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Productivity of winter wheat in the northern Steppe of Ukraine depending on weather conditions in the early spring period

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Abstract. The objective of the research was to develop scientific and methodological bases for adapting the technology of growing winter wheat depending on weather conditions in early spring. Winter wheat was grown at different sowing dates. It is established that the reserves of productive moisture in the soil at the time of renewal of spring vegetation are crucial for the formation of winter wheat harvest. After worse forecrop, the impact of moisture on productivity reaches 49.7–66.4%. The later the renewal of spring vegetation of winter wheat is, the lower the productivity of the crops. The shorter the period from the date of transition of the average daily air temperature above 0 °C to the beginning of active vegetation of plants is, the higher the productivity of winter wheat crops. Therefore, depending on weather conditions of early spring period and the time of renewal of spring vegetation of plants, it is necessary to adjust the technology of growing winter wheat during the spring-summer period.

Key words: winter wheat, weather conditions, sowing dates, timing of vegetation renewal, yield, protein.

INTRODUCTION

The most difficult task in the cultivation of field crops is successful adaptation of the already developed agricultural technologies in accordance with specific agro-climatic conditions. In general, the climate of the northern Steppe of Ukraine is favourable for growing most field plants, including winter wheat (Bazalii et al., 2014; Domaratskiy et al., 2017). It ranks second among cereals in terms of sown area. Most high-productive maize ranks first (Domaratskiy et al., 2017).

Winter wheat plants have the longest growing season among annual field crops. This fact has both its advantages and disadvantages compared to other crops. A long growing season allows managing the production process of crops more effectively. Adverse effects caused by unfavourable weather conditions can, to some extent, be successfully compensated in subsequent periods of plant growth and development.

Active plant growth occurs at all times of the year except winter. During the growing season in the northern Steppe of Ukraine there can be extremely negative factors including moisture deficit, high temperatures, plant diseases and pests (Bazalii et al., 2014; Vasylkovska et al., 2016, Mostipan, 2019).

In most years in the northern Steppe of Ukraine, the consequences of plant damage by below-freezing temperatures in winter are extremely negative factors for the formation of high productivity of winter wheat. Their aftereffect is extremely long, and therefore the process of crop density can occur before the ear stage of plants, and in some years even later. It is known that plants that are damaged in winter but survived have significantly lower individual productivity compared to undamaged plants (Mostipan & Umrykhin, 2018). Therefore, under such conditions, there is always a matter of feasibility and effectiveness of certain agronomic techniques that would increase individual productivity of plants (Mostipan et al., 2017; Pron et al., 2020).

Numerous studies have proven the undeniable role of weather conditions in the early spring period in the formation of winter wheat crop. The time of renewal of spring vegetation of plants is of particular importance (Lykhochvor, 2018; Mostipan & Umrykhin, 2018).

For the first time in Ukraine, V. Medynets established a significant influence of the time of spring vegetation of winter wheat plants on the productivity of its crops (Medynets, 1982). That is, the peculiarities of weather conditions during the renewal of spring vegetation of winter wheat plants have a decisive influence on the productivity of the crops. Moreover, for the first time he proposed effective agricultural techniques to improve grain quality and ensure the level of crop stability depending on the timing of vegetation renewal.

Based on the results of correlation analysis, M. Marenych (Marenych et al., 2010) is convinced that the optimal combination of precipitation and air temperature during grain filling is of high importance for obtaining high-quality winter wheat grain.

Also, studies by M. Marenych (Marenych et al., 2010) and co-authors found the relationship between protein content of winter wheat grain and the amount of precipitation in June (correlation coefficient is 0.74–0.81%). The correlation coefficient between gluten content and air temperature during May is 0.75–0.89%. According to the authors, in the conditions of the left-bank Forest-Steppe of Ukraine, the optimal combination of precipitation and air temperature during grain filling is extremely important for obtaining high-quality grain of winter wheat.

Scientists I. Brazhenko, V. Hanhur and others (Brazhenko et al., 2006) connect the influence of the time of spring vegetation renewal on the productivity of winter wheat crops in the left-bank Forest-Steppe of Ukraine with the circulation of warm or cold atmospheric air masses. It is argued that at different times of renewal of spring vegetation winter wheat plants have different opportunities for soil and air nutrition, which is reflected in their individual productivity. According to Bulgarian researcher E. Roumenina in the early stages of renewal of spring vegetation, plants are better provided with the main factors of life compared to the later dates (Roumenina et al., 2020).

The Polish researcher H. Bujak allows that it is no correlation between the yield of winter wheat and the total precipitation (Bujak et al., 2013). The soil type proved to be the environmental factor of particular importance in determining winter wheat yields. However, our research does not confirm this hypothesis.

Conditions of plant growth and development have a huge impact on the quality of winter wheat grain. According to O. Sozinov and V. Kozlov (Sozinov & Kozlov, 1970), the protein content in the grain of winter wheat by 70% depends on the conditions of the growing environment and only 30% on their genetic characteristics. Later studies by I. Pravdziva and N. Vasylenko (Pravdziva et al., 2017) proved that the influence of weather conditions on the protein content of winter wheat flour reaches 57%, and the effect of genotype does not exceed 5%.

Similar statements follow from the results of research by L. Bozhko and I. Burdeina (Bozhko & Burdeina, 2010). They argue that weather conditions during the growing season have a much greater impact on the protein content of winter wheat compared to agronomic methods of its cultivation.

In different parts of the world, by A. Linina and A. Ruza (Latvia), the total amount of grain varies annually, mainly due to changing climatic conditions owing to drought or excessive moisture (Linina & Ruza, 2018). Wheat yield is influenced by the interaction of a number of factors including cultivar, soil, climate, and cropping practices (Shejbalova et al., 2014).

It is important to know which agronomic techniques provide more rational use of basic plant life factors and, above all, moisture, because Kirovohrad region (Ukraine) belongs to the zone of insufficient moisture (Andriienko et al., 2020).

Therefore, the development of scientific and methodological bases for the application of ecological and adaptive technologies for growing winter wheat and their adjustment during the spring-summer period depending on weather conditions in the early spring is an extremely important issue.

The study of the relationship between the productivity level and moisture consumption in the interphase periods in the northern Steppe of Ukraine was studied for the first time.

In this regard, the main objective of our research was to develop scientific and methodological bases for adapting and adjusting the technology of growing winter wheat during the spring-summer vegetation season depending on weather conditions in early spring.

MATERIALS AND METHODS

Field studies were conducted in experimental crop rotation at the Institute of Steppe Agriculture of the National Academy of Agrarian Sciences of Ukraine. The dependence of winter wheat productivity on the time of spring vegetation renewal was studied during 1986–2005. It was sown after arable land and corn for silage in three terms: September 2nd, 17th and October 2nd. The influence of the level of moisture supply on the productivity of winter wheat crops was studied during 1992–2004. Wheat in this experiment was also sown after arable land and maize for silage, but at different times: August 25th, September 10th and 25th. This was due to the trend towards earlier sowing of winter crops due to climate change (Mostipan & Umrykhin, 2018). Yield calculation and identification of protein content in winter wheat grain were performed by generally accepted methods (USSR State standard specification 10846-91; Beljkaš et al., 2010). Measuring of soil moisture was performed by thermostatic weighting method according to CEN ISO/TS 17892-1:2007.

The soil of the experimental plot is ordinary chernozem with medium humus, heavy loam and deep, which is characterized by a very deep humus profile (80–100 cm) with a significant depth of humus horizon (40–50 cm) and a well-defined granular structure, which gradually turns into granular-fine-lump. The humus content is 4.54%. The content of moving forms of nutrients in the soil is 14.5 mg of hydrolyzed nitrogen, 12.1 mg of phosphorus and 15.7 mg of potassium per 100 g of soil. Identification of hydrolyzed nitrogen by Cornfield (Ukraine State standard specification 7863: 2015: Soil quality). The amount of absorbed bases is 39.4 mg per 100 g of soil, pH is 5.6. The identification was carried out according to ISO 10390:1994 Soil quality - identification of pH. The climate in the study area is temperate continental. The average annual air temperature, according to Kirovohrad meteorological station, is 7.9 °C, and the annual amount of precipitation is 474 mm, the main amount of which falls from May to September. The frost-free period lasts 164 days.

The statistical analysis methods, including MS-Office software, were used for the analytical study.

RESULTS AND DISCUSSION

Productivity of winter wheat crops depending on their level of moisture supply

Conditions for the growth and development of winter wheat plants during the spring-summer vegetation are extremely variable. Calendar terms of transition of average daily air temperature through 0 °C towards positive temperatures vary in a rather wide range. The earliest one can happen in early February, and the latest term takes place in the late third decade of March. Active growth of winter wheat plants begins in the period from the third decade of February to the first decade of April. From the time of renewal of spring vegetation of plants to firm-ripe stage of grain during the period of research there were 182 mm of precipitations on average. In some severely arid years, such as 1987 and 1996, only 79.1 and 60.9 mm fell, respectively. The maximum amount of precipitation during the spring-summer vegetation period fell in 1997 and 2004, respectively 317.8 and 279.9 mm.

The average daily air temperature during the spring-summer period of plant vegetation for the years of research was 15.9 °Con average. However, in cool years it might decrease to 13.3 °C, which was observed in 1990, or rise to the level of 18.1 °C in the hot, arid 1996.

Conditions for moisture supply of winter wheat crops at the beginning of active growth and development of plants differ significantly in different years. On average over the years of research, the reserves of productive moisture in a meter layer of soil at the time of renewal of spring vegetation on arable land was 164.4 mm with fluctuations from 124.2 to 210.0 mm, and after maize for silage - 156.3 mm with variation in different years in the range of 122.5–190.4 mm. Thus, water resources of crops at the beginning of spring vegetation can be characterized from acutely insufficient to the conditions of good moisture.

From the time of the cessation of autumn vegetation to its renewal in spring, the reserves of productive moisture in the soil increase. However, the absolute increases in the amount of available moisture for plants in the soil in different years can be completely different. Of the total amount of precipitation that falls during this period, only 34.2% is recorded in a meter layer of soil. In the years with the fall of rains in the late autumn or winter periods on the background of unfrozen soil, the efficiency of precipitation absorption increases and can exceed 70%.

Winter wheat crops in the northern Steppe of Ukraine are particularly sensitive to the amount of available moisture in the soil at the time of renewal of spring vegetation. When growing on arable land, the share of the influence of productive moisture reserves in a meter layer of soil at the beginning of spring vegetation renewal on crop formation is from 39.7% to 55.2%, and after maize for silage - 49.7–66.4% (Table 1). This pattern is characteristic of all different age crops of winter wheat. At the same time, the shift of sowing dates after maize for silage from early (August 25th) to later (September 25th) dates increases the dependence on the amount of productive moisture at the time of renewal of spring vegetation. If for crops sown on August 25th the share of the impact of moisture reserves on productivity is 49.7%, and for crops sown on September 25th it increases to 66.4%.

Table 1. Dependence of the productivity level of winter wheat crops of different ages on the reserves of productive moisture in the soil (average for 1992–2004), %

Sown after	Crop development phase	Sowing date		
		25.08	10.09	25.09
Arable land	renewal of spring vegetation	39.7	55.2	36.3
	start of booting	42.1	24.8	33.8
	ear stage	9.3	18.7	22.8
	other factors	8.9	1.3	7.1
Maize for silage	renewal of spring vegetation	49.7	51.3	66.4
	start of booting	9.8	9.8	10.6
	ear stage	39.9	34.8	22.3
	other factors	0.6	0.3	0.7

Forecrops have a huge impact on water and nutrient regimes of winter wheat crops. It is known that the better the conditions for plant growth and development are, the greater the density of winter wheat crops at the time of cessation of autumn vegetation. When sowing winter wheat on arable land, its plants have greater bushiness, air-dry mass and a well-developed primary and secondary root system. After the worst forecrops, the biometric performance of plants is lower. The results of the research show that the crops of winter wheat sown on arable land and after maize for silage differ in terms of sensitivity to the reserves of productive moisture in the soil at different stages of plant development. Productivity of winter wheat crops after arable are mainly determined by the amount of available moisture in a meter layer of soil at the time of spring vegetation renewal and at the beginning of plant booting, while productivity of crops after maize for silage is determined by the time of spring vegetation renewal and the ear stage of plants. That is, it possible to state that for more developed crops after arable land, soil moisture reserves at the beginning of the booting phase are also important for crop formation. Their influence on productivity is in the range of 24.8–42.1%.

Different age crops of winter wheat after maize for silage show a specific dependence on the content of productive moisture in the soil at the time of renewal of spring vegetation and in the stage of earing. The shift of sowing dates from August 25th to September 25th increases their dependence on productive moisture reserves for the time of spring vegetation renewal from 49.7% to 66.4% and at the same time reduces their moisture reserves in the ear stage from 39.9% to 22.3%.

The water needs of winter wheat plants change during their growth and development. During the booting period, when the above-ground mass of plants accumulates intensively, and the grain is filled, winter wheat plants are too sensitive to water deficiency. Droughts in these periods lead to significant crop losses. However, the absolute water consumption of winter wheat crops does not always coincide with the physiologically important needs of plants in water for crop formation. The obtained results show that the total water consumption by winter wheat crops for the whole vegetation period from a meter layer of soil is on average 342.9 mm and almost does not depend on the forecrops. At the same time, the transfer of sowing dates from early to late period reduces the total water consumption from 361.3 to 330.3 mm for arable from 361.5 to 330.3 when growing winter wheat after maize for silage (Table 2, Fig. 1, Fig. 2).

The highest water consumption by winter wheat crops is observed in the period of 'renewal of spring vegetation - start of booting' and during the 'ear stage - firm-ripe stage'. Of the total amount of water consumed by crops during the entire growing season, the share of arable costs is 28.4% and 35.2%, respectively, and after maize for silage - 26.4% and 34.1%. For comparison, during the autumn period water consumption was 14.1% after arable land and 17.1% after maize for silage. During the period of plant booting, water consumption increases to the level of 22.0–22.2%, but it is lower compared to the two previously mentioned periods.

Table 2. Water consumption by winter wheat crops from a meter layer of soil depending on sowing dates (average for 1992–2004), mm ha^{-1}

Sowing date	Indicators of water consumption in periods, mm ha^{-1}				
	Sowing - cessation of vegetation	Renewal of vegetation - start of booting	Start of booting - ear stage	Ear stage - firm-ripe stage	For the whole period
Sown after is arable					
25.08	71.1	94.3	74.6	121.2	361.3
10.09	36.6	100.4	77.2	124.0	338.2
25.09	37.4	98.1	77.2	117.7	330.3
average	48.4	97.6	76.3	121.0	343.3
Sown after maize for silage					
25.08	85.3	89.2	70.8	116.2	361.5
10.09	49.5	91.5	75.5	119.1	335.7
25.09	44.6	90.3	79.9	115.5	330.3
average	59.8	90.3	75.4	116.9	342.5

Studies have shown that in the northern Steppe of Ukraine the largest reserves of productive moisture in a meter layer of soil are achieved at the beginning of spring vegetation of winter wheat and then gradually decrease to the firm-ripe stage. Thus, on average over the years of research, the reserves of productive moisture after arable land from the time of spring vegetation to firm-ripe stage of grain decrease from 164.4 to 63.2 mm, and after maize for silage from 156.3 to 59.9 mm. Precipitation that falls during the period of active growth or accumulation of dry matter by plants does not change the existing dependence. Even after heavy rainfall, high soil moisture persists for a short period of time. This is especially evident in the significant development of aboveground vegetative mass of plants. Such plants, in the conditions of high air temperature, intensively transpirate and the amount of available moisture in a meter layer of soil decreases rapidly. This is also facilitated by the intense physical evaporation of water from the soil surface.

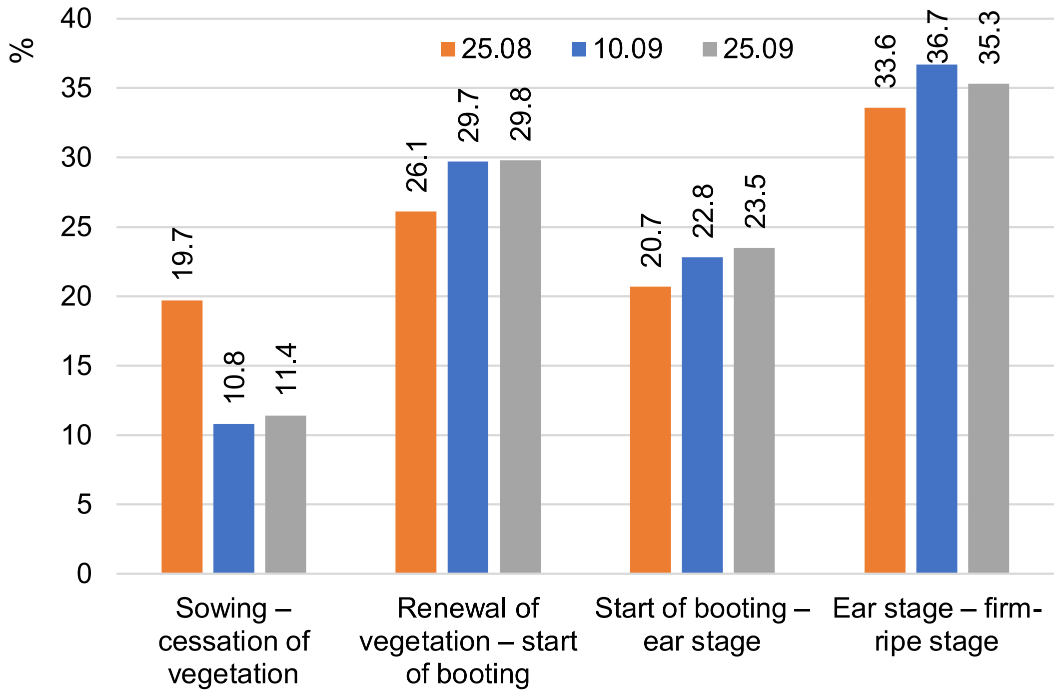

Figure 1. Dynamics of water consumption by winter wheat crops from a meter layer of soil depending on the sowing date (sown after arable land), %.

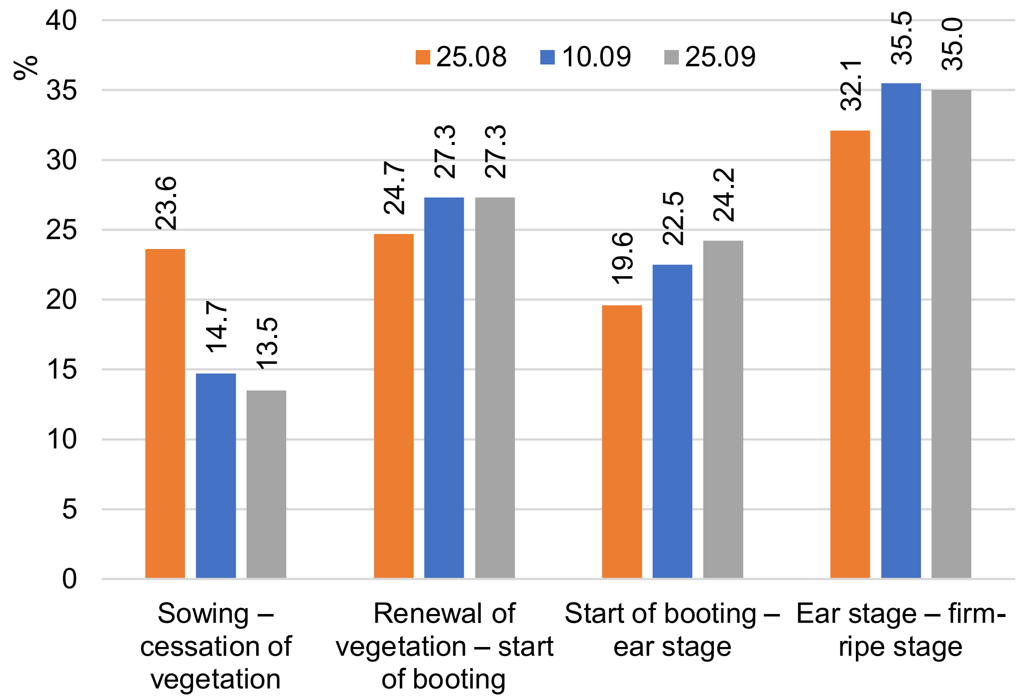

Figure 2. Dynamics of water consumption by winter wheat crops from a meter layer of soil depending on the sowing date (forecrop is maize for silage), %.

Analyzing the two periods of development of wheat crops with the highest water consumption, we note that during the 'renewal of spring vegetation - start of booting' water consumption is inefficient and they are mainly due to physical evaporation of water from the soil surface. Therefore, in practice, with the onset of physical maturity of the soil for winter wheat crops should be taken such measures that would reduce physical evaporation of water. This will save it for a later period increasing productivity.

Productivity of winter wheat crops depending on the time of renewal of spring vegetation of plants

In the northern Steppe of Ukraine, the renewal of spring vegetation of winter wheat plants can occur in a very wide range from the beginning of the third decade of February to the first decade of April. Therefore, it is proposed to distinguish very early renewal of vegetation (third decade of February), early (first - second decade of March), middle (third decade of March) and late (first decade of April) (Mostipan, 2019). The average daily air temperature from the time of renewal of spring vegetation to the beginning of booting of plants on average for the years of research was 8.93 °C with variation in different years from 4.78 °C to 12.95 °C. The sum of average air temperatures for the specified period was 260 °C with changes in different years from 57 °C to 437 °C. On average, 26.4 mm of precipitation fell from the time of spring vegetation renewal to the beginning of plant booting. In some years the amount of precipitation reached 83 mm, while in dry years the precipitation was completely absent. The earlier the vegetation of plants is renewed, the higher the productivity of winter wheat is (Table 3). This dependence is characteristic as forwinter wheatsown after arable, so forsown after maize for silage one. When growing winter wheat on arable land, the productivity of wheat in the years with very early renewal of vegetation is 6.74 t ha^{-1} against 3.68 t ha^{-1} in the years with late renewal. After maize for silage, the productivity is 6.11 and 2.9 t ha^{-1}, respectively.

Table 3. Water consumption by winter wheat crops from a meter layer of soil depending on sowing dates (average for 1986–2005), t ha^{-1}, %

Time of renewal of spring vegetation	Average	Arable land				Maize for silage			
		average	2.09	17.09	2.10	average	2.09	17.09	2.10
Productivity, t ha^{-1}									
Very early	6.42	6.74	6.96	6.81	6.44	6.11	6.13	6.18	6.02
Early	4.71	5.39	4.73	6.02	5.41	4.03	3.78	4.35	3.95
Middle	3.46	3.84	3.66	4.25	3.60	3.09	3.07	3.29	2.90
Late	3.29	3.68	2.95	4.38	3.72	2.90	2.55	3.04	3.12
Content of protein in grain, %									
Very early	12.57	13.12	13.29	13.22	13.16	12.02	11.92	12.13	12.47
Early	13.19	13.54	13.75	13.29	13.61	12.84	12.77	12.91	12.87
Middle	13.75	14.12	14.22	13.99	13.84	13.37	13.11	13.56	13.56
Late	13.13	13.90	13.88	13.77	13.74	12.35	12.46	12.16	12.55

The timing of the renewal of spring vegetation of plants can significantly change the impact of sowing dates on the productivity of winter wheat. In case of very early renewal of spring vegetation, the productivity is almost land in sops of different ages it varies from 6.44 to 6.96 t ha^{-1}, and after maize for silage - from 6.02 to 6.13 t ha^{-1}. At later dates of vegetation renewal, the highest productivity of winter wheat sown after both arable land and maize for silage is formed when sowing in the optimal time, that is on calendar dates close to September 17th.

Studies have shown that in the northern Steppe of Ukraine the highest protein content of winter wheat grain is formed in the years with the average renewal time of plant vegetation. This pattern is characteristic of all different age crops of winter wheat sown after both arable and maize for silage. On average, over the years of the research, the protein content of arable land during this period of vegetation renewal was 14.12%, and after maize for silage it was 13.11%. Both earlier and later renewal of vegetation leads to a decrease in the amount of protein in the grain of winter wheat. However, later renewal of vegetation provides higher protein content of winter wheat grain compared to earlier terms.

The weather conditions of the early spring period in the northern Steppe of Ukraine are too changeable. The timing of the onset of active growth of winter wheat plants can vary significantly depending on the conditions of the year. In some years, the duration of the period from the time of transition of the average daily air temperature through 0 °C to +5 °C, when the active growth of plants begins, can be only 2 days, while the maximum duration of this period is 46 days. It is proved that the longer this period is, the lower the productivity of winter wheat. The average productivity of winter wheat in the years with duration of this period up to 10 days is 5.31 t ha^{-1}, while in the years with the length of more than 30 days it decreases to 3.14 t ha^{-1} (Table 4).

Table 4. Influence of the duration of the period from the transition of the average daily above-freezing temperature to the renewal of spring vegetation on the productivity of winter wheat (1986–2005), t ha^{-1}, %

Duration, days	Average	Arable land				Maize for silage			
		average	2.09	17.09	2.10	average	2.09	17.09	2.10
Grain productivity, t ha^{-1}									
Up to 10	5.31	5.96	5.45	6.88	5.56	4.66	4.81	4.78	4.41
10–20	4.51	4.29	4.11	4.73	4.03	4.72	4.51	4.96	4.68
20–30	4.09	4.52	3.88	4.99	4.70	3.65	3.37	3.91	3.68
More than 30	3.14	3.89	3.15	4.52	3.99	2.39	2.07	2.69	2.41
Content of protein in grain, %									
Up to 10	13.25	14.15	14.30	14.01	14.04	12.35	12.47	12.40	12.17
10–20	13.56	14.06	13.89	14.11	13.93	13.06	12.80	13.14	13.37
20–30	13.96	14.57	14.76	14.46	14.14	13.35	13.28	13.43	13.35
More than 30	13.32	13.42	13.51	13.17	13.13	13.21	13.19	13.22	13.30

The decrease in productivity level due to the lengthening of the period from the time of transition of the average daily air temperature through 0 °C to the active growth of plants is characteristic of all different age crops of winter wheat sown after both arable land and maize for silage. In addition, when growing winter wheat on arable land, a sharp decrease in productivity is observed even in the years with duration of this period from 10 to 20 days, while after maize for silage, the productivity is almost unchanged. Therefore, the productivity on arable land in the years with the length of such a period from 10 to 20 days is 4.29 t ha^{-1} against 5.96 t ha^{-1} in the years with duration up to 10 days. After maize for silage, the productivity is 4.72 and 4.66 t ha^{-1}, respectively. The causes of this phenomenon can be significant fluctuations in night and day temperatures, the negative effects of frost, spread of pathogens, insufficient supply of nutrients from the soil to plants, suppression of microbiological processes in the soil, sharp water losses from the soil due to drought, etc.

The analysis of the research results allows stating that the largest amount of protein in wheat grain accumulates in the years with the length of the period from the transition of the average daily air temperature through 0 °C to the active growth of plants from 20 to 30 days. The average protein content in grain when growing winter wheat on arable land in such years is 14.57%, and after maize for silage it is 13.35%. In the years with longer and shorter duration of this period, the protein content decreases. However, in case of arable land, a significant decrease in grain protein is observed only in the years with duration of the specified period of more than 30 days, while after maize for silage a significant decrease is observed only in the years with duration of this period up to 10 days.

CONCLUSIONS

The above-mentioned analysis allows drawing the following conclusions:

– the later the spring vegetation of winter wheat plants is renewed, the lower the productivity of its crops is. In the years with the renewal of spring vegetation in the third decade of February, the productivity of winter wheat averages 6.42 t ha^{-1}, while with its late renewal in the first decade of April, it decreases almost twice and is 3.29 t ha^{-1}. The largest amount of protein in the grain of winter wheat accumulates in the years with the average renewal of spring vegetation in the third decade of March and is on arable on average 14.12% and 13.84% after maize for silage;

– in the years with early renewal of spring vegetation, sowing dates have almost no effect on the level of productivity of winter wheat crops. When growing it on arable land, the productivity of crops of different ages varies in the range of 6.44–6.96 t ha^{-1}, and after maize for silage, the variation of productivity indicators is 6.02–6.18 t ha^{-1};

– crops of winter wheat on arable are more dependent on the reserves of productive moisture in the soil at the time of renewal of spring vegetation and at the beginning of the booting phase and less dependent on the moisture content in the soil in the ear stage. At the same time, when growing winter wheat after maize for silage, its productivity depends more on soil moisture reserves during the renewal of spring vegetation and the ear stage of plants and less on the amount of moisture in the soil at the beginning of plant booting;

– in the northern Steppe of Ukraine, the highest water consumption by winter wheat crops is observed in the period of 'ear stage - firm-ripe stage' and is 35.2% of the total water consumption for the entire growing season, and after maize for silage it is 34.1%. Water consumption of winter wheat crops from the time of spring vegetation to the beginning of plant booting is higher compared to the period 'start of booting - ear stage' and averages 27.4% and 22.1% of the total for the entire growing season; the shorter the period from the date of transition of the average daily air temperature through 0 °C to the beginning of active vegetation of plants is, the higher the productivity of winter wheat crops. In the years with duration of this period up to 10 days, the productivity of winter wheat crops averages 5.31 t ha^{-1}. And in the years with the length of more than 30 days, it decreases by 2.17 t ha^{-1}and is 3.14 t ha^{-1}. At the same time, the largest amount of protein in winter wheat grain accumulates in the years with the length of this period from 20 to 30 days and is 13.96%. Extension of this period over 30 days causes a decrease in grain protein content to the level of 13.32%, and reduction to 10 or less days - to 13.25%.

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