moisture distribution and higher emergence rates across all sowing methods. Increasing the width to 125 cm led to a slight reduction in plant density, while 150 cm caused a significant decrease, especially in wide-row sowing systems.

Among sowing methods, the five-line system consistently provided the highest and most stable plant density, followed by the two-line system. In contrast, wide-row sowing, particularly at 60 cm spacing, showed the lowest plant density values, indicating lower efficiency under subsurface drip irrigation conditions.

Table 3 presents the results of a two-year field experiment (2023–2024) on weed infestation (contamination) of sugar beet crops depending on different sowing methods (wide-row 60 cm, wide-row 45 cm, two-line 20×50 cm, and five-line 20×5×50 cm), subsurface drip irrigation parameters (drip tape sealing depth of 20, 30, and 40 cm), and weed control strategies (mechanical, chemical, and combined mechanical + chemical control). Weed infestation was evaluated at two growth stages: at the beginning of the growing season and at the end of the growing season.

Across both years, the results clearly demonstrate that weed infestation is strongly influenced by the interaction between sowing density, irrigation configuration, and weed control method. In all treatments, weed infestation was significantly higher at the beginning of the growing season, while it decreased substantially by the end of the season due to crop development, canopy closure, and applied weed control measures. The data also show that higher plant density systems and integrated weed management significantly reduce weed pressure.

At the beginning of the growing season in 2023, weed infestation was at its highest level across all treatments. The most severe contamination was observed under wide-row sowing at 60 cm with mechanical control, where weed density reached 347–366 plants/m² depending on drip tape depth. Similarly, wide-row sowing at 45 cm also showed high weed pressure, ranging from 338 to 376 plants/m², indicating low early competitive ability of the crop in low-density planting systems.

The two-line sowing system (20×50 cm) also showed relatively high weed infestation (342–360 plants/m²), although slightly lower than wide-row systems. This confirms that moderate planting density still provides insufficient early canopy coverage for effective weed suppression.

In contrast, the five-line sowing system (20×5×50 cm) demonstrated comparatively lower weed infestation values, ranging from 302 to 356 plants/m², especially when the drip tape was placed at 40 cm depth, indicating improved moisture distribution and faster crop establishment, which enhanced weed competitiveness.

Regarding weed control methods, chemical and integrated (mechanical + chemical) treatments significantly reduced weed infestation compared to mechanical control alone. For example, under five-line sowing, chemical control reduced weed density to 47–60 plants/m², while integrated control maintained levels around 51–66 plants/m², which is substantially lower than mechanical-only treatments.

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 20x50 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 20x5x50 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 20x50 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 20x5x50 cm	mechanical	233	251	250	13	11	5
	chemical	54	43	57	12	9	6
	mechanical+chemical	47	45	52	15	8	4

*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 before sowing sugar beet and spraying with Fusilade Forte herbicide at the rate of 1.0 l/ha as weeds appear

*** application of Dual-Gold herbicide to the soil at the rate of 1.5 liters/ha before sowing sugar beet and mechanical weeding before closing the leaves in the aisles

In 2024, early-season weed infestation followed the same general pattern as in 2023, although some treatments showed slightly lower values, suggesting improved field conditions or management practices.

Under wide-row sowing at 60 cm with mechanical control, weed infestation ranged from 233 to 256 plants/m², which remained the highest among all treatments. The wide-row 45 cm system also showed high weed density (233–253 plants/m²), while the two-line system ranged from 202 to 225 plants/m².

The five-line sowing system again demonstrated relatively lower weed infestation, with values ranging from 233 to 251 plants/m² under mechanical control, but significantly lower levels under chemical and integrated treatments. This confirms that higher crop density improves early-season competitiveness.

Chemical and integrated weed control methods again proved more effective, reducing weed infestation in most cases to 37–61 plants/m², depending on sowing method and drip tape depth.

The analysis of Table 3 clearly shows that: Weed infestation is highest at the beginning of the growing season and decreases significantly by harvest due to crop development and weed control measures; Five-line sowing (20×5×50 cm) provides the most effective suppression of weeds due to high plant density, faster canopy closure, and better resource utilization; Wide-row sowing (especially 60 cm) consistently shows the highest weed infestation due to slower canopy development and weaker crop competitiveness; Chemical and integrated weed control methods are significantly more effective than mechanical control alone in reducing weed pressure; Subsurface drip irrigation depth (especially 30–40 cm) contributes to better crop establishment and indirectly reduces weed infestation by improving crop vigor.

Overall, the results confirm that the most effective strategy for weed management in sugar beet under subsurface drip irrigation is the combination of high-density sowing systems, optimal irrigation design, and integrated weed control methods, which together ensure the lowest weed infestation levels throughout the growing season.

To confirm the statistical significance of the differences, analysis of variance (ANOVA) was performed with the calculation of the least significant difference ($LSD_{0.05}$) according to the method of B.A. Dospekhov.

Table 4 summarizes the results of a two-year field experiment (2023–2024) evaluating the influence of different sowing methods, drip tape sealing width (100, 125, and 150 cm), and sealing depth (20, 30, and 40 cm) on sugar beet yield. The data clearly demonstrate a strong interaction between planting configuration and subsurface drip irrigation parameters, which significantly affects crop productivity under irrigated light chestnut soils of southeastern Kazakhstan.

Table 4 – Sugar beet yield depending on tillage methods and drip pipe sealing, kg/ha

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 20x50 cm	1714,7	1742,3	1722,5	1702,4	1636,7	1631,9	1269,9	1204,1	1159,2
Five-line seeding 20x5x50 cm	2030,0	1996,1	2044,7	2000,8	2034,5	1959,6	1800,3	1776,7	1704,0
LSD, c/ha	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 20x50 cm	1850,5	1786,2	1768,4	1765,4	1747,8	1600,0	1223,8	1043,6	1010,5
Five-line seeding 20x5x50 cm	1760,3	1765,9	1792,8	1666,0	1679,3	1792,8	1537,7	1505,2	1328,0
LSD, c/ha	82,8								

In 2023, the most productive treatment combination was observed under the five-line sowing system (20×5×50 cm). At a drip tape width of 100 cm, yields were consistently high across all depths, ranging from 1996.1 to 2044.7 c/ha, with the maximum value of 2044.7 c/ha recorded at a sealing depth of 40 cm. Even at 20 and 30 cm depths, yields remained above 1990 c/ha, indicating the stability of this sowing system under optimal irrigation layout.

When the drip tape width increased to 125 cm, a slight reduction in yield was observed, although the five-line system still maintained high productivity, ranging from 1959.6 to 2034.5 c/ha. However, further widening to 150 cm led to a more pronounced decline, with yields decreasing to 1704.0–1800.3 c/ha, showing that excessive spacing between drip lines reduces water and nutrient availability in the root zone.

The two-line sowing system (20×50 cm) showed moderately high productivity in 2023. At 100 cm width, yields ranged from 1714.7 to 1742.3 c/ha, while at 125 cm width they slightly decreased to around 1631.9–1702.4 c/ha. At 150 cm width, a sharper reduction was recorded, with yields dropping to 1159.2–1269.9 c/ha, indicating higher sensitivity of this sowing system to irrigation distribution.

The wide-row sowing at 45 cm demonstrated intermediate performance. At 100 cm drip tape width, yields ranged from 1520.8 to 1600.6 c/ha, while at 125 cm width they decreased to 1413.4–1527.1 c/ha, and further declined at 150 cm width to 978.5–1294.6 c/ha.

The lowest productivity in 2023 was recorded under wide-row sowing at 60 cm, particularly at the largest drip tape width. At 100 cm width, yields varied between 1304.6–1417.6 c/ha, while at 125 cm width they dropped to 1042.0–1218.2 c/ha, and reached minimum values of 860.0–1004.2 c/ha at 150 cm width. This confirms that wider row spacing combined with wider drip tape placement significantly limits crop performance.

The $LSD_{0.05}$ value of 95.4 c/ha indicates that most differences between treatments in 2023 were statistically significant.

In 2024, the overall pattern remained consistent, although absolute yield levels slightly increased in some treatments due to more favorable growing conditions.

The highest yields in 2024 were recorded under the wide-row sowing at 45 cm, reaching up to 1852.0 c/ha at 100 cm width and 30 cm depth. This indicates improved efficiency of this system under optimal irrigation conditions in the second year. Similarly, the two-line sowing system showed very high productivity, with a maximum of 1850.5 c/ha at 100 cm width and 20 cm depth, confirming its stability and adaptability.

The five-line sowing system also maintained high yields in 2024, ranging from 1760.3 to 1792.8 c/ha at 100 cm width, while at 125 cm width, yields remained high but slightly reduced (1666.0–1792.8 c/ha). However, at 150 cm width, yields decreased more noticeably to 1328.0–1537.7 c/ha, confirming the negative effect of excessive drip line spacing even under multi-row sowing systems.

For the wide-row sowing at 60 cm, yields remained the lowest across all irrigation treatments. At 100 cm width, productivity ranged from 1283.9 to 1527.6 c/ha, while at 125 cm width it declined to 1167.2–1292.2 c/ha, and at 150 cm width dropped further to 817.0–903.7 c/ha, which represents the minimum recorded yield in the experiment.

The $LSD_{0.05}$ value of 82.8 c/ha confirms that differences between treatments in 2024 were also statistically significant.

Overall, the data clearly show that the most favorable conditions for sugar beet yield formation were achieved when the drip tape was placed at a width of 100 cm, regardless of sowing method. Increasing the width to 125 cm caused moderate yield reduction, while 150 cm significantly decreased productivity in all cases. In terms of sowing methods, the five-line and two-line systems consistently demonstrated the highest and most stable yields, while wide-row sowing at 60 cm was the least effective.

Additionally, the results indicate that the interaction between drip tape depth and sowing method is important, with depths of 20–30 cm generally providing the most stable and high yields, ensuring optimal moisture and nutrient availability in the root zone.

Conclusion.

Based on the results obtained during the 2023–2024 growing seasons, it was established that the formation of sugar beet productivity under subsurface drip irrigation largely depends on the sowing method, as well as the width and depth of drip tape placement.

The dynamics of biomass accumulation showed that the most intensive plant growth occurred during the period from July to September, with a gradual increase in both aboveground and root mass until the end of the growing season. Sowing methods significantly influenced plant development, plant density, weed infestation, and final yield. Among the studied sowing methods, the five-line sowing (20×5×50 cm) and the two-line sowing (20×50 cm) ensured higher plant density and more favorable conditions for crop growth compared with wide-row sowing. At the same time, the wide-row sowing with 45 cm spacing demonstrated relatively high productivity in certain variants. The results also showed that the width of drip tape placement significantly affected crop productivity. Reducing the width to 100 cm contributed to higher yields across all sowing methods, whereas increasing it to 150 cm resulted in a noticeable decrease in yield. The optimal depth of drip tape placement was 20–30 cm, which provided favorable conditions for root development and water supply to plants.

The differences between the treatments in terms of weed infestation by the end of the growing season were statistically significant, as they exceeded the $LSD_{0.05}$ value ($p = 0.05$). The lowest weed infestation (4–6 plants/m²) was obtained with the five-line sowing method**, a** drip tape placement depth of 40 cm, and a combined protection system, which was significantly lower compared with the mechanical weed control method**.** Weed infestation of the crops strongly depended on the applied weed control system. The combined method (mechanical + chemical) proved to be the most effective, ensuring a stable reduction in weed population throughout the growing season. The lowest weed infestation (4–6 plants/m²) was recorded with five-line sowing, a drip tape placement depth of 40 cm, and the combined weed control system, with statistically significant differences compared to the mechanical method.

Thus, under the conditions of subsurface drip irrigation, the optimal combination of agrotechnical practices for sugar beet cultivation includes the use of five-line or two-line sowing methods, a drip tape placement width of 100 cm, and a placement depth of 20–30 cm, along with the application of a combined weed control system, which ensures stable plant development and high crop productivity.

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Author Contributions:

Doszhanova A. *– research methodology, analysis, and interpretation of the results.*

Ospanbayev Zh. *– development of the research concept and scientific supervision.*

Sembayeva A. *– conducting the research, data collection and processing, preparation of the original draft of the manuscript, manuscript editing, and article formatting.*

Abdukhaimova Sh. *– participation in conducting experiments, processing of research materials, and preparation of individual sections of the manuscript.*

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