ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Influence of Transpiration on Grain Productivity.

Svetlana Pakshina, Vladimir E. Torikov*, Nikolai Belous, Galina Malyavko, Olga Melnikova, and Vladimir V. Torikov.

Bryansk State Agrarian University, 2a, Sovetskaya st., Kokino, Vygonichi district, Bryansk region, Russia, 243365.

ABSTRACT

The researches of grain productivity dependence on transpiration, and formation of highly productive winter wheat, winter rye and spring barley crops at certain transpiration limits due to both lack and optimal plant availability of soil moisture and nutrients are given in the article. It is established that the main mechanism of crop productivity formation is the process of transpiration, with the driving force being the radiation balance and photosynthetic active radiation. The function graph of the yield on the transpiration of winter wheat and spring barley has two discontinuities caused by the demands of these crops for nutrients and available soil moisture in the tillering, booting and earing phases. The function graph of grain productivity of winter rye on transpiration has only one discontinuity coinciding with the optimum moisture content and the sufficient amount of nutrients. Mineral fertilizers increase transpiration of crops at all interval of available soil moisture. The bioavailability of soil moisture and transpiration sharply decreases without fertilizer application. A linear relationship between the coefficient of photosynthetic active radiation and relative transpiration is established.

Keywords: coefficient of photosynthetic active radiation, relative transpiration, evapotranspiration, bioavailability of moisture, meteorological indicators.

**Corresponding author*

INTRODUCTION

Productivity is a significant integral indicator of the potential of any crop under certain cultivation conditions [4,9,10,16,17]. However, this indicator does not reveal the mechanisms of formation of crop productivity needed for understanding of its theoretical content.

In the paper [13] a linear and continuous dependence of evapotranspiration of spring wheat and corn in the fields with high technologies and deep groundwater is established. The continuity of the yield function on evapotranspiration is observed over the entire period of water consumption (100-500 mm).

Transpiration is a complex geophysical phenomenon, involving the processes both in the plants and in the active layer. There are three models of plant transpiration [5,6,11]. In the model proposed by Z.N. Bichele [5], transpiration is considered as a physical process occurring in the plant leaf epidermis.

In the model by A.I. Budagovsky [6], transpiration is defined as all the evaporation in the active layer (the layer is 2 m from the ground surface).

In the model by H. Penman [11], transpiration is a process depending on solar radiation and coefficient of photosynthetic active radiation (PhAR) for the biosynthesis of plant organic matter. It is taken as an axiomatic fact, as being confirmed by numerous field experiments, that that 40% of the radiation balance is spent on plant transpiration. The coefficient of PhAR is introduced so that to record the differences between the crops of various cultures or one culture under different conditions. According to this model [11] the coefficient of PhAR of crops cannot exceed 2.5%.

EXPERIMENTAL

The aim of this work is to study the dependence of the yield on the transpiration, the identification and explanation of the yield functioning of different crops at certain transpiration limits due to the lack and sufficiency of soil moisture and nutrients.

The soil of the experiment field is agrogray forest medium-loamy, well-cultivated. Agrochemical analyzes are performed by generally recognized methods [11]. The humus content (according to Tyurin) was 3.38-3.62%, pH $_{KCL}$ was 5.7-5.9; hydrolytic acidity (H_r) was 2.63-2.86 mg-eq/100 g soil; the sum of absorbed bases was 16.3 mg-eq/100 g soil. The degree of base saturation was 85.5%; the content of mobile phosphorus forms was 220-319 mg/kg soil; exchange potassium was 115-247 mg/kg soil. Field researches included phenological observations over phases of grain crops growth and assessment of grain yield.

Actinometric studies included the computations of direct (S), diffuse (D), reflected radiation (R_k) and the radiation balance (B_K) according to the current data, available at the Meteorological station of the Bryansk State Agrarian University [3]. During the vegetation period of crops the actinometric observations are carried out 5 times a day at 8, 11, 14, 17, 20 local time. Daily values of the direct (S '), diffuse (D), reflected radiation (R_k) and the radiation balance (B_K) were calculated according to standard observations In compliance with [11]. The calculation of daily sums of S', D, R_k was conducted by the trapezium method:

$$\sum_c N = \frac{N_1}{2} t_1 + \left(\frac{N_1}{2} + N_2 + N_3 + N_4 + \frac{N_5}{2}\right) 180 + \frac{N_5}{2} t_2 \qquad (1).$$

Where N_1, N_2, N_3, N_4, N_5 are actinometric instrumentation indicators at 8, 11, 14, 17 and 20 o'clock, respectively, cal/cm^2 min, $t_1 = 8 - t_r$, $t_2 = t_s - 20$. Here t_r and t_s are sunrise and sunset local time, respectively [2].
The positive daily sums of radiation balance were computed by the formula:

$$\sum_c B_к = \sum_c (S' + D) - \sum_c R_k. \qquad (2)$$

The empirical coefficients, computed according to the data given in the papers [6], were used to calculate the daily sums of the radiation balance $\sum_c B$ ($\sum_c B = \sum_c B_к - \sum_c B_d$. Empirical coefficients take into account the decrease in value of $\sum_c B$ compared with the value $\sum_c B_к$ caused by negative values of the sums of the radiation balance ($\sum_c B_d$) from sunset to sunrise, when the long-wave radiation measurements are not conducted at the Meteorological station of the Bryansk State Agrarian University.

RESULTS AND DISCUSSION

In different periods of growth of winter crops in 2007 and 2009 the autumn vegetation happened under conditions of sufficient moistening (Table 1).

Table 1: Hydrometeorological indicators in the autumn-winter period (According to the Meteorological station of the Bryansk State Agrarian University)

Period	Autumn vegetation				Wintering		
	Shoots ÷ t<+5°C				Precipitation, mm		
	∑H	$\sum E_0$	КУ	$\sum H-\sum E_0$	liquid	solid	sum
2007/08	62.1	39.7	1.6	+22.4	37.4	230	267.4
2008/09	63.2	70.8	0.9	-7.6	113.8	196	309.8
2009/10	137.2	60.2	2.3	+77.0	75.8	242	317.8

In 2008 the moisture deficit was 7.6 mm. It is known that winter crops are particularly demanding of soil moisture in autumn and spring tillering. During the wintering of winter crops there was much precipitation, making good deficit of moisture in the spring-summer vegetation period.

Especially high moisture deficit took place in 2008 (-214.2 mm) and 2010 (-109,8mm) in the spring-summer vegetation period. In 2009 the moisture deficit in the spring-summer vegetation period was insignificant (-33.4 mm). In the critical period of winter crops vegetation from booting to heading the highest moisture deficit was in 2008 (-163 mm) and 2010 (-130 mm). Only in 2009 the moisture deficit in the critical phase was not observed.

As objects of research there were three crops: winter wheat (cultivated variety (cv) Galina), winter rye (cv Tatiana), spring barley (cv Ataman), grown in the experiment field of the Bryansk State Agrarian University in the period of 2008-2010.

The experiment with winter wheat included three seeding dates (September 5, 10, 15), three seeding rates (3.5, 4.5, 5.5 mln seeds/ha) and four variants of mineral fertilizers doses: 1- N_{120} $P_{120}K_{120}$ + N_{30}; 2 – N_{90} $P_{90}K_{90}$ + N_{30}; 3 – N_{60} $P_{60}K_{60}$ + N_{30}; 4 – N_0 P_0K_0.

The experiment with winter rye (cv Tatiana) included four variants of mineral fertilizers doses: 1. $N_{120}P_{120}K_{120}$+ N_{45}; 2. $N_{90}P_{90}K_{90}$ + N_{45}; 3. $N_{60}P_{60}K_{60}$ + N_{45}; 4. $N_0P_0K_0$.

The experiment with spring barley (cv Ataman) included four variants of mineral fertilizers doses: 1. $N_{120}P_{120}K_{120}$+ N_{45}; 2. $N_{90}P_{90}K_{90}$ + N_{45}; 3. $N_{60}P_{60}K_{60}$ + N_{45}; 4. $N_0P_0K_0$.

According to the paper [1] the coefficients for April, May, June, July, August, September were 0.81, 0.88, 0.91, 0.90, 0.83, 0.70, respectively, according to the paper [12], they were 0.73, 0.87, 0.90, 0.90, 0.86, 0.71. These data were obtained by Moscow Meteorological station and Meteorological Observatory of Moscow State University. When calculating the sum of daily values of radiation balance the second data row was used as it was closer to the research time. Daily values of PhAR were calculated by the formula [8]:

$$\sum Q_{PhAR} = 0{,}43 \sum S' + 0{,}57 \sum D \qquad (3)$$

To calculate the potential evapotranspiration (E_o) the formula by Budyko [7] was used:

$$E_o = B/L, \qquad (4).$$

Where L is specific heat of evaporation.

The air temperature was taken into account while choosing the L values. The L value in 2010 was 2 453 kJ/kg, while in 2008 and 2009 it was 2466 kJ/kg.

The coefficient of PhAR (K_{PhAR}) was calculated by the formula:

$$K_{PhAR} = Y*q*100/\sum_v Q_{Ph}, \% , \quad (5).$$

Where Y is yield of absolute dry weight (ADW), kg/ha; q is grain caloricity, J/kg; $\Sigma_v Q_{Ph}$ is sum of photosynthetic active radiation during the vegetation period, J/ha (Chirkov 1986).

The transpiration of crops during the vegetation period was calculated by the formula of H. Penman [11]:

$$\sum_v E_T=0,4\ K_{PhAR}\sum_v B/L , \quad (6).$$

Where $\sum_v B$ is the sum of daily values of the radiation balance of the vegetation period, MJ/m^2; K_{PhAR} is coefficient of photosynthetic active radiation (PhAR),%; L is specific heat of evaporation at the air temperature in the period of vegetation, J/m^2 [11].

Transpiration coefficient (K_t for grains) was calculated by the formula:

$$K_t = \sum_v E_T/Y. \quad (7).$$

Where Y is yield of ADW, t/ha.

Relative transpiration was calculated by the formula:

$$\alpha = \sum_v E_T/\sum_v E_{o.} \quad (8)$$

Water regime of the soil in the autumn-spring-summer vegetation period in 2008/09 was characterized by precipitation-evaporation ratio (PER) equal to 0.89. Therefore, it can be assumed that transpiration in 2009 was close to potential. In 2007/08 and 2009/10 PER in spring-summer vegetation period was 0.6 and 0.69, respectively. The daily sum of the radiation balance varies considerably depending on the year of researches. The maximum daily sums of the radiation balance were in 2008 (984 MJ/m^2) and 2010 (864 MJ/m^2). The minimum daily sum of radiation balance was observed in 2009 (756 MJ/m^2).

Table 2 shows the meteorological data during the spring-summer vegetation period.

Table 2: Average monthly meteorological indicators in the spring-summer period (from the temperature transition of 5°C to wax ripeness) (According to the Meteorological station of the Bryansk State Agrarian University)

Period	April	May	June	July (the 1st and 2d decades)	Total for the vegetation
Average air temperature, °C					
2008	10.1	12.8	18.9	20.0	mean: 15.2
2009	8.1	13.8	18.3	19.6	mean: 14.6
2010	12.2	17.2	20.8	23.6	mean: 18.1
Average relative humidity, %					
2008	64.3	67.7	68.0	75.7	mean: 68.9
2009	54.3	66.7	74.7	79.3	mean: 69.5
2010	68.3	68.3	66.0	68.0	mean: 67.6
Precipitation, мм					
2008	70.0	54.8	55.5	58.6	238.9
2009	4.4	78.3	126.0	65.2	273.9
2010	56.4	52.1	41.8	92.0	242.3
Average daily amount of radiation balance, MJ/m^2					
2008	198.3	272.7	400.5	146.2	1017.7
2009	119.7	236.1	246.0	154.5	756.3
2010	194.3	249.8	314.7	170.3	929.1
Daily sums of evapotranspiration, mm					
2008	80.1	110.4	163.0	99.6	453.1
2009	48.4	95.7	100.2	63.0	307.3
2010	79.0	101.6	128.4	69.7	378.7
Moisture deficit, mm					
2008	-10.1	-55.6	-107.5	-41.0	-214.2
2009	-44.0	-17.4	+25.8	+2.2	-33.4
2010	-2.0	-46.7	-83.4	+22.3	-109.8

The daily sums of evapotranspiration were calculated by the formula (4), the moisture deficit was taken as the difference between the sum of precipitation and evaporation ((∑v H-∑vEo).

Figure 1 shows the graph of grain yield (Y) of winter wheat (cv Galina) on transpiration in 2008 - 2010. As follows from Figure 1, the function graph of grain yield on the transpiration has two discontinuities at transpiration points of 150 mm and 230 mm and is divided into three segments. Within each of the three segments continuity of the function is observed. The first segment of the function refers to period of the spring-summer vegetation with a lack of nutrients under the conditions both lack and sufficiency of soil moisture (2009). Relative transpiration in the period amounted to 0.23-0.42.

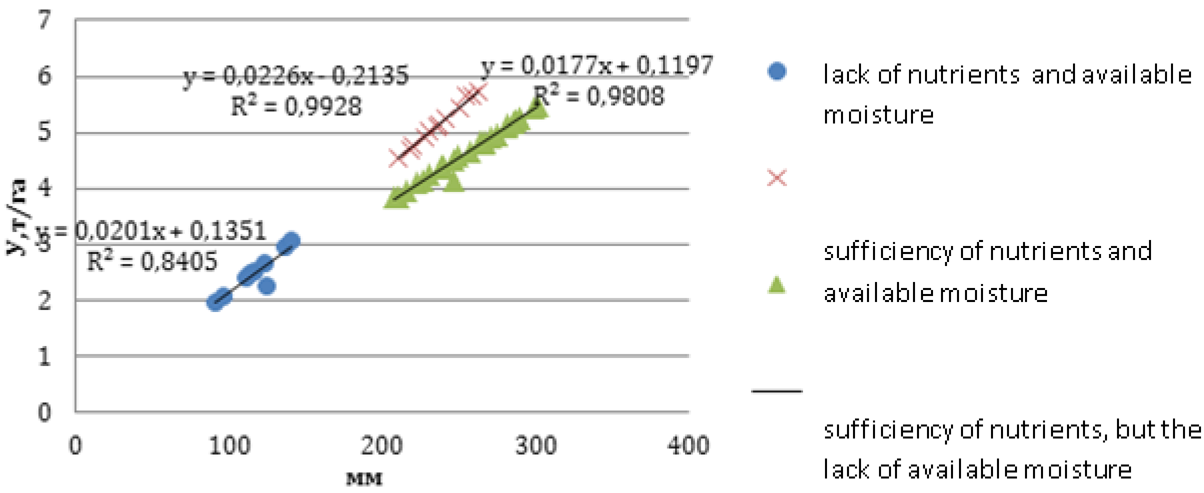

Figure 1: Dependence of the yield of winter wheat on transpiration

The second segment is due the sufficiency of nutrients, but the lack of available moisture. Relative transpiration in the period amounted to 0.5-0.61.

The third segment occurs in the period of spring-summer vegetation with the sufficiency of nutrients and available soil moisture. Relative transpiration in the period amounted to 0.63-0.79.

Thus, the lack of fertilizing leads to sharp drop of bioavailability of water, even if there is sufficiency of soil moisture.

The nutrients deficiency leads to reduction of osmotic pressure in the closing stomata of epidermis by ions coming in the cells from the water, and the transpiration decreases.

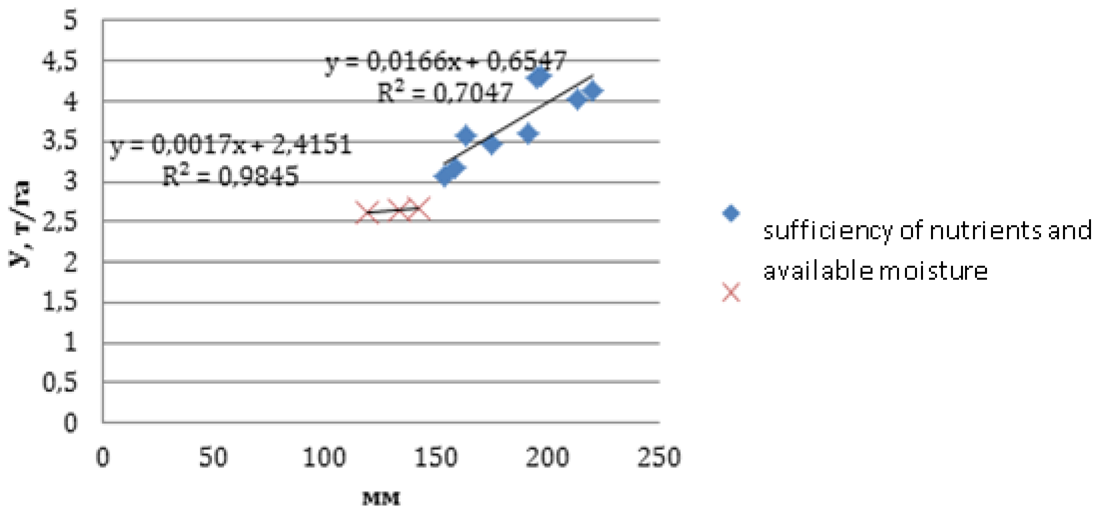

Figure 2: The dependence of grain yield of winter rye on transpiration

Figure 2 presents the graph of grain yield of winter rye (cv Tatiana) on transpiration. As follows from

Figure 2, the function graph of grain yield on the transpiration has two segments. The first segment reflects yield formation with the nutrients deficiency (control), sufficiency and lack of available soil moisture. Relative transpiration in the period is 0.23-0.33.

The second segment reflects yield formation with mineral fertilizing and with sufficiency and lack of available soil moisture. Relative transpiration is 0.27-0.65. The absence of the second discontinuity of the function of grain yield on the transpiration proves more adaptability of the crop both to the lack of moisture and to the lack of nutrients. Winter rye can assimilate nutrients out of sparingly soluble compounds.

Figure 3 shows the dependence of grain yield of spring barley on transpiration (cv Ataman).

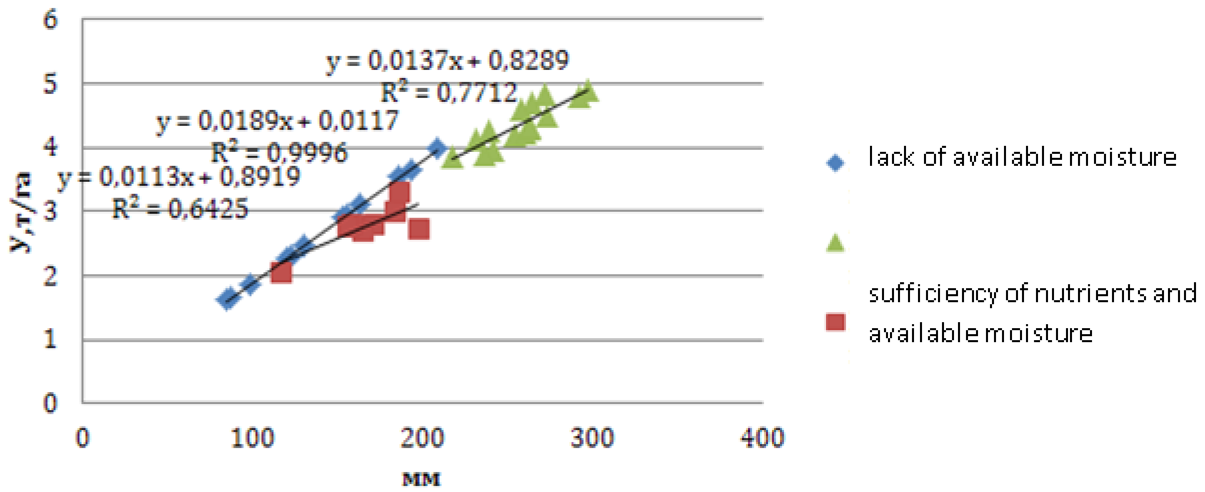

Figure 3: The dependence of grain yield of spring barley on transpiration

The function of the yield on transpiration is divided into three segments. The first segment represents the yield formation with the lack of nutrients, and sufficiency and lack of available soil moisture. Relative transpiration in the period is 0.17-0.37.

The second segment reflects the yield formation of the crop with fertilizering, but sufficiency and lack of soil moisture. Relative transpiration is 0.38-0.61.

The third segment reflects the formation of the grain yield with sufficiency of nutrients and soil moisture. Relative transpiration is 0.67-0.9. When the content of available soil moisture is optimum and the dose of fertilizer application is higher, maximum absorption of solar radiation and the acceleration of transpiration takes place.

Thus, the continuous function of grain yield of crops on transpiration is observed over the entire period of transpiration only when the content of nutrients is approximately equal.

Figure 4 shows the dependence of the absorption coefficient of PhAR of winter wheat, winter rye and spring barley on the relative transpiration.

As follows from Figure 4, there is a linear relationship between the values of K_{PhAR} and relative transpiration in different doses of mineral fertilizers. The correlation coefficient for winter wheat, winter rye and spring barley is 0.99, indicating that values are closely connected.

The maximum values of K_{PhAR} for winter wheat, winter rye and spring barley are achieved at the following values of the relative transpiration: 0.79, 0.64, 0.78. These data indicate greater sensitivity of winter wheat and spring barley to the lack of soil moisture and much less sensitivity of winter rye with equal value of the relative transpiration on the grain biosynthesis, spring barley absorbs less solar radiation than winter wheat and winter rye.

Grains transpiration coefficient remains constant values independent of the doses of fertilizer, and changes for winter wheat, winter rye and spring barley in the range of 459-554, 455-532, 518-611, respectively. These data point to a greater need for available soil moisture of spring barley and to the least one of winter rye.

The independence of the values of the transpiration coefficient of grain from mineral nutrition level was noted previously [14]. According to the work [15] the transpiration coefficient of grain is 340-500.

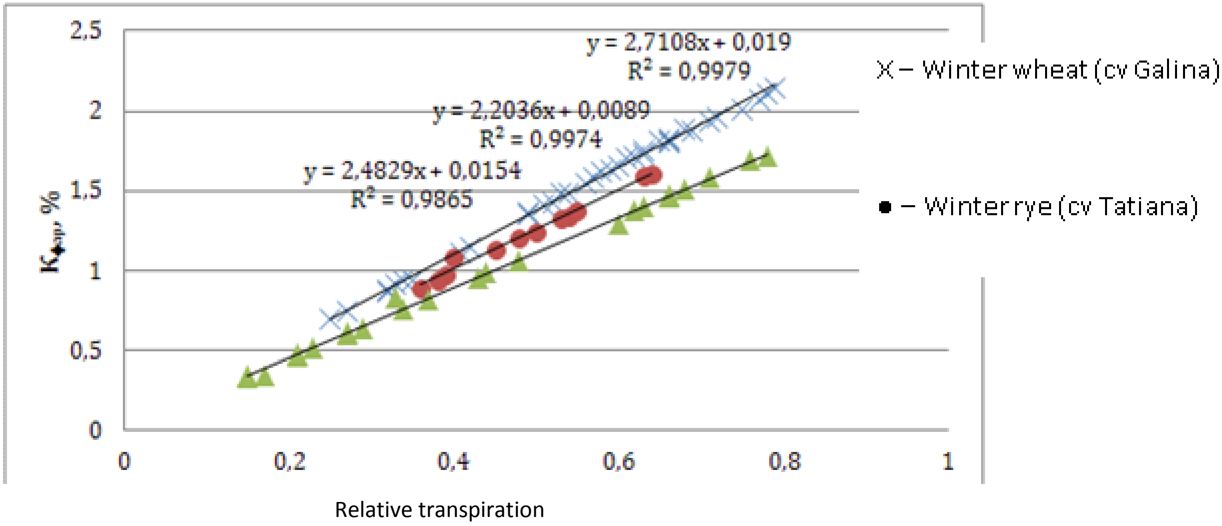

Figure 4: The dependence of coefficient of photosynthetic active radiation on the relative transpiration of barley (cv Ataman)

CONCLUSION

Thus, the main mechanism of yield formation of crops is the process of transpiration, with the radiation balance and photosynthetic active radiation being its driving force. The function graph of the yield on the transpiration of winter wheat and spring barley has two discontinuities caused by the demands of these crops for nutrients and available soil moisture in the tillering, booting and earing phases. The function graph of grain productivity of winter rye on transpiration has only one discontinuity coinciding with the optimum moisture content and the sufficient amount of nutrients.

Mineral fertilizers increase transpiration of crops at all interval of available soil moisture. The bioavailability of soil moisture and transpiration sharply decreases without fertilizer application.

A linear relationship between the coefficient of photosynthetic active radiation and relative transpiration is established. The correlation coefficient for winter wheat, winter rye and spring barley is 0.99.

REFERENCES

[1] Abakumova G.M., Gorbarenko E.V., Nezval E.I., Shilovtseva O.A. Climatic solar energy resources of the Moscow region. Moscow: Librokom, 2012.

[2] Actinometric observation manual for hydro-meteorological stations. Leningrad: Gidrometeoizdat, 1973.

[3] Agrometeorological Bulletin: Meteorological Station of the Bryansk State Agricultural Academy. Kokino, 2008-2010.

[4] Belous N.M., Torikov V.E. Shpilev, N.S., Melnikova O.V., Malyavko G.P., Naumova M.P., Nesterenko O.M., Mikhailov O.M. Winter Grain Crops: Biology and Cultivation Technology: monograph. Bryansk, 2010.

[5] Bichele Z.N., Moldau H.A., Ross J.K. Mathematical modeling of transpiration and photosynthesis of

plants with soil moisture shortage. Leningrad: Gidrometeoizdat, 1980.
[6] Budagovsky A.I. Evaporation of soil water. Physics of soil water. Moscow: Nauka, 1981.
[7] Budyko M.I. Determination of land evaporation. Meteorology and hydrology, 1955; 1: 52-58.
[8] Chirkov Y.I. Agrometeorology. Leningrad: Gidrometeoizdat, 1986.
[9] Kosyanchuk V.P., Maltsev V.F., Belous N.M., Torikov V.E. Programming of Crop Yields: a tutorial. Bryansk, 2004.
[10] Malyavko G.P., Belous N.M., Shapovalov V.F. Agrochemical substantiation of cultivation technologies of winter rye in the south-west of Russia: monograph. Bryansk, 2010.
[11] Penman H. Water cycle. Biosphere. Moscow: Mir, 1972.
[12] Pivovarova Z.I. Radiation characteristic of the climate of the USSR. Leningrad: Gidrometeoizdat, 1977.
[13] Razumova L.A. Recording of agro-meteorological factors at the planning of ameliorative measures and using of reclaimed lands. Scientific Bases of Land Reclamation. Moscow: Nauka, 1972.
Shatilov I.S. Water and transpiration of plants in the field. Scientific fundamentals of crop yield
[14] programming. Moscow: Kolos, 1978.
Shcherbakov A.P., Protasov N.A., Belyaev A.B., Stahurlova L.D. Soil science with the fundamentals
[15] of crop production. Voronezh: Voronezh State University, 1996.
Torikov V.E. Bread from the grain of the Non-Black Soil Area of Russia. Cereals, 1991; 4: 21.
[16] Torikov V.E. Winter wheat in the Non-Black Soil Area of Russia. Cereals, 2000; 4: 22.
[17] Tutorial on agricultural chemistry. Ed. V.G. Mineeva. Moscow: MGU, 2001.