Soybean Yield and Vegetative Water Consumption in Various Irrigation Methods

Rakhiya Yelnazarkyzy[1,2*], Serik Barmanbekovich Kenenbayev[1],
Z.O. Ospanbayev[2], P.A. Kalashnikov[3]

[1] Kazakh National Agrarian University, Almaty, Kazakhstan

[2] Kazakh Research Institute of Agriculture and Plant Growing, Almalybak, Kazakhstan

[3] Kazakh Research Institute of Water Management, Taraz, Kazakhstan

* Corresponding author's e-mail: yelnazarkyzy.r@mail.ru

ABSTRACT

The influence of various irrigation methods on the soybean water consumption rates and yield has been studied. It was established that the yield of the Lastochka soybean variety using the drip irrigation was 52.6 c/ha under the conditions of the Ili Alatau and 49.6 c/ha in the Kyrgyz Alatau, which is 8.0–8.14 c/ha more than when using the furrow irrigation. In both zones, the soybean consumption rates depended on the soil-hydrogeological state of the land.

Keywords: irrigated agriculture, consumption rate, drip irrigation, soybean, sowing methods, yield.

INTRODUCTION

The drip irrigation is one of the most progressive irrigation methods in terms of irrigation efficiency, water-saving and energy costs. However, the positive aspects of this irrigation method are only manifested when all elements of the irrigation technique comply with the specific soil conditions of the site and its topography, as well as the requirements imposed by the cultivated crop to various environmental factors [Akhmedov et al. 2010].

Soybean is a universal food, feed and technical culture. The variety of soybean chemical composition and the value of its protein allow applying it as a raw material in numerous industries [Podobedov, 1998a; Koryagin, 1985].

In Kazakhstan, soybean is mainly cultivated in the south-east – in the Almaty, Taldykorgan and Zhambyl regions. Irrigated southern regions are favorable for legume cultivation. The duration of the warm period, the amount of precipitation in autumn, winter and early spring, as well as the abundance of sunlight and heat, allow obtaining a high yield of soybean grain [Podobedov, 1998b].

Moisture, most of which is extracted from the soil, is required for the rateal growth and development of the cultivated crops. According to the data of many authors, soil moisture close to the lowest water capacity has the greatest accessibility for plants. Moisture, as noted by many researchers, is one of the main and irreplaceable factors of plant life [Kochegura, 2008].

A crop irrigation regime is a set of rates, the number and timing of irrigation of each crop in irrigated crop rotation corresponding to the climatic, soil, agrotechnical and hydrogeological conditions of the geographical zone [Yermukhambetova et al., 2018]. It must meet the plants' need for water in all periods of growth and development, taking into account the requirements of the agricultural culture. It must also implement optimal regulation of water and associated nutrients, as well as salt and thermal regimes of the soil, promote the soil fertility and be linked with the irrigation technique and technology [Integrated water consumption and wastewater standards for individual Industries: approved by order of the

Acting Minister of Agriculture of Kazakhstan dated October 11, 2016 No. 431].

In Kazakhstan, the shortage of water resources in average water years reaches 6.6 km³ and is significant in all basins. In dry years, the level of water supply is about 60% and in some regions – only 5–10%; the deficit is mainly observed in the irrigated agricultural zone [Current status, protection and rational use of water resources of Kazakhstan, 2018].

The analysis of literature considering the patterns of formation of the soil water regime and its influence on the soybean production process allowed us to establish that the recommendations on this issue are determined by various factors, such as the soil and climatic conditions, varietal characteristics, irrigation methods, etc. In general, most authors consider it more effective to use the irrigation regimes differentiated by interphase periods [Balakay, 1983; Russian soybean union, 2003].

The shape, area and direction of the plots were established in accordance with the generally accepted methods [Dubenok et al., 2009; Mesyats, 1984].

Having a positive influence on the irrigated areas, irrigation rationing and the appointment of irrigation terms are the main stages of the resource-saving cultivation technology allowing one to obtain a planned yield of soybean grain [Shadskikh et al. 2019].

Obtaining a high soybean yield is complicated by the unstable provision of the territory with atmospheric precipitation. Under these conditions, irrigation is of decisive importance in the complex of agro-measures for the cultivation of this culture. The irrigation regime is zonal in nature and depends on the soil-hydrogeological and weather conditions, as well as the irrigation method and technique [Shadskikh et al., 2015].

MATERIALS AND METHODS

The research on various irrigation methods was carried out in 2016–2018 in two agroecological zones of irrigated agriculture, in the south and southeast of Kazakhstan:
- Irrigated piedmont zone of the Ili Alatau (demonstration site of the Kazakh Research Institute of Agriculture and Plant Growing (KazRIAPG)) on light chestnut soils;
- Irrigated piedmont zone of the Kyrgyz Alatau (Nurzhan farm, Merke district, Zhambyl region) on gray-earth soils.

The foothill zone of KazRIAPG field stations is located at an altitude of 740 m above sea level and characterized by continental climatic conditions: mild and cool winter, cool spring, hot and dry summer, warm and dry autumn.

The average duration of the frost-free period is 170–180 days with temperature fluctuations. However, frosts that are often recurring in late spring and early autumn, shorten the frost-free period to 140–150 days.

The summer thermal resources in the zone are quite high. The average amount of the above-zero temperatures is 3,500–4,000 °C. Such a thermal regime allows growing many heat-loving crops, including soybean.

The distribution of precipitation in the zone is uneven. Thus, according to the weather station, the average annual amount of precipitation is 516.7 mm with the following distribution by seasons: 94.1 mm in winter, 177.5 mm in spring, 158.8 mm in summer and 94.1 mm in autumn. The largest amount of precipitation falls in June and amounts to 96.6 mm in summer.

Arid weather remains for most of the warm period in the irrigated piedmont zone of the Kyrghyz Alatau (Nurzhan farm, Merke district, Zhambyl region). The period of 120–140 days in the year is characterized by relative humidity below 30%. The entry of moisture into the soil corresponds to the arrival of precipitation and occurs mainly in the spring-winter and early-spring periods. The total amount of precipitation in 2018 (381.4 mm) was distributed as follows: autumn – 16.0% (61.0 mm), winter – 19.3% (73.8 mm), spring – 56.4% (215.3 mm) and summer – 31.3 mm (8.2%).

As the object of the study, the authors selected the Lastochka soybean variety, belonging to the middle-late group (III group of ripeness), approved for use in the Almaty, Zhambyl and Turkestan regions.

Sowing was conducted using a VenceTudo combination seeder (Brazil), single-line and two-line sowing methods (45 cm and 50×20 cm spacing, respectively) as well as two irrigation methods (drip and furrow).

RESULTS AND DISCUSSION

The Zhambyl region is part of the Shu-Talas basin, which consists of the Shu water district (code 08.01.14) with three water areas (codes 08.01.14.01, 08.01.14.02 and 08.01.14.03) and the Talas water district (code 08.02.15) with two water areas (codes 08.02.15.01 and 08.02.15.02).

The location of water districts and areas, administrative regions and districts of the Shu-Talas basin by natural moisture zones is shown in Figure 1.

1. The rates of water consumption of the agricultural crops are taken in accordance with the Consolidated rates of Water Consumption and Wastewater Disposal in Agriculture and are given in Table 1.

    Thus, in the Shu water district, the soybean water consumption (m³/ha) when using the drip and surface irrigation depends on the characteristics of the soil-hydrogeological state, i.e. in both cases, the rates decrease with increasing hydromorphism. At the same time, the water consumption rates when using the drip irrigation are 900–1250 m³/ha less than when using the surface irrigation.

2. The rates of vegetative irrigation were calculated using the A.N. Kostyakov's formula:

$$m = 100\gamma h(\beta_{MC} - \beta_0) \qquad (1)$$

where: m is the irrigation rate, m³/ha;
γ is the bulk density of the soil, t/m³;
h is the depth of soil moisture, m;

β_{MC} and β_0 are the lowest moisture capacity and pre-irrigation soil moisture, % of the weight.

3. The depth of soil moistening depends on the mechanical properties of the soil, the hydrogeological and ameliorative conditions, the density of the plant root system, the irrigation method, etc. and is assumed to be equal to the thickness of the active layer of the soil.

4. The intra-vegetational distribution of the irrigation rates for crops was developed on the basis of the variation-statistical method for the years of varying degrees of supply (50%, 75%, 95%).

Total water consumption and irrigation rates

Total water consumption is the total water consumption of the field associated with evaporation from the soil surface and plant transpiration during the growing season. The water consumption is made up of the soil moisture reserves used by plants, the precipitation of the growing season, the capillary feeding of groundwater (when it is close to the ground) and irrigation.

Evapotranspiration (total water consumption) was established based on the bioclimatic method according to dependencies:

$$ET_{crop} = K_o K_{в} ET_0 \qquad (2)$$

where: ET_{crop} is crop evapotranspiration, m³/ha;
K_o is the microclimatic coefficient;
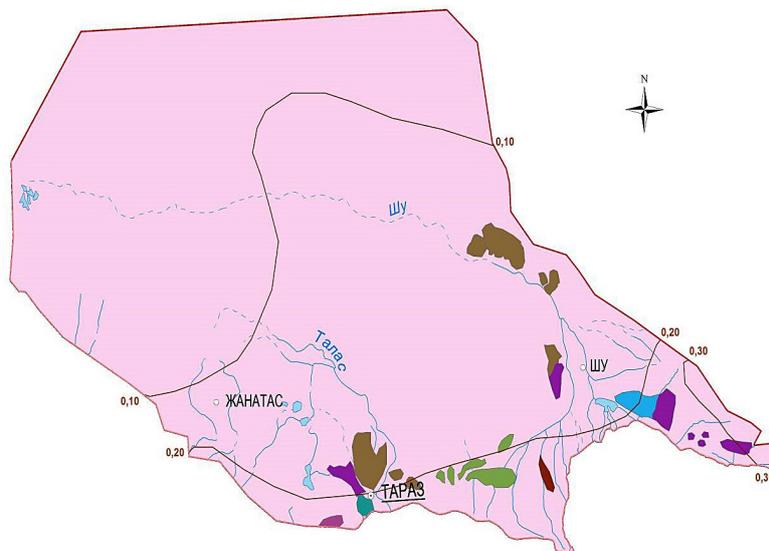
Figure 1. The location of water districts and areas, administrative regions and districts of the Shu-Talas basin by natural moisture zones

Table 1. Aggregated soybean water consumption rates for drip and surface irrigation in the Shu water district 08.01.14, water area 08.01.14.02.

Q, natural areas	Irrigated crops	Water consumption rates, m³/ha								
		Soil-hydrogeological areas								
		automorphic, ground water level > 3 m			semi-hydromorphic, ground water level = 2–3 m			hydromorphic, ground water level = 1–2 m		
		Probability level of excess, %								
		50	75	95	50	75	95	50	75	95
0.25–0.20, annual intake limit	Surface irrigation									
	Soybean	4,300	4,950	6,100	3,050	3,700	4,850	2,150	2,800	3,900
	Drip irrigation									
	Soybean	3,400	3,900	4,850	2,400	2,950	3,850	1,700	2,200	3,100

K_B is the biological coefficient characterizing the role of plants;

ET_0 is evaporation for monthly intervals of time, determined using the N.N. Ivanov's formula:

$$E = 0.018(25+t)\,2(100-a), \text{ m}^3/\text{ha} \qquad (3)$$

where: t is the air temperature, °C;

a is the relative air humidity, %.

The irrigation rate is defined as the difference between evapotranspiration (total water consumption) of an agricultural crop and its natural moisture supply. On the irrigated lands with deep groundwater (more than 3 m) and non-saline soils, its values were established as follows:

$$M = ET_{crop} - W_a - P_{ef} \qquad (4)$$

where: M is the irrigation rate (net) on non-saline soils with deep (> 3 m) groundwater table, m³/ha;

ET_{crop} is crop evapotranspiration, m³/ha;

W_a is productive soil moisture reserve used by plants, m³/ha;

P_{ef} is precipitation that fell during the growing season, m³/ha.

The irrigation rates that take into account the soil-ameliorative and hydrogeological conditions of the irrigated field were established according to the following relationship:

$$M_{(PM)} = \frac{M - ET_{crop}K_g}{K_M} \qquad (5)$$

where: M_{PM} is the ecological and melioration irrigation rates ensuring the melioration welfare of irrigated lands, m³/ha;

M is net irrigation rate for non-saline soils with deep (> 3.0 m) groundwater table, m³/ha;

ET_{crop} is crop evapotranspiration, m³/ha;

K_g is coefficient of permissible use of groundwater for sub-irrigation.

The Almaty region is part of the Balkash-Alakol basin (code 02) and includes the Ili water district (code 02.01.07) with seven water areas (codes 02.01.02.01–02.01.02.07), the Karatal-Aksu water district (code 02.02.03) with two water areas (codes 02.02.03.01 and 02.02.03.02), the Alakol-Sasykolskiy water district (code 02.03.00) with two water areas (codes 02.03.00.01 and 03.03.00.02) and the North-Pribalkashsky water district (code 02.04.00) with one water area (code 02.04.00.00).

The location of water districts and areas, administrative regions and districts by natural moisture zones is shown in Table 2 and Figure 2 (Q-contour lines are constructed according to data of hydromagnetic system located no higher than 1,000 m above sea level).

The total water consumption and irrigation rates in the Balkhash-Alakol basin in the Ili water district were calculated in the same way as in the Shu-Talas basin, according to formulas 2–5.

The rates of water consumption of the agricultural crops are taken in accordance with the Consolidated rates of Water Consumption and Wastewater Disposal in Agriculture and are given in Table 2.

In the Balkhash-Alakol basin in the Ili water district, the quantitative indicators of the water consumption rate (m³/ha) also depend on the features of the soil-hydrogeological state: the higher hydromorphism, the lower irrigation rates. At the same time, in the Shu water district. due to the aridity of the region, the water consumption rate, in general, is 200–300 m³/ha higher than in the Ili water district.
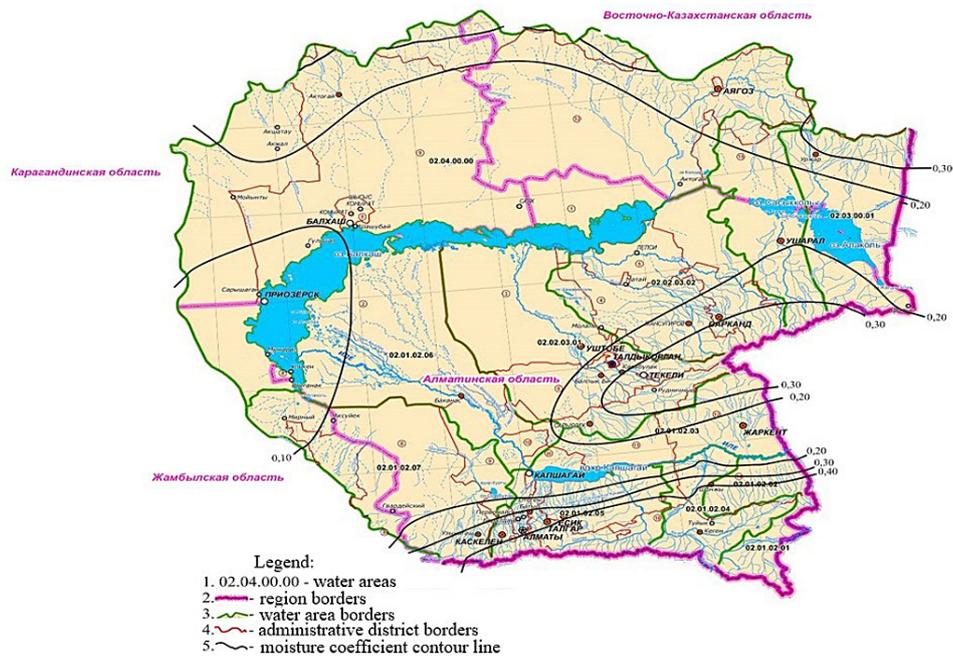
Figure 2. The Balkhash-Alakol basin

Studying the soybean productivity features associated with different irrigation methods allows determining the most optimal growing conditions for a particular variety, providing for a significant yield increase.

Plant height, as one of the productivity features, is rather indirect, although such property as the manufacturability of the variety depends on it. Both low and high rates can lead to lower yields due to the difficulties in mechanized harvesting. The optimal parameters of the height of soybean are 80–100 cm.

For the varieties with an indefinite growth point, the furrow irrigation methods associated with a higher level of moisture can lead to uneven stretching and lodging of plants, which adversely affects harvesting. The plant height also depends

on the sowing density: for instance, with 45-cm row spacing the height was lower than with two-line sowing since with single-line sowing plants grow less densely.

The sowing and irrigation methods have a similar effect on the height of attachment of the lower beans in addition to the height of the plant itself. The highest rates are characteristic of drip irrigation and two-line sowing (Table 3).

The seed productivity is determined by the weight of seeds per plant – this indicator is the most important and economically valuable feature of a soybean plant. The number of beans per plant is also a relative indicator for characterizing its productivity and is used in the samples with the same size of seeds since the weight of 1,000 seeds and the number of seeds in a bean

Table 2. Aggregated soybean water consumption rates for drip and surface irrigation in the Ili water ditrict 02.01.02, water area 02.01.02.05.

Q, natural areas	Irrigated crops	Water consumption rates, m³/ha								
		Soil-hydrogeological zones								
		automorphic, ground water level > 3 m			semi-hydromorphic, ground water level = 2–3 m			hydromorphic, ground water level = 1–2 m		
		Probability level of excess, %								
		50	75	95	50	75	95	50	75	95
0.25–0.20, annual intake limit	Surface irrigation									
	Soybean	4,050	4,700	5,800	2,600	3,200	4,200	1,550	2,000	3,000
	Drip irrigation									
	Soybean	3,200	3,700	4,600	2,050	2,550	3,350	1,250	1,600	2,350

Table 3. Comparative assessment of elements of productivity, yield and quality of the Lastochka soybean variety, depending on sowing and irrigation methods

Irrigation method	Sowing method, row distance, cm	Plant height, cm	Height of lower beans, cm	Weight of seeds per plant, g	Weight of 1,000 seeds, g	Yield, c/ha	Protein, %	Fat, %
Kyrgyz Alatau								
Drip irrigation	45	120.3	7.5	20.1	165.4	49.6	40.2	19.8
	50x20	110.5	10.2	19.5	163.5	51.6	39.8	19.5
Furrow irrigation	45	90.1	7.8	14.2	171.4	41.5	40.1	20.1
	50x20	85.4	5.6	21.6	163.2	43.6	40.6	20.4
Ili Alatau, KazRIAPG station								
Drip irrigation	45	125.3	12.5	25.1	166.4	52.6	39.1	19.2
	50x20	115.5	15.2	24.5	164.5	54.6	39.6	19.5
Furrow irrigation	45	94.6	12.8	19.2	172.4	44.5	39.4	19.8
	50x20	90.4	10.6	26.6	164.2	46.6	39.8	19.2

have a wide variation range. Therefore, in all other cases, when determining the productivity of a plant, the indicator of the weight of seeds per plant is used.

The highest weight index of 1,000 seeds (21.6 g) was established under two-row sowing and furrow irrigation in the Kyrgyz Alatau. This indicator amounted to 26.6 g under the same growing conditions in the Ili Alatau.

In terms of the weight of seeds per plant, the Lastochka variety is averagely large with the average weight of seeds on 160–170 g. In all experiments in the two cultivation zones, no significant differences were observed in terms of the weight of 1,000 seeds based on different sowing and irrigation methods. In all variants of the experiment, this indicator was within its genetic limits. Despite the growing conditions, a rather high level of stability can be observed in terms of the large size of seeds, as well as the quality indicators. The level of protein of the Lastochka variety was in the range of 39.1–40.6% and the level of fat – 19.2–20.4%.

The crop productivity varies with the crop conditions. The highest yields in both test areas were obtained when using the drip irrigation and wide-row two-line sowing (51.6 c/ha in the Kyrgyz Alatau and 54.6 c/ha in the Ili Alatau). The lowest yields were obtained when using the furrow irrigation in wide-row single-line sowing.

CONCLUSIONS

In the Ili water district of the Almaty region and in the Shu water district, the quantitative indicators of the water consumption rate (m^3/ha)

depend on the features of the soil-hydrogeological state, i.e. the higher hydromorphism, the lower irrigation rates.

It has been established that the sowing and irrigation methods have a significant effect on the plant height, the height of lower beans attachment and the seed weight per plant. However, the methods did not have a significant effect on the weight of 1,000 seeds, as well as the seed protein and fat content. The highest yields in both test areas were obtained when using the drip irrigation and wide-row two-line sowing (51.6 c/ha in the Kyrgyz Alatau and 54.6 c/ha in the Ili Alatau). Conversely, the lowest yields were obtained when using the furrow irrigation and wide-row single-line sowing.

REFERENCES

1. Akhmedov, A.D., Temerev, A.A., Galiullina, E.Yu. 2010. Reliability of the drip irrigation system. Agronomy Forestry, 3(19), 1–6.

2. Balakay, G.T. 1983. The effect of moisture supply on the soybean crop. Hydrotechnics and Land Reclamation, 10, 83–84.

3. Current status, protection and rational use of water resources of Kazakhstan. Baribar 25.11.2018. URL: https://ru.baribar.kz

4. Dubenok, N.N., Borodychev, V.V., Lytov, M.N., Belik, O.A. 2009. Features of soil irrigation with drip irrigation of crops. Achievements of science and technology of agrarian and industrial complex, 4, 22–25.

5. Integrated water consumption and wastewater standards for individual Industries: approved by order of the Acting Minister of Agriculture of Kazakhstan dated October 11, 2016 No. 431.

6. Kochegura, A.V. 2008. The main results on breeding, seed and technology of soybean production and prospective areas of research. Proc. 2nd international conference on soybeans «Modern problems of breeding and technology of cultivation of soybeans». Krasnodar, 8–14.

7. Koryagin, Yu.G. 1985. Selection and technology of cultivation of soybeans in Kazakhstan. Bulletin of agricultural science of Kazakhstan, 8, 27–34.

8. Mesyats, I.I. 1984. Soybean cultivation in Europe. Moscow.

9. Podobedov, A.V. 1998a. Soybean processing products for feeding animals and poultry. Agrarian Science, 8, 11–14.

10. Podobedov, A.V. 1998b. Therapeutic and profilactic properties of soybean products. Agrarian Science, 5, 9–11.

11. Russian soybean union. 2003. Target sectored program «Development of production and deep processing of soybeans in the Russian Federation 2003–2010». Moscow.

12. Shadskikh, V.A., Brel, V.K., Peshkova, V.O. 2019. The application of differentiated irrigation regimes in the cultivation of crops on the dark chestnut buds of the Saratov Trans-Volga region. The ways to improve the efficiency of irrigated farming, 52, 19–26.

13. Shadskikh, V.A., Peshkova, V.O., Kizhaeva, V.E., Lapshov, A.G. 2015. Cultivation of promising soybean varieties based on resource-saving technology in the Volga region. The ways to improve the efficiency of irrigated agriculture, 3(59), 87–91.

14. Yermukhambetova, R.Zh., Dogabayev, A.Zh., Bari, A.A., Masalimov, Zh.K. 2018. Oxidativestress plants for combined abiotic and biotic stress factors. Bulletin of the L.N. Gumilyov Eurasian National University. Bioscience Series, 1(122).