WATER AVAILABILITY OF WINTER WHEAT CROPS AND THEIR PRODUCTIVITY IN THE NORTHERN STEPPE OF UKRAINE

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Abstract. The main objective of the research was to develop scientific and methodological bases for the development and adaptation of ecologically-adaptive winter wheat cultivation technologies in the northern Steppe of Ukraine. The studies were conducted from 1986 till 2005. Winter wheat was sown after black fallow and corn for silage three times. The main method of research is the field method. It is proved that in the conditions of the northern Steppe of Ukraine winter wheat crops after black fallow and corn for silage are characterized by almost identical indicators of total water transpiration during vegetation period, which is 3256 and 3293 m^3/ha on average. Winter wheat crops, irrespective of weather conditions, forecrops and sowing dates, consume the greatest amount of moisture in the northern Steppe of Ukraine in the early spring and from the ear stage to the firm ripeness of the grain. On average, the transpiration ratio is 1070 m3/ha in early spring before the booting of plants after black fallow, and after corn for silage it is 1069 m^3/ha, which is 32.9 and 33.1% of the total water transpiration for the whole period. Changing sowing period from August 25 to September 25 reduces water transpiration of winter wheat after black fallow from 3613 to 3303 m^3/ha, and after corn for silage from 3615 to 3303 m^3/ha. In this case, the most significant changes in total water transpiration under the influence of sowing periods are observed in the autumn period. After black fallow, total water transpiration in autumn decreases from 711 to 374 m^3/ha, and after corn for silage it was from 853 to 446 m^3/ha. Sowing winter wheat after non-fallow forecrop corn for silage reduces water efficiency of the plants. The average

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evapotranspiration ratio for the crops after corn for silage was 95.1 m^3/c, and for black fallow – 71.8 m^3/c. After both forecrops, the increase in total transpiration for the entire vegetation period of the plants has a positive effect on grain productivity level of winter wheat. The correlation coefficient between the productivity level and total water transpiration for the entire period of plant growth and development after black fallow is 0.34, and after corn for silage is 0.39. There is a close negative correlation between evapotranspiration and winter wheat productivity, which, when sown after black fallow, is minus 0.87 and, after non-fallow forecrop is minus 0.79. Winter wheat sowing after corn for silage, irrespective of sowing time, is the most dependent on water resources from the time of spring vegetation renewal until the start of booting. Their influence on the formation of the crop, depending on the time of sowing is in the range of 38.56-45.62%. The later sowing time of winter wheat after corn for silage is made, the more sensitive are the crops to water resources during the period. When sowing winter wheat after black fallow, the sensitivity of crops to water resources during spring and summer growing season depends on the sowing time. Sowing on August 25 is the most sensitive to water resources during booting of plants. The crop sown on September 10 is the most sensitive to water resources from the booting stage to firm ripeness, and the crop sown on September 25 is the most sensitive to water resources from the time of spring vegetation renewal until the start of the booting stage.

1. Introduction

Water is one of the most important factors in plant life. Its content in the cells of the vegetative organs is about 85%. It serves not only as the environment for various biochemical reactions that take place in cells, but also for the relationship between plants and the environment [1, p. 99].

Numerous studies show that water balance of plants, including field crops, is extremely variable and depends on weather conditions and agro-technical methods of their cultivation. At the same time, the effect of one or another agricultural technique on the efficiency of water use by plants is largely modified by a large number of natural factors. Therefore, many studies pay particular attention to the regulation of the plants moisture status during the growing season or in general crop rotation [2, p. 165; 3, p. 38; 4, p. 18]. The studies can serve as the basis for the development of new ecologically-adaptive technologies of growing crops or for the adjustment of agro-technology in the process of plant vegetation in the conditions of changing environment.

The transpiration ratio is often used to assess the efficiency of water transpiration from plants. However, the results of a number of studies show that this ratio is extremely variable, not only from climatic and weather conditions, but also from almost all agro-technical techniques that are part of the cultivation technology [5, p. 146]. Therefore, the total water transpiration ratio is suggested to use in practice, which includes not only the transpiration of water from plants, but also physical evaporation from the soil surface. At the same time, it is suggested to assess the efficiency of water use by the indicator of evapotranspiration [6, p. 7].

The main objective of the research was to develop scientific and methodological bases for the development and adaptation of ecologically-adaptive winter wheat cultivation technologies in the northern Steppe of Ukraine. Winter wheat was sown in three periods after black fallow and corn for silage.

2. Transpiration of water by winter wheat crops during vegetation

The results of our research clearly show obvious consistency of plant consumption by crops of winter wheat under different weather conditions in the area of the northern Steppe of Ukraine. Regardless of the forecrops, the largest total plant consumption in winter wheat crops is observed in the early spring growing season and from the ear stage to the firm ripeness of grains. The lowest plant consumption is observed in the autumn growing season, the average plant consumption is from the beginning of the booting stage to the ear stage (Table 1). On average, during the years of research, the total plant consumption of winter wheat crops after black fallow from the time of spring vegetation to the beginning of booting of plants amounted to 1070 m^3/ha with fluctuations from 691 to 1285 m^3/ha in different years. It was 1190 m^3/ha during the ear stage to firm ripeness. However, the variation of indicators during this period was much larger than in the previously indicated period and ranged from 148 to 2447 m^3/ha. The large total plant consumption in early spring is mainly due to the physical evaporation of water from the soil surface.

Table 1

Indicators of plant consumption by winter wheat crops at one meter layer of soil after different forecrops, m³/ha (sowing on September 10)

	Inter-stage periods				
	sowing period – stop of vegetation	**vegetation renewal – beginning of booting stage**	**beginning of booting stage – ear stage**	**ear stage – firm ripeness**	**for the whole period**
Black fallow as forecrop					
average	366	1070	630	1190	3256
variation	128 – 661	691–1285	352–925	148–2447	2361-4694
Corn for silage as forecrop					
average	495	1069	600	1128	3293
variation	108 – 1015	613-1464	296-1080	151-2118	2804-4503

The highest amount of productive moisture in a meter layer of soil in winter wheat crops in the area of the northern Steppe of Ukraine is observed at the time of spring renewal of vegetation [7, p. 79], but at the time the accumulation of aboveground mass of plants is insignificant before booting stage in comparison with the booting stage or the grain formation period. At the same time, strongly developed above-ground mass of plants can cause high plant consumption by crops from the time of the ear stage to firm ripeness of the grains. A strongly developed above-ground mass of plants is characterized by high intensity of transpiration and high evaporation of water from the soil surface. Identification of moisture content in a meter layer of soil has repeatedly convinced that during favourable years, when dense crops with more than 750 pc/m² spikes were formed during the ear stage, despite heavy rainfalls, productive moisture stocks sharply decreased over the days. The bulk of the water was pumped by the plants in the process of transpiration, since physical evaporation of water from the soil in dense crops is much smaller than in thin crops.

The total transpiration during autumn period is much lower and averages 366 m³/ha after black fallow, with changes in the range of 128-661 m³ in the years with different weather conditions.

It is established that the average water transpiration from winter wheat crops after black fallow during the whole growing season averages 3256 m³/ha.

In general, there is a direct correlation between water resources and total water transpiration. In the years with heavy rainfalls, the total water transpiration of winter wheat plants increases, and in the drier years, on the contrary, decreases.

When sowing winter wheat after a non-fallow forecrop, the above-mentioned consistency is generally preserved. The highest water losses are observed in early spring and from the ear stage to firm ripeness. The lowest water losses take place during autumn growth period of winter wheat. In addition, the indicators of total water transpiration by crops after corn for silage during spring-summer growing season, as well as for the whole growing season, are close to those of black fallow. For example, the total water transpiration of winter wheat crops for the whole period after black fallow averaged 3256 m^3/ha, and after corn for silage – 3293 m^3/ha. In early spring period the figures were 1070 and 1079 m^3/ha, respectively. In this case, the data in Table 1 show that in one year, i.e. in the same weather conditions, the indicators of total water transpiration in spring-summer period of vegetation of plants after black fallow and corn for silage are close. This suggests that the total water transpiration of winter wheat crops from a meter of soil in spring-summer period of plant growth and development under the same weather conditions is almost independent of its forecrops. However, the accumulation of the total amount of dry matter by winter wheat plants in the end is not the same, and therefore the efficiency of water use after the studied forecrops is different.

The research revealed some differences between winter wheat crops after different forecrops according to the total water transpiration during autumn growing season. In most years, it was higher compared to black fallow and non-fallow forecrops and averaged 495 and 366 m^3/ha, respectively. In our opinion, higher water transpiration in autumn after corn for the silage was due to its physical evaporation and penetration into the deeper layers of soil. In none of the years, the above-ground mass of winter wheat plants at the time of cessation of autumn vegetation after corn for silage was greater than that of black fallow. Higher water losses of winter wheat crops after corn for silage are caused by the condition of the surface of the field, in the state of loosening of soil and the presence of plant residues in the upper layer of soil.

The calculations of the structure of total water transpiration by winter wheat crops in relative terms confirm the existence of the above-mentioned consistencies. After both forecrops, the largest water losses of winter wheat crops are observed in two periods – early spring and from the ear stage to firm ripeness of grains. After black fallow, on average, over the years of the studies, these figures account for 32.9% and 36.5% of the total amount of water transpired, and after corn for silage – 33.1% and 32.4% (Table 2).

In autumn, total water transpiration of winter wheat crops after black fallow averages 11.3% of the total, varying from 3.9 to 23.4% in different weather conditions. When sowing winter wheat after corn for silage, the proportion of water transpiration in autumn period is slightly higher than that after black fallow and equals 15.0%. This consistency has been observed throughout the years of the study, regardless of weather conditions that are too variable in the area of the northern Steppe of Ukraine.

Table 2

Effect of forecrops on the structure of water transpiration at one meter layer of soil with winter wheat crops, % of total (sowing time is September 10)

	Inter-stage periods			
	sowing period – stop of vegetation	**vegetation renewal – beginning of booting stage**	**beginning of booting stage – ear stage**	**ear stage – firm ripeness**
Black fallow as forecrop				
Average	11,3	32,9	19,3	36,5
Variation	3,9-23,4	24,5-40,4	7,7-29,1	6,3-56,8
Corn for silage as forecrop				
Average	15,0	33,1	19,5	32,4
Variation	3,9-31,2	25,8-41,9	4,6-38,5	6,0-58,8

Changing sowing time of winter wheat significantly affects the conditions of growth and development of winter wheat plants during autumn growing season [8, p. 61]. The postponement of sowing at a later date primarily shortens the period of autumn vegetation, and the development of plants occurs at lower air temperatures and reduced duration of daylight. The consequence of such conditions is a decrease in tilling capacity of plants at the time of the cease of autumn vegetation and, accordingly, the density of the stem of winter wheat crops [9, p. 50].

Table 3 shows that the shift in the sowing period from August 25 to September 25 causes identical changes in the total water transpiration of winter wheat crops after both of the studied forecrops. It is clearly seen that the later the sowing of winter wheat is, the smaller the indices of water loss in autumn period and increase from the beginning of booting stage to the ear stage of plants. Thus, in the variants of the experiment after black fallow with sowing on September 25, water loss averaged 374 m^3/ha, and with sowing on August 25 it was 711 m^3/ha, which is almost twice as much. When sowing winter wheat on non-fallow forecrop, the sowing shift from August 25 to September 25 reduced the total water transpiration from 853 to 446 m^3/ha.

Table 3

Indicators of water transpiration by crops of winter wheat at one meter layer of soil depending on the sowing time (average for 1992-2004)

sowing time	Inter-stage periods				
	sowing period – stop of vegetation	vegetation renewal – beginning of booting stage	beginning of booting stage – ear stage	ear stage – firm ripeness	For the whole period
Black fallow as forecrop					
25.08	711/19,7	943/26,1	746/20,7	1212/33,6	3613/100
10.09	366/10,8	1004/29,7	772/22,8	1240/36,7	3382/100
25.09	374/11,3	981/29,7	772/23,4	1177/35,2	3303/100
Corn for silage as forecrop					
25.08	853/23,6	892/24,7	708/19,6	1162/32,1	3615/100
10.09	495/14,7	915/27,3	755/22,5	1191/35,5	3357/100
25.09	446/13,5	903/27,3	799/24,2	1155/35,0	3303/100

– In the numerator, the indicators of water transpiration are in m3/ha
– In the denominator, the share of water transpiration of the total amount for the entire growing season, %

In the sowing variants on September 10, both after black fallow and after corn for silage, the total water losses during the period from the renewal of vegetation to the beginning of the booting stage and from the ear stage to firm ripeness were higher than the sowing variants carried out on

August 25 and September 25. Thus, in case of sowing on September 10, after black fallow, the total water transpiration during the early spring period was 1004 m^3/ha against 943 m^3/ha when the crops were sown on August 25, and 981 m^3/ha when sowing tine was September 25.

It is well known that the transpiration of water through the leaves does not belong to synthetic processes that take place in plant cells. However, it is an essential part of the plant's biological and physiological function, which ensures the normal course of all biochemical reactions in plants. Therefore, the transpiration productivity ratio is widely used in both scientific and industrial practices. It correlates the amount of water transpired by the plant with the amount of solids that have been synthesized during that time. The performance of transpiration can be judged on the efficiency of water use by plants. But, like the transpiration coefficient, transpiration performance in the same plant species exhibits excessively high variability under the influence of climatic, weather, and agro-technical factors. In agriculture, the determination of transpiration coefficient and transpiration performance has considerable complexity. This is due to the inability to identify the volumes of water that were actually used by the plants from the soil.

Evapotranspiration indicators, which take into account all water transpiration by crops for crop formation, including physical evaporation from soil surface, as shown in Table 4, fairly objectively assess the efficiency of water use by plants. The process of physical evaporation of water from the surface of the soil at first glance has nothing to do with the formation of the crop. However, if winter wheat crops with high stem density have the same amount of rainfalls, the rate of water evaporation from the soil surface will be less than in thin crops, and therefore the amount of water that will be absorbed by the plants in such crops will be greater. Accordingly, increasing the amount of available water for plants will certainly have a positive impact on improving crop productivity.

It is established that with almost equal amount of water resources, the efficiency of their use by winter wheat crops after black fallow is much higher compared to its non-fallow forecrops. On average, during the years of research, the evapotranspiration coefficient after black fallow was 71.8 m^3/c, and after corn for silage – 95.1 m^3/c. During nine years out of eleven, evapotranspiration coefficients of winter wheat crops after black fallow were higher than after corn for silage. In severely dry and unfavourable years in winter, the evapotranspiration coefficients after corn for silage were several times higher than after black fallow crops. So, in 1996, with only 58.2 mm of rainfalls during the entire spring and summer growing season, the evapotranspiration coefficients of crops after corn for silage amounted to 201.5 m^3/c against 84.0 m^3/c after black fallow. In the conditions of the year 2000, under extremely unfavourable conditions in winter in combination with arid conditions of spring-summer vegetation (110 mm of rainfall), the evapotranspiration coefficients of crops after corn for silage were three times higher than after black fallow and were 455,2 and 152,7 m^3/c, respectively.

Table 4

Evapotranspiration coefficients of winter wheat crops after different forecrops (sowing on September 10)

Years	Black fallow			Corn for silage		
	Total water transpiration, m^3/ha	Productivity, c/ha	Evapotranspiration coefficient, m^3/c	Total water transpiration, m^3/ha	Productivity, c/ha	Evapotranspiration Evapotranspiration coefficient, m^3/c
1993	3263	52,1	62,6	3579	58,0	61,7
1994	2819	67,2	41,9	3011	54,8	54,9
1995	3184	49,4	64,5	2804	40,6	69,1
1996	2361	28,1	84,0	2519	12,5	201,5
1997	4694	40,1	117,1	4503	30,0	150,1
1998	3212	65,8	48,8	3339	41,7	80,1
1999	2552	22,9	111,4	2563	18,3	140,1
2000	2962	19,4	152,7	2777	6,1	455,2
2001	3777	68,0	55,5	3578	43,1	83,0
2002	2998	43,7	68,6	2668	23,5	113,5
2004	3554	61,8	57,5	3106	59,9	51,9
Average	3382	47,1	71,8	3357	35,3	95,1
Correlation coefficient	0,34			0,39		
		– 0,87			– 0,79	

All adverse factors that impair the conditions of plant growth and development lead to the reduction of the efficiency of water consumption by winter wheat crops. The evidence of this is that the lower the productivity of winter wheat crops, the higher the evapotranspiration coefficients. There is a close inverse relationship between the grain productivity and evapotranspiration coefficients, which is confirmed by the correlation coefficient calculations. If sowing after black fallow, it is minus 0.87, and if sowing after corn for silage, it is minus 0.79. The relationship between total water transpiration and winter wheat crop productivity is positive but much smaller. It is 0.34 after black fallow and 0.39 after corn for silage.

Sowing periods have significant effect on the productivity of winter wheat, and therefore the efficiency of water resources use with different crops is different (Table 5).

Table 5

Evapotranspiration coefficients of winter wheat crops at different sowing periods, (average for 1993-2004)

Year	Black fallow			Corn for silage		
	Total transpiration, m^3/ha	Productivity, c/ha	Evapotranspiration coefficient, m^3/c	Total transpiration, m^3/ha	Productivity, c/ha	Evapotranspiration coefficient, m^3/c
25.VIII	3613	38,1	94,8	3615	29,7	121,7
10.IX	3382	47,1	71,8	3357	35,3	95,1
25.IX	3303	40,5	81,6	3303	36,7	90,0

When sowing winter wheat after black fallow, as can be seen from the data in Table 5, the shift of sowing time from August 25 to September 25 causes a decrease in the amount of water resources from 3613 to 3303 m^3/ha. At the same time, the highest grain productivity of winter wheat was formed at sowing on September 10 and amounted to 47.1 c/ha, which is 9.0 c/ha more than at sowing on August 25 and 6.6 c/ha more than the sowing variants on 25 September. Evapotranspiration coefficient according to the obtained data amounted to 71.8, 94.8 and 81.6 m^3/c, respectively. After corn for silage, changing the sowing time in these terms reduced the evapotranspiration coefficients from 12.2 in sowing variants of 25 August to 9.0 m^3/c of winter wheat in sowing variants on 25 September. On average, in the years of non-fallow forecrops, winter wheat sown on September 25 had most effective water consumption.

3. Winter wheat productivity depending on water availability during spring and summer

The spring-summer growing season is extremely important for the formation of winter wheat crop. During this period the potential of crops planted in autumn and the processes that will positively affect productivity are realized. In such cases, the losses caused by the negative factors of autumn growing season are to some extent compensated.

In the northern Steppe of Ukraine, the moisture content of crops in spring and summer, together with the air temperature, are the determining factors for the growth and development of winter wheat. Research results show that during the whole growing season of winter wheat crops, their highest moisture content is reached in early spring. Due to winter rains, soil moisture is replenished, but differences among forecrops still remain. On average, over the years of research, the content of productive moisture at a meter layer of soil under winter wheat after black fallow was 164.4 mm against 156.3 mm in crops after corn for silage. However, significant differences among the crops of different sowing periods within one forecrop were not observed.

Starting from the time of spring vegetation renewal, the productive moisture reserves in a meter layer of soil under winter wheat crops, regardless of their forecrops, are constantly reduced and are minimal at firm ripeness stage. Rains that occur during the period of active growth do not change the specified consistency. Even in the years with heavy rainfalls, the increased soil moisture persists for a short period of time. This is especially evident with the significant development of aboveground vegetative mass of plants. Such plants, on the background of high air temperature, intensively transpired and the amount of available moisture in a meter layer of soil rapidly decreases. This is also facilitated by the intense physical evaporation of water from the soil surface at high air temperatures.

In winter wheat, sown on September 17, both after black fallow and after corn for silage (at all stages of plant development during spring-summer period), the moisture content in a meter layer was higher than in the plants sown on August 25 and September 25. Thus, the reserves of productive moisture in the variant sown on September 17 after black fallow, from the time of renewal of spring vegetation to the ear stage varied from 167.1 mm to 79.5 mm, respectively. And in the variant sown on September 17 the productive moisture varied from 162.6 mm to 77.2 mm. In some years of study, the difference between variants with different sowing periods was significantly greater than the average for the years of study (Table 7). Winter wheat sown on August 25 and September 25, unproductive moisture losses could be caused by excessively high evaporation of water from the soil surface.

Table 7

Indicators of content of productive moisture in a meter layer of soil during growing season of winter wheat crops depending on the sowing time, mm (average for 1993-2005)

Sowing time	**Indicator**	**Stages of crops development**			
		at the time of spring vegetation renewal	**at the beginning of booting stage**	**at the ear stage**	**at the firm ripeness stage**
1	**3**	**3**	**4**	**5**	**6**
Black fallow					
25.08	average	163,4	106,4	76,5	63,9
	variation	124,2 – 196,8	91,9 – 142,2	27,8 – 187	32,4 – 128
10.09	average	167,1	107,4	79,5	62,1
	variation	133,4 – 210,0	71,7 – 146,2	29,7 – 189,0	35,1 – 124,0
25.09	average	162,6	106,3	77,2	63,5
	variation	128,4 – 199,8	72,5 – 136,9	22,3 – 188,0	23,1 – 127,0
Corn for silage					
25.08	average	154,3	97,9	66,5	57,4
	variation	125,0 – 180,7	59,8 – 125,8	20,1 – 115,5	26,0 – 108,3
10.09	average	158,4	101	69,5	54,8
	variation	137,7 – 190,4	60,4 – 139,1	22,7 – 173,9	17,9 – 106,2
25.09	average	156,2	100,3	69,4	56,7
	variation	122,5 – 187,4	60,2 – 138,8	23,3 – 169,9	28,2 – 107,0

At the same time, as it can be seen from the data in Table 7 after such forecrops at the firm ripeness stage on average during the years of research, such dependence is not observed. Higher moisture reserves in a meter layer of soil are characteristic of sowing time which was carried out on August 25 and September 25. On average, during the years of research in the sowing variants on August 25 and September 25, after corn for silage, the moisture content in a meter layer of soil was 57.4 and 56.7 mm, respectively, against 54.8 mm of the variant sown on September 17.

Weather conditions of the spring-summer growing season of winter wheat crops in the northern Steppe of Ukraine are too variable both in the amount of rainfalls and the air temperature. These factors are crucial to soil moisture accumulation as a major source of aquatic nutrition for plants. Plant consumption of winter wheat crops in spring and summer depends to a large extent on the state of their development. More powerful crops require more water than less developed ones.

The regression analysis revealed that there is a fairly complex relationship between productivity levels of multiple-aged winter wheat crops and the reserves of productive soil moisture during the main stages of plant growth and development. The reserves of productive moisture in soil have different effects on grain productivity of different crops of winter wheat after different forecrops (Table 8).

After black fallow, the reserves of productive moisture in the soil at the time of spring vegetation renewal and the beginning of the booting stage have the greatest influence on productivity level of varied crops of winter wheat. It is in the range of 39.7-55.2% and 24.8-42.1% respectively. When sowing winter wheat after corn for silage, the most important for the formation of the grain productivity of winter wheat are moisture reserves in the soil at the beginning of spring vegetation renewal and during the ear stage of the plants. According to the results of the regression analysis, the share of influence of moisture reserves in a meter layer of soil on the productivity level of such crops of winter wheat is 49.7-66.4, and 22.3-39.9%, respectively.

At the same time, sowing times within one forecrop can significantly change the dependence of productivity of winter wheat crops on the reserves of productive moisture in the soil at different stages of their development. So, for crops sown on August 25 after black fallow, the main influence on the productivity has soil

Table 8

Dependence of productivity level of multiple-aged crops of winter wheat on the reserves of productive moisture in the soil, % (average for 1993-2004)

Forecrop	Stage of crops development	Sowing time		
		25.VIII	10.IX	25.IX
Black fallow	Renewal of spring vegetation	39,7	55,2	36,3
	beginning of booting stage	42,1	24,8	33,8
	ear stage	9,3	18,7	22,8
	remaining factors	8,9	1,3	7,1
Corn for silage	Renewal of spring vegetation	49,7	51,3	66,4
	beginning of booting stage	9,8	9,8	10,6
	ear stage	39,9	34,8	22,3
	remaining factors	0,6	0,3	0,7

moisture reserves at the time of spring vegetation renewal and at the beginning of the booting stage. The share of the influence of soil moisture reserves at the ear stage does not exceed 10%. Sowing on September 10 is also most dependent on soil moisture at the time of spring vegetation (55.2%) and early booting (24.8%), but the share of soil moisture at the ear stage reaches 18.7%. For sowing on September 25, the importance of productive soil moisture at the ear stage (22.8%) increases, and at the same time plants' dependence on moisture reserves at the beginning of spring vegetation is reduced.

It should also be noted that winter wheat productivity, regardless of the sowing period after corn for silage forecrop, unlike sowing after black fallow, is more dependent on moisture content of the soil during the ear stage. On average, during the years of research, the influence of soil moisture reserves at the ear stage on the productivity of crops after black fallow varies from 9.3 to 22.8%, and after corn for silage it varied from 22.3 to 85.8%.

During spring-summer period of winter wheat, dry matter accumulates through crops. At the beginning of booting, their weight intensely increases to the ear stage. Later, the rate of accumulation of dry matter by plants decreases. Water requirements for plants during the booting stage are greatest, which is why this period is considered critical. Water scarcity primarily causes a decrease in the aboveground weight of plants, which in turn leads to a sharp decrease in crop productivity.

The water resources available to winter wheat plants during spring and summer growing season have a huge impact on winter wheat crop production process. But according to the results of the research, they are extremely variable in different years, and therefore winter wheat crop grows in spring under different conditions of wet crop provision, starting from severely arid and ending with sufficient wet supply. The data in Table 9 show that, in the spring and summer, water resources for winter wheat crops average 348.4 mm. They are slightly higher for crops sown after black fallow (358.1 mm) and smaller for crops on non-fallow forecrop (336.7 mm). At the same time for crops on black fallow they can vary from 214,3 to 540,3 mm, and after corn for silage – 203,2-438,0 mm.

The calculations of water resources in separate inter-stage periods of crop vegetation showed that the best conditions for water supply of winter wheat crops are created in the period from the time of spring vegetation renewal to the beginning of plant booting. On average, over the years of research, they are 204.3 mm for the crops after black fallow, and for the crops after corn for silage (190.1 against 154.1 and 143.9 mm, respectively), in the period from the beginning of booting to the ear stage.

The above data indicate that the greatest variability of water resources for winter wheat crops during spring and summer vegetation is characteristic of the period from the ear stage to firm ripeness of the grain. The least variability occurs from spring vegetation renewal to the beginning of booting stage. The variation of water resources during the period from the ear stage to the firm ripeness for the plants sown after black fallow is 58.1-368.7 mm/ha, and after corn for silage it is 34.0-342.5 mm/ha against 164.4-237,5 mm and 152.5-233.8 mm/ha respectively from the beginning of spring vegetation to booting of plants.

The sowing time does not significantly alter water resources for winter wheat sown after black fallow and after corn for silage. Thus, on average during the years of research water resources for winter wheat crops after black fallow for the whole spring-summer period depending on sowing periods make in the range of 354,1-363,7 mm/ha, and for crops sown after corn for silage is 333,7-341.4 mm/ha.

The main elements of the structure of winter wheat crop are formed during spring and summer growing season. Among them, the density of the productive stem, the number of grains per a spike and the weight of grains

Table 9

Water resources of winter wheat crops during spring and summer vegetation, mm/ha (average for 1993-2005)

	Stages			
	Vegetation renewal – beginning of booting	**Beginning of booting – ear stage**	**Ear stage – firm ripeness**	**For the whole period**
Black fallow				
Average	204,3	154,1	184,1	358,1
Variations in years	146,4 – 237,5	83,0 – 265,2	58,1 – 368,7	214,3 – 540,3
Corn for silage				
Average	143,9	172,9	338,7	143,9
Variations in years	73,7 – 278,8	34,0 – 342,5	203,2 – 438,0	73,7 – 278,8

per a spike are of great importance. Due to the fact that the formation of the aforementioned elements of the structure of the crop occurs consistently in different periods of growth and development of winter wheat plants, it is quite often observed that the achievement of the maximum productivity level is possible at different levels of their development.

The reasons for the variability of winter wheat agrocenoses according to the indicators of basic elements of the crop structure are weather conditions during the vegetation of plants and, particularly, the level of their moisture supply. The results of the regression analysis convincingly show that productivity of winter wheat crops after corn for silage depends more on the amount of water resources from the time of spring vegetation to the beginning of booting. At the same time, when winter wheat is grown after black fallow, the sowing time (Table 10) has a significant effect on the sensitivity of crops to water resources during different phases of plant development during spring vegetation.

The data in Table 10 show that the impact of water resources from the time of spring vegetation to the beginning of booting of plants on productivity level of wheat after corn for silage, depends on the sowing period and it is 38.56-45.62%, whereas the impact of water resources in the period from the ear stage to firm ripeness is 13,58-16,12%. Crops of winter wheat after corn for silage are the least dependent on water resources during the period from the ear stage to the firm ripeness of plants. In addition, the

Table 10

Influence of water resources during spring-summer period on the formation of winter wheat crops, % (1993-2004)

Forecrop	Stages	Sowing time		
		25.VIII	10.IX	25.IX
Black fallow	renewal of spring vegetation – beginning of booting	21,71	14,82	26,91
	beginning of booting – ear stage	32,79	11,01	22,29
	ear stage – firm ripeness	27,25	27,44	22,38
	remaining factors	18,25	46,73	28,42
Corn for silage	renewal of spring vegetation – beginning of booting	38,56	41,95	45,62
	beginning of booting – ear stage	18,98	13,71	28,02
	ear stage – firm ripeness	15,12	13,58	16,12
	remaining factors	27,34	30,76	10,24

later the sowing of winter wheat after corn for silage is made, the greater dependence of such crops on water resources in early spring.

Similar consistency is typical of winter wheat sown on September 25. The influence of water resources in the period from the ear stage to the firm ripeness of the plants on the formation of the crop, according to the results of regression analysis is 26.91%. However, productivity of these crops is also largely conditioned by water resources from the beginning of the booting to the ear stage of plants and from the ear stage to their firm ripeness. Their impact on productivity level is 22.29% and 22.38% respectively. Early winter wheat crops sown after black fallow on August 25, which during autumn growing season form a powerful above-ground mass, are sensitive to water resources from the beginning of the booting to the ear stage (32.79%) and from the ear stage to the firm ripeness (27,25%).

4. Conclusions

Based on the above-mentioned material, we can make the following conclusions:

– in the conditions of the northern Steppe of Ukraine, winter wheat crops after black fallow and corn for silage are characterized by almost identical indices of total water loss during the vegetation period of plants, which average 3256 and 3293 m3/ha, respectively. The difference between the total water loss in winter wheat crops after these forecrops, depending on weather conditions, may be in the range of 4.0-11.9%;

– winter wheat crops, irrespective of weather conditions, forecrops and sowing times, consume the greatest amount of moisture in the Northern Steppe of Ukraine in early spring and from the ear stage until the grain is firm. On average, in early spring, water transpiration before booting of plants after black fallow is 1070 m^3/ha, and after corn for silage – 1069 m^3/ha, which is 32.9 and 33.1% of the total water transpiration for the whole period. During the period from the ear stage to the firm ripeness of the grain, the total water transpiration by crops is respectively 1190 and 1128 m^3/ha, which is 36.5 and 32.4% of the total;

– the shift of winter wheat sowing time from August 25 to September 25 reduces water transpiration of winter wheat after black fallow from 3613 to 3303 m^3/ha, and after corn for silage from 3615 to 3303 m^3/ha. However, the most significant changes in total water transpiration are observed in autumn. According to its forecrops, black fallow, total water transpiration in autumn decreases from 711 to 374 m^3/ha, and after corn for silage from 853 to 446 m^3/ha;

– sowing winter wheat after a non-fallow forecrop corn for silage reduces water efficiency of the plants. The average evapotranspiration ratio for sowing crops after corn was 95.1 m^3/c, and after black fallow – 71.8 m^3/c of grains. After both forecrops, the increase in total water transpiration for the entire vegetation period of the plants has a positive effect on grain productivity level of winter wheat. The correlation coefficient between the productivity level and the total water transpiration for the entire period of plant growth and development after black fallow is 0.34, and after corn for silage, it is 0.39. There is a close negative correlation between evapotranspiration and winter wheat productivity, which is minus 0.87 when sown after black fallow, and it is minus 0.79 after the non-fallow forecrop;

– winter wheat sowing after corn for silage, regardless of sowing time, is the most dependent on water resources from the time of spring vegetation renewal until the start of booting. Their influence on the formation of the crop, depending on the time of sowing is in the range of 38.56-45.62%. The later the sowing of winter wheat after corn for silage is made, the more sensitive the crops to water resources are in the period from the time of the renewal of spring vegetation to the ear stage;

– when sowing winter wheat after black fallow, the sensitivity of crops to water resources during spring and summer growing season depends on the sowing time. The crops sown on August 25 are most sensitive to water resources during booting of plants. The crops sown on September 10 are sensitive to water resources from the booting stage to firm ripeness of the crop, and the crops sown on September 25 are sensitive to water resources from the time of spring vegetation renewal until the start of booting of plants. The impact of the aforementioned water resources on productivity of different crops is 32.79; 27.44% and 26.91%;

– according to the regression analysis, the productivity of winter wheat after black fallow depends to a large extent on the content of productive moisture in the soil at the time of spring vegetation renewal and at the beginning of booting, and is respectively 39.7 and 42.1% for sowing on August 25; 55,2 and 24.8% – for sowing on September 10, and 36.3 and 33.8% – for sowing on September 25. The productivity of winter wheat after corn for silage is most influenced by the productive moisture content of the soil at the time of spring vegetation renewal and, depending on the sowing period, ranges from 49.7 to 66.4%, and at the ear stage of plants it ranges from 22.3 to 39, 9%. The shift of sowing dates from August 25 to September 25 increases the dependence of crops on the content of productive moisture in the soil at the time of spring vegetation renewal and reduces the impact of productive moisture in the soil at the booting stage.

References:

1. Musiienko M.M. (2005). *Fiziolohiia Roslyn* [Plant Physiology]. Kyiv: Lybid. (in Ukrainian)

2. Yermolaiev M.M., Shylina L.I., Litvinov D.V. (2002). Vodnyi rezhym chornozemu typovoho v korotkorotatsiinykh zernovykh sivozminakh [Water system of typical chernozem in short rotational grain rotations]. *Zbirnyk naukovykh prats NNTs «Instytut zemlerobstva UAAN,* pp. 161–166. (in Ukrainian)

3. Litvinov D.V. (2007). Dynamika produktyvnoi volohy v grunti za vyroshchuvannia zernovykh kolosovykh kultur [Dynamics of productive moisture in soil for growing cereals]. *Zbirnyk naukovykh prats NNTs «Instytut zemlerobstva UAAN»,* pp. 34–38. (in Ukrainian)

4. Litvinov D.V. (2015). Formuvannia vodnoho rezhymu gruntu v systemi korotkorotatsiinykh sivozmin [Formation of soil water system in the system of short rotational crop rotations]. *Visnyk ahrarnoi nauky,* pp. 13–18. (in Ukrainian)

5. Pastukh N.R. (2014). Vplyv dobryv ta obrobitku chornozemu typovoho na transpiratsiinyi koefitsiient pshenytsi ozymoi v umovakh Livoberezhnoho Lisostepu [Influence of fertilizers and typical black soil cultivation on the transpiration coefficient of winter wheat in the conditions of the Left Bank Forest Steppe]. *Naukovi pratsi instytutu bioenerhetychnykh kultur i tsukrovykh buriakiv,* pp. 144–147. (in Ukrainian)

6. Bondarenko V.Y., Nesterets V.H. (1978). Zymostoikost, vodopotreblenye y produktyvnost raznovozrastnykh rastenyi ozymoi pshenytsy [Winter hardiness, water consumption and productivity of winter wheat varieties]. *Doklady VASKhNYL,* 9, pp. 5–8. (in Russian)

7. Mostipan M.I. (2017). Volohozabezpechenist posiviv ozymoi pshenytsi u vesniano-litnii period vehetatsii ta yikh vrozhainist v pivnichnomu Stepu Ukrainy [Moisture availability of winter wheat crops during spring and summer growing season and their yield in the northern steppe of Ukraine]. *Visnyk Stepu,* 14, pp. 77–82. (in Ukrainian)

8. Mostipan M.I., Savranchuk V.V., Liman P.B. (2003). Formuvannia urozhainosti ozymoi pshenytsi pry riznykh normakh vysivu zalezhno vid strokiv sivby v pivnichnomu Stepu Ukrainy [Formation of winter wheat productivity at different seeding rates depending on sowing time in the northern Steppe of Ukraine]. *Zbirnyk naukovykh prats UDAU,* 57, pp. 57–63. (in Ukrainian)

9. Mostipan M.I., Savranchuk V.V., Liman P.B. (2004). Dynamika hustoty roslyn novykh sortiv ozymoi pshenytsi protiahom vehetatsiinoho periodu zalezhno vid strokiv sivby u pivnichnomu Stepu Ukrainy [Dynamics of plant density of new winter wheat varieties during growing season depending on sowing time in the northern Steppe of Ukraine]. *Zbirnyk naukovykh prats UDAU,* 58, pp. 48–56. (in Ukrainian)