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The soil water balance and the development of spring soft wheat under various cultivation technologies

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The steppe zone has always attracted people with its resources, despite the fact that it is a zone of risky agriculture. In this research we discovered that soil water balance under the spring soft wheat was negative most of the time of the vegetation period in the Rebrikhinsky district of the Altai Region, and soil moisture consumption during the observation period depends on the technology options and an average values was in the range from 100.9 mm to 131.9 mm. An average soil moisture consumption was 42.5% of spring moisture reserves. In the plots where autumn soil cultivation was not carried out, the average water consumption for the vegetation period was 41.7% of the spring moisture reserves, while in those plots where it was 43.2%, i.e., only 1.5% more. The absence of both autumn and spring tillage led to the consumption of 38.8% moisture from spring soil moisture reserves during the growing season. In the case when only spring tillage was carried out, this value was 44.7%, and if both cultivations were carried out - 43.2%. The difference in the sowing rates practically did not affect the total moisture consumption from the soil, it amounted to 42.2-42.8% of the spring moisture reserves. The maximum difference in water consumption was found when comparing the equipment used for spring tillage and sowing. So, when using Catros and DMC-9000, respectively, an average of 47.5% of spring moisture reserves was spent during the growing season, while using Russian-made equipment – KPE-3,8 or BDM-6*4 and SZP-3.6A, it was 38.9%. The moisture reserves in the meter soil layer decreased in direct proportion to the increase in average plant height.

Key words: Spring soft wheat; Cultivation technologies; Soil water balance; Altai Region

Introduction

Altai Region occupies one of the leading places in the sown area of spring soft wheat in Russia. The steppe zone has always attracted people with its resources, despite the fact that it is a zone of risky agriculture. Under the arid conditions, the level of soil moisture is one of the decisive factors in the normal development of plants (Bischoff et al., 2016; Meissner et al., 2016).

It subdues itselfs all agricultural technologies, therefore it is the care of moisture that is the main in agriculture of the steppe and forest-steppe zones of Altai Region (Tsvetkov, 2010). Moisture deficiency here has been and remains an obstacle to sustainable agriculture. The whole complex of agrotechnical measures should be aimed primarily at the maximum accumulation of precipitation, their conservation and the rational expenditure of soil moisture and precipitation on the formation of a unit of yield. It is necessary to reduce unproductive moisture losses and to direct them to increase the yield (Panov, 2017). Under the climate change conditions, we need to select and adapt the optimal farming technologies for the cultivation of crops (Schmidt et al., 2016; Norton, 2016). That is why the studying of the soil water balance and the development of agricultural plants in the steppe are of great scientific and practical interest (Belyaev et al., 2016). The aim of this research is to to identify the influence of the autumn soil processing, pre-sowing soil cultivation, sowing and the rates of sowing seeds on the soil water balance and the development of spring soft wheat plants in the Rebrikhinsky district of the Altai Region.

Material and Methods

Study site

Farm "Teikhrib S.I." is located in the Priobskaya zone of the Altai Region in the Rebrikhinsky district (Figure 1). It is mainly an open forest-steppe on the left bank of the Ob river. The average temperatures of July are +19.3...+19.8°C, of January are -17.5...-19.2°C. The average annual rainfall is 350-410 mm, including 180-205 mm during the growing season. The distribution of precipitation over the years is more uniform compared to the steppe regions. Years with an acute moisture deficit range from 30 to 35%. The zone is characterized by dissected relief, a significant part of the arable land is located on the slopes and is subject to both deflation and water erosion. There are ordinary medium humus medium thick loamy chernozems dominate in the central part of the zone (Agroclimatic, 1971).

Crop and agrotechnical characteristics

The experimental field was 163 hectares. The forecrop was barley. Variants of spring wheat cultivation technologies were compared with various methods of autumn tillage, pre-sowing cultivation, sowing and seed sowing rates (Table 1).

Figure 1. Location of Rebrikhinsky District in the Altai Region (in red) (sourse: https://ru.wikipedia.org).

Table 1. Compare variants for spring wheat cultivation technologies.

Variant nomber	Autumn soil processing, unit	Pre-sowing soil processing, unit	Sowing unit	Sowing rate, kg ha^{-1}
1	-	-	DMC-9000	200
2	-	-	DMC-9000	175
3	-	Catros	DMC-9000	175
4	-	Catros	DMC-9000	200
5	BDM-6*4	Catros	DMC-9000	200
6	BDM-6*4	Catros	DMC-9000	175
7	BDM-6*4	KPE-3,8	SZP-3.6A	200
8	BDM-6*4	BDM-6*4	SZP-3.6A	175

The width of the plot was taken as a multiple of the working width of the sowing unit and was 18 m (in case of DMC-9000) and 21.6 m (in case of SZP-3.6A). The sowing date was May 29, 2008. Wheat variety - Altayskaya Stepnaya. Mass of 1000 grains - 40.8 g. Laboratory germination of seeds was 93%. The sowing was carried out without fertilizing.

Measured parameters

In the spring period (April 29, 2008), soil and agrochemical analysis was carried out in all experimental plots, soil moisture was determined by layers up to one meter. According to vegetation, with the advent of seedlings, every 10 days till for the harvesting period in experimental plots soil moisture was determined by layers up to one meter, moisture reserves in a meter layer and plant height. Determination of soil moisture by layers to a depth of one meter (with an interval of 10 cm) was carried out by the HH-2 device.

Statistical analysis

Sampling and data processing was carried out in full accordance with standard methods (Dospekhov, 1979).

Results and Discussion

Weather conditions

The growth and development of agricultural plants and their productivity directly depend on how the weather conditions of the growing season are formed. Vegetation period of 2008 was not usual, the amount of precipitation was lower than perennial average on almost 40 mm. The distribution of rainfalls by monthes was not equal and there were drought in the first two decades of May, as well as in late June and in late July-early August (Table 2).

The content in the soil of the basic elements of plants mineral nutrition is also one of the key factors in their normal growth and development (Motuzova & Bezuglova, 2007). The content of substances in the soil in a layer of 0-20 cm and average soil moisture reserves according to the variant of autumn soil processing are showen in the Table 3. The amount of nitrate nitrogen contained in the soil before sowing in the absence of autumn tillage turned out to be low (13.4 mg kg^{-1}). In the case when the autumn tillage was carried out using BDM-6*4, the content of nitrate nitrogen in the soil in the spring was much higher and amounted to 35.9 mg kg^{-1}, which is a high level. The phosphorus content in both variants was at a high level, and potassium was at an average level. The humus content in the soil was also high in both cases. As for soil moisture before sowing, to a depth of 1 m the water content was higher on the variant without autumn tillage. The difference averaged 8.8 mm.

Table 2. Rainfall during the growing season, v. Rebrikha (2008).

Month	The amount of rainfall in ten-days, mm			Total, mm
	I	II	III	
May	3.0	3.0	21.0	27.0
June	26.0	18.0	6.0	50.0
July	11.9	27.0	0.3	39.2
August	3.3	11.1	12.3	26.4
Total	-	-	-	142.6

Table 3. The content of substances in the soil in a layer of 0-20 cm and average soil moisture reserves according to the variant of autumn processing (April 29, 2008).

Variant of autumn soil processing	Content of substances				Moisture reserves in the soil layers, mm		
	Nitrate nitrogen, mg kg^{-1}	Phosphorus, mg kg^{-1}	Potassium, mg kg^{-1}	Humus, %	0-20 cm	0-50 cm	0-100 cm
No processing	13.4	190.0	96.0	5.9	59.4	151.1	271.2
BDM-6*4	35.9	185.0	88.0	6.6	49.9	142.2	263.1

Soil moisture

The average water content in the soil during the growing season was 38.0 mm in a layer of 0-20 cm, 96.4 mm in a layer of 0-50 cm and 200.4 m in a meter layer (Tables 4-6). The maximum amount of in a meter soil layer on average over the entire period was observed on the 2 variant of technology (without autumn and pre-sowing soil processing; sowing by DMC-9000, sowing rate 175 kg ha^{-1}) – 210.7 mm. The minimal soil water content in a meter layer on average over the entire period was on the variant 6 of technology (autumn soil processing by BDM-6 × 4; pre-sowing soil processing by Catros; sowing by DMC-9000, sowing rate 175 kg ha^{-1}) – 182.5 mm. So, we can see that the absence of soil processing allows to save at least 28.2 mm of water for plants. At all, there were higher soil moisture on the variants of technology without autumn soil processing (No. 1-4) than on the others (No 5-8). The difference was 2.6 mm in a layer of 0-20 cm, 3.9 mm in a layer of 0-50 cm and 9.5 m in a meter layer of soil. Analyzing the water content in the soil by months of vegetation, it can be noted that it was also not identical. The maximum occurred on 07.21.2008, the minimum - on 01.08.2008. In general, the water content in the soil layers during the growing season was characterized by rather low values of the coefficient of variation. The largest scatter of values was observed in the soil layer 0-20 cm.

Table 4. Average moisture reserves in the soil layer 0-20 cm per vegetation period according to technology variants, mm (2008).

Technology variant number	10/06	22/06	02/07	12/07	Date 21/07	01/08	19/08	mean
1	42.1	44.2	26.3	40.1	62.2	23.7	32.6	38.7
2	44.2	37.8	32.0	35.6	71.1	28.9	28.1	39.7
3	41.5	41.6	32.8	39.4	65.3	33.4	28.7	40.4
4	45.2	33.8	32.9	35.7	63.4	29.2	28.8	38.4
5	43.0	35.1	31.3	32.0	64.4	25.1	30.0	37.3
6	42.4	32.6	28.4	32.6	62.6	20.7	28.8	35.4
7	47.6	33.6	30.6	36.2	66.0	24.3	29.1	38.2
8	43.7	32.1	25.9	40.6	57.9	24.1	27.5	36.0
$\dot{x}$	43.7	36.4	30.0	36.5	64.1	26.2	29.2	38.0
σ	1.8	4.2	2.6	3.1	3.5	3.8	1.5	1.6
± 95%	0.7	1.5	0.9	1.1	1.3	1.3	0.5	0.6
C_v	4.2	11.5	8.8	8.4	5.5	14.4	5.0	4.2

Dynamics of soil moisture consumption shows that soil water balance was negative most of the time (Table 7). The exception was the periods from 10/06 to 22/06 and from 12/07 to 21/07. From the observation periods, the highest soil moisture consumption was obtained on 21/07-01/08 (on average 72.0 mm or 7.2 mm per day), and the maximum increase in soil moisture was 34.7 mm for the previous period 12/07-21/07. It should also be noted that on average about 45% of the total moisture consumption from the soil was observed for the period 29/04-10/06. An average soil moisture consumption during the observation period was, according to technology options, in the range of 100.9 mm (variant 8: autumn soil processing by BDM-6*4; pre-sowing soil processing by BDM-6 × 4; sowing by SZP-3.6A, sowing rate 175 kg ha^{-1}) - 131.9 mm (variant 6: (autumn soil processing by BDM-6*4; pre-sowing soil processing by Catros; sowing by DMC-9000, sowing rate 175 kg ha^{-1}). Moreover, on average, according to two sowing rates, the smallest soil moisture consumption was obtained according to variants 7-8 and 1-2 (102.4 mm and 105.2 mm, respectively). Consumption was higher for variants 3-4 and 5-6 (121.2 mm and 125.0 mm, respectively).

An average soil moisture consumption was 42.5% of spring moisture reserves. In the plots where autumn soil cultivation was not carried out (Variants 1-4), the average water consumption for the vegetation perid was 41.7% of the spring moisture reserves, while in those plots (Variants 5-8) where it was 43.2%, i.e. only 1.5% more. The absence of both autumn and spring tillage led to the consumption of 38.8% moisture from spring soil moisture reserves during the growing season (variants 1-2). In the case when only spring tillage was carried out, this value was 44.7% (variants 3-4), and if both cultivations were carried out - 43.2% (variants 5-8). The difference in the sowing rates practically did not affect the total moisture consumption from the soil, it amounted to 42.2-

42.8% of the spring moisture reserves. The maximum difference in water consumption was found when comparing the equipment used for spring tillage and sowing. So, when using Catros and DMC-9000, respectively (variants 5-6), an average of 47.5% of spring moisture reserves was spent during the growing season, while using Russian-made equipment – KPE-3,8 or BDM-6*4 and SZP-3.6A (variants 7-8), it was 38.9%.

Table 5. Average moisture reserves in the soil layer 0-50 cm per vegetation period according to technology variants, mm (2008).

Technology variant number	10/06	22/06	02/07	12/07	21/07	01/08	19/08	mean
1	117.3	117.3	80.4	97.4	122.9	71.8	78.6	98.0
2	111.9	105.7	94.9	92.7	142.6	81.2	73.4	100.3
3	113.2	117.8	91.1	87.7	129.6	81.9	68.4	98.5
4	110.6	111.0	97.4	87.6	124.3	75.6	67.5	96.3
5	107.7	105.8	86.7	88.2	126.7	72.0	75.1	94.6
6	108.5	103.0	82.9	83.1	119.0	62.9	68.4	89.7
7	115.7	104.4	91.1	99.4	132.9	72.3	76.6	98.9
8	116.0	105.3	82.1	95.7	116.2	73.7	75.5	94.9
$\dot{x}$	112.6	108.8	88.3	91.5	126.8	73.9	72.9	96.4
σ	3.3	5.5	5.9	5.3	7.8	5.6	4.0	3.1
±95%	1.2	2.0	2.1	1.9	2.8	2.0	1.4	1.1
C_v	3.0	5.1	6.6	5.8	6.2	7.6	5.5	3.3

Table 6. Average moisture reserves in the soil layer 0-100 cm per vegetation period according to technology variants, mm (2008).

Technology variant number	10/06	22/06	02/07	12/07	21/07	01/08	19/08	mean
1	236.9	239.4	202.5	201.7	240.3	169.0	167.0	208.1
2	225.7	230.2	216.7	207.7	253.4	176.2	165.1	210.7
3	221.3	244.3	212.8	193.3	232.0	171.7	159.9	205.0
4	190.0	240.7	230.6	194.7	223.8	158.4	140.2	196.9
5	217.5	216.0	194.3	194.3	232.7	156.3	144.9	193.7
6	199.2	219.4	195.6	179.3	212.9	139.7	131.3	182.5
7	221.8	225.8	204.3	214.2	252.6	158.4	159.2	205.2
8	220.1	228.9	193.4	210.6	226.0	168.1	162.2	201.3
$\dot{x}$	216.6	230.6	206.3	199.5	234.2	162.2	153.7	200.4
σ	14.0	9.6	12.2	10.7	13.1	10.8	12.3	8.6
±95%	5.0	3.4	4.3	3.8	4.7	3.9	4.4	3.1
C_v	6.5	4.1	5.9	5.3	5.6	6.7	8.0	4.3

Table 7. Dynamics of soil moisture consumption according to technology variants, mm (2008).

Technology variant number	29/04-10/06	10/06-22/06	22/06-02/07	02/07-12/07	12/07-21/07	21/07-01/08	01/08-19/08	Total
1	-34.3	2.5	-36.9	-0.8	38.6	-71.2	-2.0	-104.2
2	-45.5	4.5	-13.5	-0.9	45.7	-77.2	-11.1	-106.1
3	-49.9	23	-31.5	-19.5	38.7	-60.3	-11.8	-111.3
4	-81.2	50.7	-10.1	-35.9	29.1	-65.4	-18.2	-131.0
5	-45.6	-1.5	-21.7	0	38.4	-76.4	-11.4	-118.2
6	-63.9	20.2	-23.8	-16.3	33.6	-73.2	-8.4	-131.8
7	-41.3	4.0	-21.5	9.9	38.4	-94.2	0.8	-103.9
8	-43.0	8.8	-35.5	17.2	15.4	-57.9	-5.9	-100.9
$\dot{x}$	-50.6	14.0	-24.3	-6.8	34.7	-72.0	-8.5	-113.4
±95%	4.7	5.3	3.1	3.9	2.9	3.6	1.8	3.9

Height of plants

An average height of spring soft wheat plants to the harvest was 88.5 cm (Table 8, Figures 2 and 3). In the plots where autumn soil cultivation was not carried out (variants 1-4), it was 87.3 cm, while in those plots (Variants 5-8) where the height was 89.8, i.e. only 2.5 cm more. The absence of both autumn and spring tillage led to 84.5 cm high spring soft wheat plants (Variants 1-2). In the case when only spring tillage was carried out, this value was 90.0 cm (Variants 3-4), and if both cultivations were carried out – 89.8 cm (Variants 5-8). The difference in the sowing rates affect the height of the plants the same way as a difference in autumn soil processing. It was an average 89.8 cm in the variants with the sowing rate of 175 kg ha^{-1} and 87.3 cm with the 200 kg ha^{-1}. The maximum difference in height of spring soft wheat plants was found when comparing the equipment used for spring tillage and sowing. So, when using Catros and DMC-9000, respectively (Variants 5-6), it was 86.5 cm an average, while using Russian-made equipment – KPE-3,8 or BDM-6*4 and SZP-3.6A (Variants 7-8), it was 93.0 cm (Figures 2 and 3).

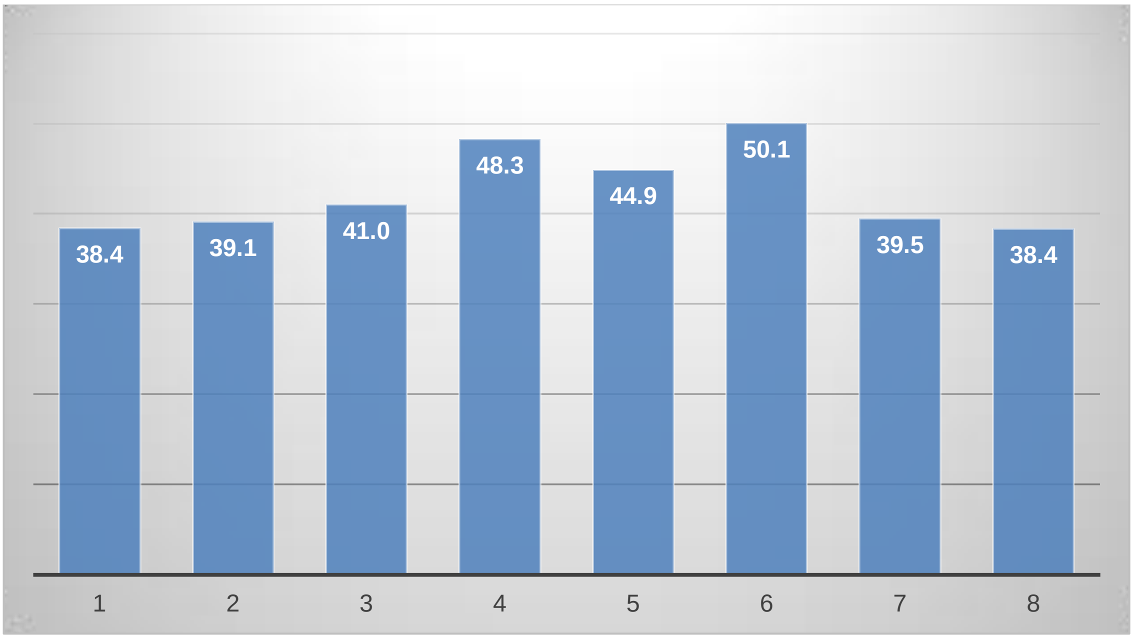

Figure 2. Soil moisture consumption from a meter soil layer in comparison to spring moisture reserves according to technology variants, %.

Table 8. Dynamics of changes in the average height of wheat plants according to technology variants, cm (2008).

Technology variant number	10/06	22/06	02/07	12/07	21/07	01/08	19/08
1	21.8	27.6	31.3	42.7	65.4	67.1	83.0
2	19.3	31.8	33.9	49.0	78.8	79.9	86.0
3	25.5	33.5	41.6	56.3	82.7	83.6	91.0
4	25.1	36.4	45.6	59.1	80.8	82.4	89.0
5	22.6	34.5	40.4	50.6	72.6	75.1	83.0
6	24.0	34.7	44.9	55.5	83.1	83.5	90.0
7	23.3	34.1	41.5	51.0	74.2	80.2	94.0
8	23.2	36.8	42.3	57.1	80.5	83.4	92.0
$\dot{x}$	23.1	33.7	40.2	52.7	77.3	79.4	88.5
σ	1.8	2.7	4.7	5.0	5.7	5.4	3.8
±95%	0.7	1.0	1.7	1.8	2.0	1.9	1.4
C_v	8.0	8.1	11.7	9.5	7.4	6.8	4.3

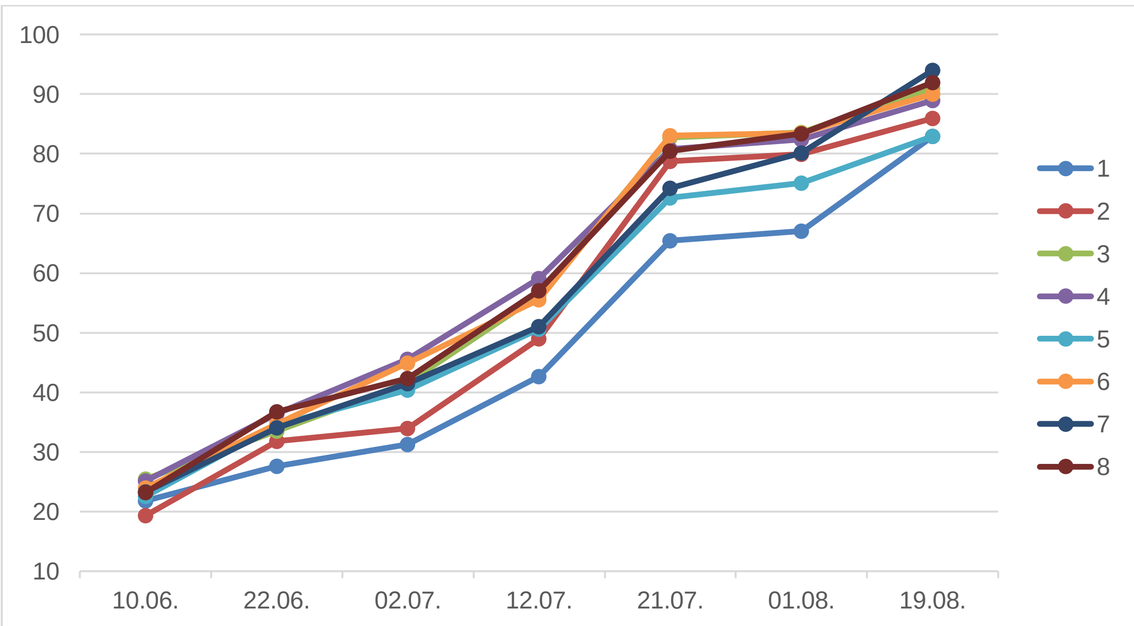

Figure 3. Average height of wheat plants according to technology variants, cm.

Linear equations

As the analysis shows, the moisture reserves in the meter soil layer decreased in direct proportion to the increase in average plant height (except for measurements on July 21, when they had a significant increase in moisture reserves in the soil due to the large amount of precipitation). The obtained communication equations for the studied technology variants are of the form:

Variant 1: W_{0-100}=257.0 - 0.119 × Hp, R=0.92 (1)
Variant 2: W_{0-100}=252.0 - 0.097 × Hp, R=0.98 (2)
Variant 3: W_{0-100}=262.0 - 0.112 × Hp, R=0.94 (3)
Variant 4: W_{0-100}=259.8 - 0.120 × Hp, R=0.78 (4)
Variant 5: W_{0-100}=255.3 - 0.138 × Hp, R=0.96 (5)
Variant 6: W_{0-100}=246.9 - 0.125 × Hp, R=0.95 (6)
Variant 7: W_{0-100}=254.3 - 0.106 × Hp, R=0.95 (7)
Variant 8: W_{0-100}=250.7 - 0.099 × Hp, R=0.98 (8)

That is, an increase in the height of wheat plants for every 100 mm led to a decrease in moisture reserves in the meter layer by an average of 9.7 mm (variant 2) - 13.8 mm (variant 5). A significant relationship was found between the standard deviation of plant height and moisture reserves in the meter soil layer as of June 10 (R=0.72). That is, the less moisture in the meter-long soil layer on June 10 (greater consumption for the first observation period), the more uniform the plants in height.

Conclusion

In this research we discovered that soil water balance under the spring soft wheat was negative most of the time of the vegetation period in the Rebrikhinsky district of the Altai Region, and soil moisture consumption during the observation period depends on the technology options and an average values was in the range from 100.9 to 131.9 mm. An average soil moisture consumption was 42.5% of spring moisture reserves. In the plots where autumn soil cultivation was not carried out (variants 1- 4), the average water consumption for the vegetation period was 41.7% of the spring moisture reserves, while in those plots (variants 5-8) where it was 43.2%, i.e. only 1.5% more.The absence of both autumn and spring tillage led to the consumption of 38.8% moisture from spring soil moisture reserves during the growing season. In the case when only spring tillage was carried out, this value was 44.7% (variants 3-4), and if both cultivations were carried out - 43.2%. The difference in the sowing rates practically did not affect the total moisture consumption from the soil, it amounted to 42.2-42.8% of the spring moisture reserves. The maximum difference in water consumption was found when comparing the equipment used for spring tillage. So, when using Catros and DMC-9000, respectively (variants 5-6), an average of 47.5% of spring moisture reserves was spent during the growing season, while using Russian-made equipment – KPE-3,8 or BDM-6*4 and SZP-3.6A (variants 7-8), it was 38.9%. The moisture reserves in the meter soil layer decreased in direct proportion to the increase in average plant height.

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