Dependence of winter wheat yield by various precedors on growing conditions in the steppe Crimea

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Abstract. The materials of two-factor field experiments conducted in the steppe Crimea over the past 18 years are presented, on the basis of which mathematical and statistical models were developed that describe the dependence of the formation of winter wheat yield on the predecessors black fallow, occupied fallow, corn for silage, sunflower, winter wheat stubble on growing conditions. It is proposed to use them in the development of digital agricultural technology for winter wheat.

1 Introduction

Currently, one of the main areas of development and efficiency improvement of the agro-industrial complex is its digital transformation. By the order of the Government of the Russian Federation and the project of the Ministry of Agriculture of the Russian Federation "Digital Agriculture", development and implementation of digital technologies and platform solutions to ensure a technological breakthrough in the agro-industrial complex is being provided [1, 2]. "Digital farming" is actively developing, using big data tools, digital modeling of agricultural technologies, all production processes in crop production.

To make optimal or rational agro-technological decisions, it is necessary to have appropriate digital models that adequately describe the formation of crop yield from the main agro-technical factors and growing conditions.

In this regard, at this stage, in order to develop digital agricultural technology for growing winter wheat, it is necessary to establish quantitative dependencies, patterns of formation of its productivity from the parameters of the complex of agricultural practices and the actual growing conditions.

In the formation of winter wheat productivity from agrotechnical factors, one of the most significant roles is played by predecessors [3, 4, 5, 6]. Therefore, in this article we present the results of modelling the dependence of the yield of winter wheat grown at different predecessors on growing conditions. Subsequently, they will be used to create a digital agricultural technology for growing winter wheat.

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2 Material and methods of research

The materials presented in the article were obtained in two-factor field experiments in which the influence of five predecessors (black fallow, occupied fallow, corn for silage, sunflower, winter wheat) and ten increasing doses of nitrogen fertilizers (applied to thawed soil in early spring before the resumption of vegetation at doses from 0 to 180 kg/ha of active ingredient), as well as growing conditions on the formation of winter wheat crop productivity was studied. Winter legume-cereal mixture was sown in occupied fallow for green forage. The experiments were carried out over the past 18 years (2004 - 2022) in the experimental field of the Institute of Agrotechnological Academy of the V.I. Vernadsky Crimean Federal University. They were laid out using the split plot method in three replicates. The studied doses of nitrogen were applied manually to the plots in early spring before the resumption of vegetation on thawed frozen soil. In the fall, only a nitrogen background sufficient for autumn vegetation was provided. On all the studied predecessors diagnostics of nitrate nitrogen in the soil layer (0-40 cm) were carried out before sowing wheat. Based on its results, the amount of nitrogen missing to the total level of N_{70} was "added" manually before sowing wheat, under pre-sowing cultivation. The form of nitrogen fertilizer was ammonium nitrate. Otherwise, the agricultural technology in the experiments was one generally accepted for Crimea.

The accounting area of the plot of the last order was 36.0 m^2. The crop was harvested plot by plot by direct combining. Primary data on grain yield were reduced to basic moisture and 100% purity.

The soil of the experimental plot is southern carbonate chernozem with a humus content of 3.5–4.1% in the arable layer, 3.2–3.8% mobile phosphorus, and 36.5–42.5 mg of exchangeable potassium in 100 g of dry soil. Phosphorus fertilizers (P_{10}) were applied only during sowing of winter wheat, since the content of mobile phosphorus in the experimental plots was high. Potassium fertilizers were not applied due to the high content of exchangeable potassium in the soils of the experimental plots. Winter wheat of the Tanya variety was sown in the experiments. The research materials presented in the article were analyzed using the regression method. To assess the effect of growing conditions on the yield of winter wheat, the parameter proposed by L.V. Smiryaev and M.V. Gohman was used (1985) – index of conditions, established by the arithmetic mean value of the studied feature (in our case – the average yield values for the variants in the years of research) based on the use of the method of inverse regression at the middle, which they improved. Such an improved method of regression at the middle, with comparative simplicity and adequacy of models, has a significantly higher resolution in comparison with other models. In its essence, it is one of the possible mathematical expressions of the method of assessing the environment using the plants themselves, applied in geobotany and ecology [7].

3 Results and discussion

According to a number of domestic and foreign researchers, the yield increase obtained when cultivating winter wheat with a good predecessor reaches 40...60%, i.e. more than from fertilizers, variety or other factors. The share of their influence on the final yield of winter wheat among other agricultural practices ranged from 11% on occupied fallow to 39% on sunflower and stubble. The role of the predecessor is higher, the lower the soil fertility and the level of agricultural technology of the crop [8, 9, 10].

As a result of numerous works, the best and worst predecessors have been identified for all soil and climate zones, both in terms of winter wheat yield and in terms of obtaining good quality grain [3, 4, 5, 6]. However, the need to develop digital agricultural technology has determined the practicability of returning to assessing the role and effectiveness of predecessors in order to quantitatively evaluate the strength and nature of their impact on the productivity of winter wheat, that was not done in previous studies, which allowed mainly to establish only qualitative differences in predecessors in terms of their impact on the productivity of winter wheat, without their proper quantitative assessment, which is necessary to create digital models of agricultural technologies.

Due to the different water availability, winter wheat plants develop differently after different predecessors and react in another way to weather conditions, as evidenced by the variability of its yield [11, 12, 13]. The coefficient of variation in wheat yield by year on fallows is the lowest. For black fallow it is 21.4%, for occupied fallow - 26.7%. Wheat yield varies to a greater extent after non-fallow predecessors, since its value is more significantly affected by precipitation during the warm growing season (late spring and summer). The coefficient of variation by year on non-fallow predecessors is significantly higher - 30 - 32% [9, 10].

The data obtained in our studies, presented in Table 1, confirm a smaller variation in the yield of winter wheat for fallow predecessors (25.18% and 29.21%, respectively, for black and occupied fallow) in comparison with non-fallow predecessors - silage corn (39.96%) and sunflower (31.02%).

Table 1. Summary statistics on winter wheat yield depending on the predecessor

Indicators	Predecessors				
	Black falloow	Occupied fallow	Corn for silage	Sun-flower	Winter wheat
Average, c/ha	45,3	39,9	32,8	29,3	25,0
Standard deviation	11,41	11,65	10,48	9,10	6,98
Coeff. of variation, %	25,18	29,21	31,96	31,02	27,90
Minimum, c/ha	26,7	21,4	16,4	15,0	13,8
Maximum, c/ha	63,1	58,4	49,7	44,0	36,1
Range, c/ha	36,4	37,0	33,3	29,0	22,3

For the winter wheat stubble predecessor, the yield variation coefficient was lower compared to other non-fallow predecessors, amounting to 27.9% and was at the level of fallow predecessors. For all studied predecessors, yield variability was strong.

Black and occupied fallows are characterized by a greater dispersion of wheat yield values (standard deviation, respectively, 11.41 and 11.65) compared to non-fallow predecessors. For predecessors corn for silage, sunflower and winter wheat stubble, the standard deviations are 10.48; 9.10 and 6.98, respectively, which indicates a smaller dispersion of data across the years of research.

The range of variation in wheat yield over 18 years of experiments was greatest for black and occupied fallows (36.4 and 37.0 c/ha), less for corn for silage (33.3 c/ha), somewhat lower for sunflower (29.0 c/ha), and the least for winter wheat stubble (22.3 c/ha).

Regression analysis of the data from our studies allowed us to establish the nature of the dependence of winter wheat productivity for each predecessor on growing conditions, which is described by the corresponding equations presented in Table 2.

The given equations with high probability, above 95%, show that the yield of winter wheat for different predecessors largely depends on growing conditions. The latter in Crimea for predecessors black and occupied fallow, corn and sunflower mainly (determination coefficients R^2 are respectively equal to 0.86; 0.91; 0.94; 0.89) determine the level of variability of crop productivity. For the predecessor, winter wheat stubble, growing conditions affect the variation of crop yield to a lesser extent (R^2 = 0.53). The high significance and determination of the regression equations developed by us indicate their suitability for use in the developed digital agricultural technologies for winter wheat.

Table 2. Regression equations for the dependence of winter wheat yield (Y) for different predecessors on growing conditions (X)

Predecessor	Regression equation	R	R^2	P-value
Black fallow	$Ybf=2{,}0058983*X^{0{,}86464}$	0,93	0,86	0,0000
Occupied fallow	$Yof=1{,}0258956*X^{1{,}013458}$	0,95	0,91	0,0000
Corn for silage	$Ycs=0{,}5831569*X^{1{,}114346}$	0,97	0,94	0,0000
Sunflower	$Ysr=0{,}5913271*X^{1{,}080378}$	0,94	0,89	0,0000
Winter wheat	$Yww=0{,}768659*X^{0{,}964648}$	0,73	0,53	0,0000

Our research also allowed us to establish the nature of the influence of growing conditions on the productivity of winter wheat for each of the studied predecessors – black fallow (1), occupied fallow (2), silage corn (3), sunflower (4), and winter wheat stubble (5) (Fig. 1).

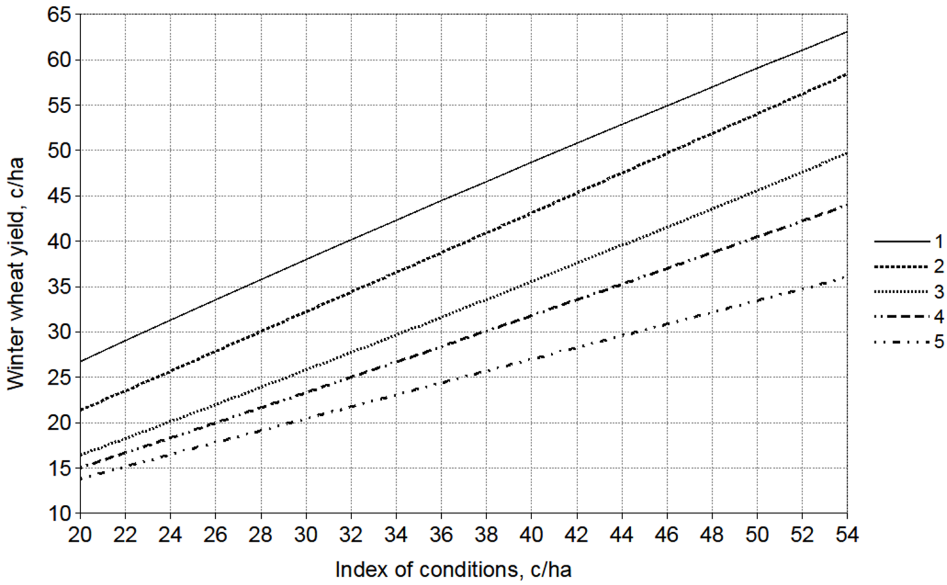

Fig. 1. Dependence of winter wheat yield at different predecessors on growing conditions.

The yield of winter wheat is higher on fallow predecessors in comparison with non-fallow ones and when growing conditions change from worse to better it increases synchronously, identically, almost in parallel. Its value is consistently higher on black fallow in comparison with occupied fallow.

The nature of the increase in winter wheat yield on non-fallow predecessors as the growing conditions improve is somewhat different than on fallows. At low indices of growing conditions, the yield of wheat on them is very close, differing insignificantly. It is higher on silage corn, lower on sunflower and the lowest on winter wheat stubble. As the index of conditions increases, the differences in the yield between these predecessors increase. In more favorable conditions, winter wheat is most productive on silage corn compared to its placement after sunflower.

The nature of the change in winter wheat yield depending on the growing conditions for the winter wheat stubble predecessor does not have synchronicity, such similarity as for fallow predecessors. The discrepancies in the value of wheat yield increase in comparison with other non-fallow predecessors as the growing conditions improve. The response of the increase in yield to the increase in the index of conditions for this predecessor is the smallest.

Thus, the patterns of dependence of winter wheat yield on growing conditions for various predecessors, established and quantitatively described by us using regression analysis, are quite applicable for use in the development of digital agricultural technology for winter wheat.

4 Conclusions

The materials we have obtained over the past 18 years in two-factor field experiments have allowed us to develop for the first time for the steppe part of the Crimean peninsula regression models of the dependence of winter wheat yield on predecessors black fallow, occupied fallow, silage corn, sunflower, winter wheat stubble on growing conditions, which quantitatively with a high level of significance describe the nature of the influence of the identified patterns, which is necessary for the creation of a digital technology for growing winter wheat in Crimea.

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