PRODUTIVIDADE POTENCIAL DAS CULTURAS DE INVERNO NA REGIÃO DO VOLGA CENTRAL

POTENTIAL PRODUCTIVITY OF WINTER CROPS IN THE MIDDLE VOLGA REGION

ПОТЕНЦИАЛЬНАЯ ПРОДУКТИВНОСТЬ ОЗИМЫХ КУЛЬТУР В СРЕДНЕВОЛЖСКОМ РЕГИОНЕ

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RESUMO

A pesquisa dedicada ao estudo do rendimento das culturas de inverno foi realizada em 2002-2019 nos campos de reprodução do Instituto de Pesquisa Agrícola de Samara, localizado na zona de estepe da região do Transvolga Médio. O experimento envolveu 5 variedades de centeio de inverno, 6 variedades de tritcale de inverno e 2 variedades de trigo de inverno. Foi calculada a produtividade potencial (R_t), o rendimento potencial realmente possível (R_{prp}), o rendimento máximo realmente possível (R_{mrp}), o potencial bioclimático (PBC), análise de correlação. O objetivo do trabalho é: identificar o potencial das culturas de inverno, comprovar cientificamente os dados obtidos. O rendimento máximo do tritcale foi obtido em 2017 – 7,48 t/ha, centeio – 5,88 t/ha, em 2016 – 4,65 t/ha de trigo. Calculado, levando em consideração que $\sum T > 10^\circ\text{C}$ para o período de cultivo da cultura, o rendimento potencial para o tritcale em 2017 é de 3,02 t/ha, para o centeio de inverno em 2005 – 6,83 t/ha, para o trigo de inverno em 2005 – 2,79 t/ha. O indicador (PBC) variou significativamente ao longo dos anos: de 0,62 a 1,16 pontos para o centeio de inverno, de 0,30 a 0,60 para o tritcale de inverno e trigo. A análise de correlação mostrou que a produtividade está interligada com a duração do período de cultivo, com um complexo de condições climáticas para o período primavera-verão. O ciclo de vida do tritcale depende da precipitação em maio e do complexo de condições em junho, do centeio de inverno – depende das temperaturas durante o período de semeadura-germinação, da soma das temperaturas ativas durante o período de cultivo.

Palavras-chave: centeio, tritcale, trigo, rendimento real e potencial.

ABSTRACT

The study of winter crop cultivars was carried out in the breeding fields of the Samara Agricultural Research Institute, located in the steppe zone of the Middle Volga region, in the nursery of competitive testing in 2002-2019. For calculations, 5 varieties of winter rye, 6 varieties of winter tritcale, and 2 varieties of winter wheat were taken. For scientific justification, the authors calculated the potential productivity (Y_p), the actual possible potential yield (Y_{pp} a), the maximum possible potential yield (Y_{pp} m), the bioclimatic potential (BCP), and correlation analysis. The study aims to calculate the possible yield of winter crops to substantiate the data obtained scientifically. In the dry conditions of Bezenchuk, the maximum yield of tritcale was obtained in 2017 – 7.48 t/ha, rye – 5.88 t/ha, and in 2016 for wheat – 4.65 t/ha. Potential productivity, taking into account $\sum T > 10^\circ\text{C}$ for the vegetation period of the crop, for tritcale in 2017, 3.02 t/ha, for winter rye in 2005, 6.83 t/ha, for winter wheat in 2005-2.79 t/ha. The variation of the indicator (BCP) over the years reached significantly higher values from 0.62 to 1.16 points for winter rye, from 0.30 to 0.60 for winter tritcale and winter wheat. The trend of the interrelations between yield is observed with the length of the vegetation period, with a set of climatic conditions for the spring-summer period. The tritcale vegetation duration depends on the precipitation in May and on the set of conditions in June. The winter rye vegetation duration depends on the temperatures during the sowing-germination period and on the sum of active temperatures during vegetation.

Keywords: rye, tritcale, wheat, actual, potential yield.

АННОТАЦИЯ

Исследования по изучению урожайности сортов озимых культур проводилось в 2002-2019 годах на селекционных полях Самарского НИИСХ, расположенных в степной зоне Среднего Заволжья. В эксперименте участвовали 5 сортов озимой ржи, 6 сортов озимого тритикале и 2 сорта озимой пшеницы. Производили подсчёт потенциальной продуктивности (Ут), действительно возможного потенциального урожая (Удву п), действительно возможного максимального урожая (Удву м), биоклиматического потенциала (БКП), корреляционного анализа. Цель работы: выявить потенциальные возможности озимых культур, научно обосновать полученные данные. Максимальный урожай тритикале был получен в 2017 году – 7.48 т/га, ржи-5.88 т/га, в 2016 году пшеницы 4.65 т/га. Рассчитанный, с учётом $\sum T > 10^{\circ}\text{C}$ за вегетацию культуры, потенциальный урожай для тритикале в 2017 году 3.02 т/га, для озимой ржи в 2005 году 6.83 т/га, для озимой пшеницы в 2005 году – 2.79 т/га. Существенно варьировал показатель (БКП) по годам: от 0.62 до 1.16 баллов для озимой ржи, от 0.30 до 0.60 для озимых тритикале и пшеницы. Корреляционный анализ показал, что урожайность взаимосвязана с продолжительностью вегетационного периода, с комплексом климатических условий за весенне-летний период. Жизненный цикл тритикале зависит от осадков мая месяца и от комплекса условий в июне, озимой ржи зависит от температур в период посева-всходов, от суммы активных температур за вегетацию.

Ключевые слова: *рожь, тритикале, пшеница, фактическая, потенциальная урожайность.*

1. INTRODUCTION:

At present, all over the territory of the Russian Federation and all over the world, unfavorable conditions for winter crops are developing (Kirchev *et al.*, 2016). There is a sharp increase in the continentality of the climate (Grabovets and Fomenko, 2015; Tuktarova, 2019; Goryanina and Medvedev, 2019). With traditional cultivation technology, more nutrients, and water required to bring crop yields to their climatic potential (Licker *et al.*, 2010; Ray *et al.*, 2012). The potential productivity is interconnected with the bioclimatic potential based on the regularity of changes in plant productivity, depending on climatic factors – heat and moisture. Traditional winter crops have a wide range of ecological plasticity in relation to a complex of environmental factors (Lonbani and Arzani, 2011; Fayaz and Arzani, 2011; Khalifeie and Mohammadi Nejad, 2012).

A theoretically estimated maximum yield is nothing more than potential productivity. The potential productivity must be measured by the number of fertile tillers, and the actual yield – by the number of grains per ear of a plant (Nasrallah *et al.*, 2020). Potential and actual yield depends on the number of productive stems, their grain size, and the mass of 1000 grains. The actual possible yield, in theory, is provided by the genetic potential of the varieties and limiting factors. In real conditions, an actual possible yield can only be obtained in fields with a sufficiently high fertility level (Williams *et al.*, 2020). On less fertile soils, yields will be, accordingly, lower than actually possible. One of the main factors limiting the

growth of crop productivity is the moisture supply of plants. Consequently, the yield value must be predicted by moisture in the meter layer of soil and the amount of precipitation during the vegetation period, taking into account the water consumption coefficient (Kukal and Irmak, 2020).

The insufficient number of new domestic crop varieties, in market conditions, is why a slow changing of seed variety and, accordingly, a limited choice. The created and cultivated varieties react rather weakly to improving the farming standards and the use of intensive cultivation technologies. It is not possible to fulfill its potential. This situation is due to the weak genetic protection against climatic stress factors. The development of new competitive cultivars, their comprehensive evaluation for targeted use is relevant, economically, and environmentally beneficial (Mahmood *et al.*, 2020; Vasco Silva *et al.*, 2020).

Domestic and foreign selectionists have created many highly productive cultivars, but their potential is revealed only with favorable thermal and moisture conditions (Wang *et al.*, 2020; Yang *et al.*, 2020). The situation is deteriorating sharply due to climate change. In the conditions of the Samara region, with the return of favorable years 3 times less frequently than dry years, it is challenging to fulfill the productivity potential. As a result, the elements of productivity vary greatly from year to year. Thus, the problem of counteracting unfavorable environmental factors and adaptability is highly relevant.

When planning and making management decisions, the main thing is the input parameters of the predicted values. Therefore, it is imperative

to provide a high-quality information base for decision-making by building sound forecasts of the main input parameters (Lichko and Shumskaya, 2007). It is possible to guarantee the objectivity of the reflection and the reality of the planned targets and the adoption of real management decisions, only under a reasonable forecast of the yield of crops. At present, it can be affirmed with mathematical precision that an integrated system for forecasting the development of agricultural production in the country does not exist. Research conducted by K.P. Lichko and E.V. Shumskaya (2007) indicates that the Russian Federation has not yet established strict terms for the development of forecasts at various government levels, there are no unified forecasting methods. As a biological property, productivity contains information about the optimal and actual values of many factors for the growing cycle phases (Khvorova and Gavrilovskaya, 2008).

For the arid conditions of the Middle Volga region, the topic of scientific programming of productivity is of particular relevance. In the Samara region, A.A. Vyushkov, S.N. Shevchenko (2008) studied the bioclimatic potential of spring crops. In their papers, the authors revealed the issues of the actual and potential formation of crop yields in the central zone of the Samara region. Potential and actual yield depend on the number of productive stems, their grain size, and the mass of 1000 grains (Kuperman *et al.*, 1980).

Purpose of the study, to calculate the possible yield of winter crops and scientifically substantiate the obtained data.

2. MATERIALS AND METHODS:

The Middle Volga region belongs to the zone of "risky farming". The sum of temperatures was more than 10 °C – 2563.5 ... 3061.7 °C, annual precipitation – 290.3 ... 596.7 mm (Goryanina, 2020). Severely arid conditions of spring-summer vegetation were observed in 2004, 2005, and 2006. (hydrothermic coefficient (HTC) = 0.23-0.34), spring vegetation April-May 2002, 2008, 2010, 2012 (HTC = 0.41-0.57) vegetation in the May in 2004, 2005, 2007, 2008, 2009, 2010, 2012, 2013, 2014, 2016, 2018 and 2019. (HTC = 0.12-0.58). Thus, the arid growing conditions for May were observed in 12 out of 18 studied years. Thus, for the triticale culture, unfavourable growing conditions developed in 2002, 2006, 2007, 2011, 2012, 2013, 2015, 2019, the average (normal growing conditions) – 2003, 2004, 2005, 2008, 2010 and 2018, favourable – in 2009, 2014, 2016 and 2017. For winter rye, since the culture

ripens earlier than triticale and, accordingly, a shift in the development phases was observed, unfavorable growing conditions developed in 2005, 2006, 2007, and 2019, the average (normal growing conditions) – 2002, 2003, 2004, 2008, 2010, 2012, 2013 and 2018, favorable – 2009, 2014, 2015, 2016 and 2017. In the medium term, there was no positive climate change. The calculation of the potential productivity of cultivars was carried out for 18 years (2002-2019).

Bioclimatic potential (BCP) indicates the productivity of plants under the conditions of the experiment. Productivity is the total biomass synthesized during the vegetation period [unit of mass/ (unit of area · unit of time)]. Coefficients of biological productivity by cultivars were calculated based on indicators of maximum and a minimum yield of crops (Equation 1). For winter rye $C_{bp} = 0.35-0.47$, wheat $C_{bp} = 0.24-0.28$, triticale $C_{bp} = 0.14-0.42$. Bioclimatic potential (BCP) was calculated taking into account the coefficients according to the formula of P.I. Koloskov (1963) (Equation 2), where: T – the average daily air temperature (the summation of its values for a calendar year was made for those days when it exceeds 10 °C); C_{bp} – coefficient of biological productivity of the cultivar, depending on moisture availability. Basic conditions for calculation: $\sum T > 10$ °C, the sum of the effective temperatures at the northern border of field agriculture was 1000 °C.

Potential productivity (Y_p) was a yield climatically provided by heat, dt/ha, calculated according to Equation 3, of M. K. Kayumov (1989), where: β – the maximum yield of cultivars, reflects the level of farming standards and the use of active photosynthetic radiation by crops. The main limiting factor that prevents obtaining high yields in the Samara region was the provision of crops with moisture. The actual possible potential yield (Y_{pp}) in terms of moisture supply was calculated taking into account the actual moisture reserves by the years of research and the optimal moisture requirement according to the formula of M.K. Kayumov (1989) (Equation 4), where: W – actual available moisture in the soil, m³/ha; R_w – water-use ratio, m³; C_{eff} – coefficient of plant ear efficiency.

Water-use ratio (R_w), i.e., moisture consumption for the formation of a unit of commodity weight of the crop at standard humidity. It was determined by the actual harvests for several years and was an integrated indicator that included effective soil fertility and the level of agricultural technology. High R_w values indicated a low agrotechnical level. With the growth of

agricultural technology, the introduction of farming intensification, the values of the indicator decreased and stabilized at a certain value (Equation 5), where: Y_a – actual yield of the main product at standard humidity, dt/ha; E – total water-use of crops during the vegetation period, mm. The maximum possible potential yield (Y_{pp} m) in terms of moisture supply was calculated using the same formula as the actual possible potential yield (Y_{pp} a), but according to the long-term annual average moisture reserves (W) in the soil 453.8 mm (Goryanin *et al.*, 2019) and the optimal moisture requirement according to M. K. Kayumov (1989). The optimal moisture requirement for winter crops (R_w) was 326 mm (Bykov, 1968). Correlation analysis of yield and elements of bioclimatic potential was calculated using Excel 2019 program.

To determine the yield of crops by the combination of the interaction of heat, light, and moisture, a model for determining the biohydrothermal potential (Equation 6) was used, where: K_p – biohydrothermal productivity potential, point; W – reserves of productive moisture before sowing, mm; T_v – growing season in decades; R – total PAR for the growing season, kJ/cm². This coefficient was calculated for each cultivar for each year of study. Further, in the aggregate of 18 years, favorable and unfavorable years were selected, and the average values were calculated. These indicators were taken as the basis for calculating the biological productivity of cultivars.

The research was carried out in the Samara Research Institute of Agriculture fields located in the chernozem steppe of the Samara Trans-Volga region. In the experiments, 5 varieties of winter rye, 2 varieties of winter soft wheat, 6 varieties of winter triticale were studied (Table 1). Rye (*Secale cereale* L.) has a fibrous root system that penetrates the soil to a depth of 1.5 m, more powerful than that of wheat. The stem is a hollow straw up to 1-1.5 m high, with 5-7 internodes. Leaves are linear, wider than wheat. The uvula is short, rounded at the top. Ears are short without cilia. Inflorescence – an ear, includes a rod on one two-flowered (rarely three-flowered) spikelet on the ledges. The awns are serrated. The grain is bare, elongated, narrowed towards the grain kernel, with a deep groove and tuft. The grain is greenish, yellow, light brown, gray. The mass of 1000 grains is from 28 to 40 g.

The peculiarity of winter rye is strong tillering in the fall, with the formation of up to 4-5 stems and rapid spring regrowth. Cross-pollinated (wind-pollinated) plant. Ripens 8-10 days earlier

than winter wheat. Winter rye is a relatively drought-resistant plant due to its powerful root system. The transpiration coefficient was from 265 to 420. The maximum moisture consumption occurs during the period of intensive growth – autumn earing and from tube to earing. Lack of moisture during this period leads to the formation of small and unproductive ears.

Winter wheat bushes in autumn and spring. Enhanced tillering is noted at sufficient humidity and a temperature of 8-10 °C. At temperatures less than 3-4 °C and moisture deficit, tillering stops. The toughness increases with the introduction of nitrogen fertilizers and when sowing with large seeds. Before leaving for winter, winter wheat forms 4-8 shoots, and the length of germinal roots on chernozem soils reaches 100-120 cm. The increased temperature and moisture deficit in the soil in the spring have a negative effect on tillering. Late formed stems are late with earing and form a fit, which causes uneven maturation.

The root system is capable of penetrating to a depth of 1.5 m. It makes good use of the moisture of the root layer. In the south of the country, soil moisture during the germination and autumn tillering period is the main factor for the normal growth and development of plants. When the moisture content in the 10 cm soil layer is higher than 10 mm, seedlings, appear evenly. Tillering occurs more vigorously if there is at least 30 mm of available moisture in the 20 cm soil layer. Autumn precipitation increases grain yields compared to straw yields. Spring precipitation leads to increased vegetative mass growth and creates favorable conditions for the emergence of new shoots. During spring awakening to earing, winter wheat spends about 70% of the total water requirement for the growing season, during the period from flowering to the gold ripeness of grain – 20%. The highest productivity was observed at a soil moisture content of 70-75% of the lowest (field) moisture capacity in the zone of the location of the main mass of roots, that is, up to 60 cm. The transpiration coefficient was 250-500.

Winter wheat is more drought-resistant than spring crops due to earlier grain formation and better use of autumn-spring precipitation. However, with dry spring, moisture deficit is possible, which occurs at the stage from entering the tube to hatching, during intensive growth. From the beginning of spring growth to hatching, wheat plants consume 70% of all water consumed during the growing season, from flowering to waxy ripeness – 20%. The total bushiness at the optimal sowing time for the autumn period is 3-6. Triticale

is a self-pollinating plant, but cross-pollination is possible. Ripening occurs 3-5 days later than winter wheat. The growing season is 250-325 days. Winter forms of triticale are relatively winter-hardy, withstand frosts down to -18 ... -20 °C in the zone of tillering node.

For the swelling and germination of triticale seeds, 50-60% of water is consumed from the mass of dry seeds. The highest productivity is noted when soil moisture is 65-75% of the lowest moisture capacity. The maximum moisture consumption occurs during the period of intensive growth – in the phase of tubing and during the formation and filling of the caryopsis. The critical temperature for winter forms in the tillering node zone was up to 18-20°C. In winter and spring, triticale was less sensitive to low temperatures than winter wheat. Triticale bushes more in autumn and continues in spring. The total bushiness in autumn at the optimum sowing time was 3-6. The optimum temperature for seed germination is 20 °C, the minimum is 5 °C and the maximum is 35 °C. Triticale seedlings appear on the 5-7th day after sowing.

Sowing was carried out at the optimal time for the research area (2nd decade of August for winter rye, 3rd decade of August-1st decade of September for wheat and triticale), the area of the plots is 20m², fourfold replication, the predecessor was pure fallow. In the spring, on the sowing of the studied crops, the harrowing of the crops was carried out, the application of fertilizers (ammonium nitrate, 30 kg a.i. each), the treatment with the herbicide Disulam 0.5 l/ha. The standard of winter triticale is Krokha variety, zoned for the Middle Volga region. The standard of winter rye is Antares variety, zoned for the Middle Volga region. The standard of winter wheat is Malakhit variety, zoned for the Middle Volga region.

Sowing was carried out with a CH 10c seeder, the seeding rate was calculated for each crop and variety separately according to the formula. The seeding rate was set by weight (weight of 1000 seeds) and the number of seeds sown per hectare. The weight seeding rate (WSR) is determined by the formula (Equation 7), where: M – the mass of 1000 seeds, N – the number of millions of clean and viable seeds sown per 1 ha in a certain zone of Russia. The coefficient for the Volga region was 4.0-4.5 million viable seeds per hectare for wheat and triticale and 4.5-5.0 million viable seeds per hectare for rye. In reality, the seed material has a seed yield below 100%. Therefore, the growing rate must be adjusted for the actual sowing capacity. The correction for the actual seed yield was calculated using the formula

(Equation 8). Next, the seeding rate was determined, taking into account the germination ability (Equation 9). Mineral fertilizers were not used. Harvesting was carried out by direct combining Sampo 130. The research was carried out in the nursery of competitive variety trials in 4 repetitions, the location of plots was randomized.

3. RESULTS AND DISCUSSION:

Based on the indicators of the maximum and minimum yield of crops, the coefficients of biological productivity were determined for studied cultivars. For winter rye Cbp = 0.35-0.47, winter wheat Cbp = 0.24-0.28, winter triticale Cbp = 0.14-0.42. Taking these factors into account, the bioclimatic potential (BCP) was calculated (Table 2). The variation of the indicator (BCP) over the years reached significantly higher values from 0.62 to 1.16 points for winter rye, from 0.30 to 0.60 for winter triticale and winter wheat. The effects of climate and the consequences of its changes have not been equally reflected in cultures. In arid conditions of the urban-type settlement Bezenchuk, the maximum yield of triticale was obtained in 2017 – 7.48 t/ha, rye – 5.88 t/ha, and in 2016 – 4.65 t/ha for wheat. Potential productivity, taking into account $\sum T > 10$ °C for the vegetation period, for triticale in 2017 is 3.02 t/ha, for winter rye in 2005 6.83 t/ha, for winter wheat in 2005 – 2.79 t/ha. The actual crop yields varied greatly and differed from the potential. The potential of the cultivars was revealed only under extreme conditions. The same conclusions were reached by A. A. Fedotov *et al.* (2014), S. Asseng *et al.* (2011).

In dry and average years, the potential productivity prevailed over the actual yield: for rye, the potential productivity was 4.06-6.83 t/ha, the actual yield was 1.92-4.31 t/ha, and for wheat, the potential productivity was 1.91-2.79 t/ha, and the actual yield was 0.93-1.97 t/ha. For the triticale crop in dry years, the potential productivity prevailed (2.01-2.99 t/ha) over the actual (1.28-2.39 t/ha). The actual yield is higher for the triticale crop than the potential in average and favorable years (2.56-7.48 t/ha and 2.13-3.02 t/ha). For wheat (1.74-4.65 t/ha and 1.58-2.18 t/ha) and rye (4.52-5.88 t/ha and 4.19-4.97 t/ha), respectively, the actual yield prevails over the potential in favorable years. However, for winter rye in favorable 2015 and 2016 years, the potential productivity (5.24-5.34 t/ha) prevailed over the actual yield (4.39-4.58 t/ha). During these years, not all resources were used.

The main limiting factor that prevents the

high yields in the Samara region is the provision of crops with moisture. Potential grain yield, calculated based on actual moisture reserves, is higher in almost all years than the actual yield (Table 3). From this, it was concluded that crops do not consume all moisture during the vegetation period. The taxonomy is observed only for winter wheat. The potential yield (1.78-9.64 t/ha) prevailed over the actual (0.93-3.86 t/ha) in all study years. The potential yield in dry years prevailed over the actual yield in rye and triticale in terms of moisture supply. So, for winter rye, the potential yield was 3.46-8.21 t/ha, and the actual 1.92-2.88 t/ha, for triticale, respectively 2.92-6.95 t/ha and 1.28-2.39 t/ha. In the average statistical and favorable years, there was no taxonomy for triticale and rye crops. In some years (2003, 2004, 2005, 2008, 2014, 2017, 2018) for triticale, there was an excess of potential yields (4.60-9.61 t/ha) over the actual (2.70-7.48 t/ha), and in some (2009, 2010, 2016), the actual yield (2.56-5.59 t/ha) prevailed over the potential (1.68-3.19 t/ha). For winter rye, the actual yield (2.81-4.58 t/ha) prevailed over the theoretical (1.98-3.98 t/ha) in 2002, 2010, 2015, and 2016. Based on the data obtained, these crops do not use moisture sufficiently during the vegetation period. The maximum yield was obtained based on the average annual moisture reserves in all years. Thus, it is theoretically possible to obtain a significantly higher grain yield.

Correlation analysis of yield with climate elements and bioclimatic potential for 2002-2019 revealed significant differences in the influence of growing conditions on crops. According to the data obtained, the triticale yield is significantly correlated with the HTC for April-June ($r=0.63^{**}\pm 0.15$) (** – favorable conditions growing season). At a low level, a correlation is observed with the total precipitation in April ($r=0.27\pm 0.22$), May ($r=0.24\pm 0.23$), May-June ($r=0.32\pm 0.22$), precipitation during the vegetation period ($r=0.23\pm 0.24$), air temperature in May-June ($r=-0.32\pm 0.22$), HTC for May ($r=0.36\pm 0.21$), for June ($r=0.28\pm 0.22$). For winter rye, there is a significantly greater number of interrelations with yield. The duration of the vegetation period ($r=0.61^{**}\pm 0.15$) is observed significant at the 001% level. The average yield of rye depends on air temperatures during the sowing-germination period ($r=-0.40\pm 0.20$), on the sum of active temperatures ($r=0.46\pm 0.19$), HTC of April-June ($r=0.45\pm 0.19$). At a low level, a correlation is observed with the bioclimatic potential ($r=-0.31\pm 0.22$), the total precipitation for August-September ($r=0.31\pm 0.22$), for November-March ($r=-0.28\pm 0.22$), for April ($r=0.28\pm 0.22$), May

($r=0.24\pm 0.23$), temperature in May ($r=-0.25\pm 0.23$), HTC for August-September ($r=0.30\pm 0.22$), and for May ($r=0.21\pm 0.22$).

Studies of the dependence of yield on climatic conditions have revealed a much bigger dependence between yield and vegetation conditions in the autumn for winter rye. The triticale yield is much more interrelated with the climatic conditions of the vegetation period in the spring and summer. The potential productivity (Y_p) for triticale is significantly correlated with the bioclimatic potential ($r=0.61^{**}\pm 0.15$) and the sum of temperatures for the vegetation period ($r=0.85^{**}\pm 0.07$) for winter rye with bioclimatic potential ($r=0.97^{**}\pm 0.01$).

Actual possible yield calculated from the moisture content significantly correlates for the triticale cultivar with the amount of precipitation for August-September ($r=0.59^{**}\pm 0.16$), May-June ($r=0.79^{**}\pm 0.09$), during the vegetation period ($r=0.97^{**}\pm 0.0$), air temperature in May-June ($r=-0.50^*\pm 0.18$), HTC in August-September ($r=0.57^{**}\pm 0.16$), April-June ($r=0.63^{**}\pm 0.15$), June ($r=0.60^*\pm$). For winter rye, this indicator shows significantly less interrelations with the total precipitation in May-June ($r=0.78^{**}\pm 0.09$), precipitation during the vegetation period ($r=0.91^{**}\pm 0.04$), and the temperature in May-June ($r=-0.49^*\pm 0.18$), November-March ($r=0.55^*\pm 0.17$), HTC in June ($r=0.69^{**}\pm 0.13$). The yield of rye, calculated from the average long-term moisture supply, significantly correlates with the November-March temperature ($r=0.55^*\pm 0.17$). The grain yield calculated for the rye crop is interrelated with the duration of the vegetation period ($r=0.51^*\pm 0.18$) (* – arid conditions of spring-summer vegetation). The duration of the triticale vegetation period depends on the amount of precipitation in May ($r=0.51^*\pm 0.18$), HTC in June ($r=0.51^*\pm 0.18$). In winter rye, the duration of the vegetation depends on the air temperatures of the autumn ($r=-0.63^{**}\pm 0.15$), the entire vegetation period ($r=0.76^{**}\pm 0.10$). For the triticale culture, the dependence of the HTC on the temperatures of August-September ($r=0.47^*\pm 0.19$) and the sum of temperatures for the vegetation period ($r=0.78^{**}\pm 0.09$).

The tendency for the interrelation of productivity for both rye and triticale is observed throughout the vegetation period ($r=-0.20-0.66^{**}$), with a complex of climatic conditions for the spring-summer period ($r=0.45-0.63^{**}$). The duration of the triticale vegetation period depends on the precipitation in May ($r=0.51^*\pm 0.18$) and on the complex of conditions in June ($r=0.51^*\pm 0.18$). The duration of the rye vegetation period depends on

the temperatures during the sowing-germination period ($r=-0.63^{**}\pm 0.18$), on the sum of active temperatures during the vegetation period ($r=0.76^{**}\pm 0.10$). The data obtained indicate that the reason for the insufficient crop yields is not a low BCP, but its critically weak implementation, reaching in some years 40% of the potential. An important role also belongs to introducing adapted highly productive cultivars and the improvement of cultivation technology.

However, with this calculation, it is necessary to consider the unpredictability of the number of precipitations for the following agricultural year. Moreover, suppose the attention is focused on the average long-term moisture reserves in the soil, then in years with precipitation above the norm. In that case, significant losses in the yield are possible because other factors may appear in the first minimum. Therefore, when programming yields, the author suggests focusing not on average long-term reserves but on moisture reserves corresponding to climatically optimal ones. This means that the yield should be estimated by such a level of moisture supply, which will make it possible to benefit from an increase in yield in favorable years and cover losses from the cost of fertilizing and the formation of a sowing structure in unfavorable years. Thus, the gain from additional annual harvest costs in favorable years should be higher than the sum of these costs in unfavorable years.

Over the exploration period, noticeable climate changes were revealed. In studies, $t^{\circ}\text{C}$ in May 2002 was 11.4°C , in 2018 – 16.3°C . The average temperature of this month over 18 years is 15.9°C . The temperature rise during the period was 0.28°C per year. The air temperature in May-June in 2002 was 14.3°C ; in 2018 – 17.2°C . Average over 18 years, during this period – 17.6°C . The increase is 0.21°C per year. The temperature in April-May in 2002 was 8.2°C ; in 2018 – 10.9°C . The average temperature over 18 years over this period is 11.5°C . Based on this, the increase is 0.21°C . The authors noted an increase in air temperature during the sowing of winter crops in August-September. If in 2002 and 2003 it was 15.8°C , then by 2018 it was 17.5°C . The average over 18 years, during this period, is 17.3°C . The increase is 0.09°C per year.

The time of active vegetation of plants is from April to June. From an agricultural standpoint, the manifestation of droughts in these months is important. Drought trends can be monitored using the hydrothermic coefficient (a comprehensive indicator of the provision of plants with moisture and heat). Of the years analyzed, during the

sowing-germination period, severely arid conditions were observed for 4 years (2006, 2011, 2016, and 2018), with hydrothermic coefficient = 0.13-0.34. At the same time, dry conditions were noted in 9 out of 18 years ($\text{HTC} = 0.13-0.59$).

On average, over the years of the study, the duration of the winter period was 176 days, ranging from 151 days (2014) to 199 days (2010). Modern cultivars created in the Samara Research Institute of Agriculture are distinguished by high winter hardiness. However, low air temperatures, in the absence of snow cover, negatively affect the crops. The average long-term sum of winter temperatures below 0°C (November-March) was -107.4°C . Thus, winters with a sum of negative temperatures for November-March of -73°C and less are warm, $-81-92^{\circ}\text{C}$ is the norm, more than -119°C are cold. The height of the snow cover, on average, over 17 years, amounted to 27.9 cm. Proceeding from this, the winters before 2003, 2005, 2006, 2008, 2010, 2011, 2012, 2017, and 2018 harvest were favorable (the height of the snow cover is 26.5-37.1 cm, $\Sigma t^{\circ}\text{C} = -106.0-154.3^{\circ}\text{C}$).

Warm winters preceded the 2002, 2004, 2007, 2009, 2013 and 2019 harvests (snow depth 11.5-18.1 cm, $\Sigma t^{\circ}\text{C} = -69.4-98.9^{\circ}\text{C}$). Abnormally warm winters preceded 2014, 2015, and 2016 harvests (snow depth 21.0-33.8 cm, $\Sigma t^{\circ}\text{C} = -55.1-99.7^{\circ}\text{C}$). Severely arid spring-summer conditions were observed in 2004, 2005 and 2006, $\text{HTC} = 0.23-0.34$. In the spring period April-May, dry conditions were in 2002, 2008, 2010, 2012 $\text{HTC} = 0.41-0.57$. In 2004, 2005, 2007, 2008, 2009, 2010, 2012, 2013, 2014, 2016, 2018, and 2019, the driest month of May was observed in 12 years out of 18 studied. The mean annual precipitation for April-May was 55.6 mm. A severely arid spring period was observed in 2002, 2005, 2008, 2010 ($\Sigma o = 20.1-27.4$ mm). An analysis of the summer period (May-June) indicated a lack of precipitation in 13 years out of 18 considered (11.4-74.7% of the norm).

It is advisable to associate the manifestation of droughts with the level of productivity. The yield level is significantly related to the level of moisture supply and temperature regime. Studies have shown that the grain yield was largely determined by the growing conditions of May and June. The low yield in 2002 is explained by the lack of precipitation in the spring ($\text{HTC} = 0.57$). During this period, the laying of the future harvest takes place. In 2006, the dry conditions of the autumn period ($\text{HTC} = 0.02$) and June ($\text{HTC} = 0.33$). In June, flowering and formation of caryopses take place. In 2007, the

lack of precipitation ($\Sigma o = 10.3$) and increased temperatures (16.7°C), $\text{HTC} = 0.22$, led to a decrease in yield. In 2011, the dry conditions of the autumn period ($\text{HTC} = 0.26$) contributed to uneven germination. In the spring, the crops have not leveled off. In 2012, the yield was reduced by the dry conditions of May ($\text{HTC} = 0.41$). In 2013, the decline in yields was due to the dry conditions in May ($\text{HTC} = 0.36$) and June ($\text{HTC} = 0.27$). In 2015, the dry conditions of the autumn period ($\text{HTC} = 0.48$) and June ($\text{HTC} = 0.21$) reduced yields. The average duration of the spring-summer period (April-July), over the years of research, was 100 days. A significant fluctuation in the duration of this period from 113-119 days (2002 and 2006) to 88-90 days (2010, 2013, 2018) was established.

To obtain preplanned yields, it is necessary to know the potential of the cultivar (variety). In natural conditions, the potential of the same cultivar varies depending on the growing area. Such data can be obtained by conducting direct experiments or using the materials of state variety sections. With such data, it is possible to select varieties that will make better solar energy use during the growing season. Thus, one of the principles of yield planning is to determine the potential of the variety concerning the conditions where the variety is supposed to be cultivated. Productivity is determined not only by the biological characteristics of the crop but also by its cultivation conditions. When preplanning the yield, it is necessary to take into account and correctly apply the basic laws of agriculture and crop production.

Agricultural science has accumulated a large amount of experimental material on the water consumption of various cultivated plants. The optimal soil moisture has been established at different stages of development of any type of field crop. The critical periods in the development of various crops concerning moisture are clearly defined. Based on the foregoing, the principle of planning yields is to meet the needs of plants for water in optimal sizes in irrigated agriculture and in rainfed conditions to determine the yield level based on the prevailing climatic conditions.

In the conditions of rainfed agriculture, it seems possible to determine the probable water regime of plants based on meteorological data and calculate the water balance and yield level. The accumulation of reliable experimental data on obtaining a pre-calculated yield allows us to approach mathematical modeling of the yield. The obtained data are mathematically processed to determine the optimal variant of the complex of agricultural practices, which will ensure the receipt

of the planned harvest. Thus, crop programming covers three main aspects – agrometeorological, agrophysical, and agrotechnical. Factors reasonably taken into account and applied in a complex combination make it possible to grow planned yields.

With an increase in photosynthetic productivity and solar radiation utilization, it is possible to increase the yield. The implementation of photosynthetic activity in grain harvest depends on its distribution and use by plants. Figures 1 and 2 show the distribution of photosynthetic energy. To construct the scheme, averaged data on crops for favorable and unfavorable years were used. Organic products formed during photosynthesis are distributed, in addition to grain, respiration, root system, leaves, and stems. According to the data obtained, the photosynthesizing surface distribution in drought and favorable years is different. In unfavorable years, the plant spends much energy on breathing. The ratio of grain to straw is 1:4. In terms of moisture supply, a significantly larger biomass is formed before harvesting in favorable years, and the ratio of grain to straw is 1:2.5.

Thus, when plants are deficient in moisture and nutrients, an unsatisfactory absorption of PAR occurs. Varieties of triticale, wheat, and rye differ in height, size of leaf surface, but in dry conditions, these differences are not compensated. At any rate, it cannot develop a large mass of leaves if moisture and nutrients are absent. Nevertheless, in favorable conditions, the leaf surface develops as much as possible. The yield is then influenced by the properties of the plants themselves, their ability to efficiently use thermal and water resources. And thus, the role of the variety increases. The calculations used the average grain: straw ratio for winter rye 1:1.5 ($L = 2.5$), for triticale 1:2 ($L = 3$), for wheat 1:2 ($L = 3$). The highest rate of PAR arrival was noted in 2009 and 2017 (161.15 and 163.7 kJ/cm^2). The minimum arrival of PAR was noted in 2011 and 2018 (122.21 and 129.29 kJ/cm^2). Based on the indicator of the arrival of PAR, years can be conditionally divided into dry ($Q \text{ PAR} = 122.21\text{-}138.65 \text{ kJ/cm}^2$) and favorable ($Q \text{ PAR} = 140.69\text{-}161.15 \text{ kJ/cm}^2$). Thus, it turns out that 2003, 2004, 2005, 2006, 2010, 2011, 2012, 2015, 2018, and 2019 were dry years, and 2002, 2007, 2008, 2009, 2013, 2014, 2016, and 2017 were favourable.

4. CONCLUSIONS:

Based on the data obtained, it can be concluded that winter crops do not use moisture

sufficiently during the vegetation period. The maximum yield was obtained based on the average annual moisture reserves in all years. Thus, it is theoretically possible to obtain a significantly higher grain yield in dry years. The indicator (BCP) varied significantly over the years for winter rye from 0.62 to 1.16 points, much less for winter triticale and winter wheat 0.30 to 0.60.

Thus, the high-performance potential of the cultivars of the Samara Research Institute of Agriculture has been revealed. In some years, low productivity is caused not by the low BCP, but by its critically weak implementation, reaching 40% of the potential. With the improvement of the cultivation technology, the cultivars can grow intensively with a lack of moisture, form a good strong root system, a well-developed conductive stem system, and a large ear that can intensively use the flow of thermal energy.

Another significant factor that needs to be taken into account is the irregularity of precipitations in the agro-climatic regions of a certain region. In this regard, the calculation of actual possible yields based on the average annual moisture supply and climatically optimal moisture supply should be carried out differentially for each specific region and for each field, taking into account the soil characteristics and terrain. Calculation of the potential productivity of winter cereal crops allows to foresee possible options for the production structure of the enterprise, the size of the branches of agricultural production, analyze the current situation and coordinate the results with the strategic goals and objectives of the agricultural facility, i.e., determine the development strategy of the organization.

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$$C_{bp} = Y_{min} / Y_{max} \quad (\text{Eq. 1})$$

$$BCP = C_{bp} \times \frac{\sum t > 10^{\circ}C}{1000^{\circ}C} \quad (\text{Eq. 2})$$

$$Y_p = \beta \times BCP \quad (\text{Eq. 3})$$

$$Y_{ppa} = \frac{W \times 100}{R_w} \times C_{eff} \quad (\text{Eq. 4})$$

$$R_w = \frac{E}{Y_a} \quad (\text{Eq. 5})$$

$$Kp = \frac{W \times Tv}{8.595 \times R} \quad (\text{Eq. 6})$$

$$\text{WSR} = M \times N \quad (\text{Eq. 7})$$

$$\text{PG} = \text{Purity} \times \text{Germination} / 100 \quad (\text{Eq. 8})$$

$$\text{SAR} = \frac{M \times N \times 100}{GA} \quad (\text{Eq. 9})$$

Table 1. Cultivars used in research

No.	Cultivars of crops	Year of zoning	Region	Yield 2014-2019, t/ha
1	Antares, winter rye	2002	7	44.5
2	Bezenchukskaya 87, winter rye	1993	4,5,7	44.0
3	Olga, winter rye	-	-	47.9
4	Roxana, winter rye	-	-	42.3
5	Bezenchukskaya 110, winter rye	2019	7	43.6
6	Malakhit, winter wheat	2000	7	32.6
7	Biryuza, winter wheat	2008	4,5,7	31.1
8	Krokha, winter triticale	2014	7	36.1
9	Capella, winter triticale	2019	7	39.7
10	Spica, winter triticale	-	-	43.0
11	Arcturus, winter triticale	-	-	42.4
12	Vasilisa, winter triticale	-	-	45.3
13	Stepanida, winter triticale	-	-	42.3

Table 2. Actual and potential productivity

Years*	Cultivar	Vegetation, days	$\sum T > 10^{\circ}\text{C}$ during vegetation	Grain yield, t/ha	BCP, score	Yp, t/ha
2006	rye	166	2349.6	2.68	0.93	5.45
	triticale	158	2349.6	1.80	0.56	2.68
	wheat	155	2106.9	1.29	0.47	2.18
2007	rye	156	1746.3	2.39	0.69	4.06
	triticale	152	1757.3	2.09	0.42	2.01
	wheat	152	1757.3	2.30	0.35	1.63
2016	rye	124	2252.4	4.58	0.89	5.24
	triticale	126	2067.2	5.59	0.42	2.57
	wheat	123	1826.3	4.65	0.45	2.09
2017	rye	145	1797.8	5.88	0.72	4.19
	triticale	147	2422.5	7.48	0.49	3.02
	wheat	148	2197.8	3.76	0.36	2.05

Note: * the table includes years with contrasting moisture supply.

Table 3. Actual possible potential yield by moisture consumption

Years*	Cultivar	Precipitation during the vegetation, mm	Ceff, %	Grain yield, t/ha	Ypp a, t/ha	Ypp m, t/ha
2006	rye	154.3	0.82	2.68	3.83	11.35
	triticale		0.71	1.80	3.32	9.83
	wheat		0.73	1.29	3.44	10.17
2007	rye	339.8	0.79	2.39	8.21	10.97
	triticale		0.67	2.09	6.95	9.29
	wheat		0.69	2.30	7.23	9.66
2016	rye	130.4	0.78	4.58	3.14	10.91
	triticale		0.76	5.59	3.04	10.56
	wheat		-	4.65	-	-
2017	rye	398.0	0.82	5.88	7.88	11.47
	triticale		0.79	7.48	9.61	10.95
	wheat		0.79	3.76	9.64	10.98

Note: * the table includes years with contrasting moisture supply.

Figure 1. The distribution diagram of the photosynthesis elements in unfavorable years

Figure 2. The distribution diagram of the photosynthesis elements in favorable years