Growing grain of winter wheat without the use of herbicides

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Abstract. The models for predicting the contamination of winter wheat crops are presented, including a method of tillage, sowing time and sowing density. They make it possible, after appropriate calculations, to establish the parameters of agricultural practices, the use of which allows growing high grain yield of winter wheat without the use of herbicides, thereby making its growing technology more environmentally friendly and less energy-intensive, reducing not only the cost of grain but also natural environment pollution.

1. Introduction
As known, in the south of Russia, winter wheat is the main grain food crop. Weed control is one of the most important tasks in the technology of growing this crop. The development of weeds in its crops leads to a decrease in productivity from 10 to 70%. Currently, the use of herbicides is considered the most effective way to control weeds [1, 2]. Despite the progress in the creation of chemical means of controlling weeds and the improvement of methods for their use, it is not always possible to effectively reduce the negative impact of herbicides on the natural environment and humans. Moreover, the emergence of herbicide-resistant weeds is becoming a growing global problem in crop systems, and reducing the number of chemical treatments of crops is an urgent task for agricultural enterprises [3-5]. Particularly acute is the issue of weed control in organic farming. In this case, the soil cultivation system has a significant effect on the diversity and abundance of weeds [6–9]. Along with this, a phytocenotic method of controlling weeds is promising, which is based on the ecological interaction of the cultural and weed component of wheat crops. In particular, it is known that thickening of wheat sowing leads to a significant increase in its competitiveness with respect to weeds [10, 11].

However, in the specific soil and climatic conditions of southern Russia, the methods of phytocenotic optimization of agricultural technology have not been adequately studied to date, allowing, with the exception of treatments with herbicides, to form highly productive winter wheat crops that are highly competitive with weeds.

2. Material and research methods
Our research was carried out on the experimental field of the Academy of Bioresources and Nature Management (structural unit) of V.I. Vernadsky Crimean Federal University in four-factor field experiments with winter wheat, which were placed in a crop rotation with combined tillage. In the experiments, we studied the complex effect of the method of tillage (plowing by 18-20 cm, surface tillage by 8-10 cm), sowing time (17.09; 24.09; 01.10; 08.10; 15.10; 22.10), seeding rates (1.5; 3.5; 5.5; 7.5 million seeds per hectare) and treatment with herbicides (in the spring during tillering) for weed crops and grain yields. The experiments were carried out according to the method of split blocks. The
The weediness of crops was taken into account by the quantitative-weighted method, and the yield of wheat grain was divided by direct harvesting. The data obtained were interpreted using the methods of variance and regression analysis.

3. Results and discussion

The influence of tillage methods on the weediness of winter wheat crops is estimated by researchers ambiguously. Many authors indicate an increase in weediness of crops when replacing plowing with surface tillage and admit the latter only on weed-free soils and when using herbicides. It is believed that deep plowing dramatically, by 1.2...2.0 times reduces soil weediness. The materials obtained in our studies show that the largest number of weeds is observed in winter wheat crops, that are plowed (Table 1).

| Tillage  | Indicator       | Total Weed |
|----------|-----------------|------------|
| Surface  | Number of weeds, pcs/m² | 123        |
|          | The mass of weeds, g m² | 452.5      |
| Plowing  | Number of weeds, pcs/m² | 152        |
|          | The mass of weeds, g m² | 569.4      |
| HCP₀₅    | Number of weeds, pcs/m² | 16         |
|          | The mass of weeds, g m² | 26.0        |

On average, over 4 years of research, the number of weeds per unit area for surface tillage was on 19% lower than for plowing. This pattern steadily manifested itself in all years of the study. Therefore, in the combined multi-depth tillage system, the use of plowing for winter wheat turned out to be excessive, moreover, it led to such negative effects as an increase in sowing weediness and a decrease in crop productivity by 3...5 c/ha.

Another important factor in agricultural technology, which largely determines the hydrothermal and photoperiodic conditions of the autumn period of formation of winter wheat agrophytocenosis, is the sowing period. In our studies, the degree of weediness of early crops by young weeds, represented mainly by winter and wintering species, was in all cases significantly higher than the crops of the second half of optimal and late sowing dates. In general, sowing at a later date leads, ceteris paribus, to a regular decrease in the availability of heat during the autumn vegetation period of winter wheat. The experimental data on the weediness of rare winter wheat crops (100 plants/m²), where the competitive pressure on the weeds from the crop side is minimized, closely correlates with the heat supply after the sowing season - the sum of positive temperatures above 5 °C from pre-sowing cultivation until the end of the autumn vegetation (1).

\[ Z = 338.7 + 0.00000417T^3 \] (1)

where \( Z \) is the aboveground weed biomass in the wheat ear formation phase, g/m²; \( T \) is the sum of temperatures from sowing to the end of autumn vegetation.

The regression model (1) controls more than 75% of the fluctuations in the aboveground mass of weeds according to the studied options for providing heat after the sowing season of winter wheat. Its graphical representation is given in Figure 1.

This dependence describes up to 77% of the variability of weed biomass in winter wheat sowing from the effect of differences in the sum of average daily temperatures for the period from pre-sowing cultivation to the transition through +5 °C. Wheat sowing after October 15, when the average daily temperature averages less than 300 °C until the end of the autumn vegetation, leads to a significant reduction in the weediness of crops. Their biomass in such crops is two to three times less in comparison with crops of early dates. Therefore, winter wheat, being a violent dominant in relation to the majority of dicotyledonous young weeds, is able to effectively suppress their development in crops. Moreover, the leading factor determining the competitiveness of the crop plant community is their number per unit
area. From this point of view, it is advisable to find out the reaction of the individual components of the field plant community: the aboveground part of the phytomass of wheat on the one hand, and weeds on the other, on the consistent thickening of plants of the cultural dominant. The optimal time for carrying out such studies is the winter wheat ear formation phase, which coincides with the period of greatest development of weeds.

**Figure 1.** Dependence of weed biomass in sowing during the winter wheat ear formation phase on the sum of average daily temperatures for the period from pre-sowing cultivation to the end of autumn vegetation.

Based on the data of field experiments, we obtained a regression equation describing the dependence of the aboveground mass of wheat during wheat ear formation period on the standing density of cultivated plants (2).

\[
Cr = -261.4 - 2.9P + 161.9P^{0.5}
\]  

(2)

where \(Cr\) is the aboveground biomass of wheat in the ear formation phase, g/m²; 
\(P\) is the standing density of winter wheat plants, pcs/m².

An equation with a high degree of responsibility (at a 1% significance level) controls more than 94% of wheat biomass fluctuations according to the experimental options. The responses of the aboveground mass of wheat to the increasing density of sowing obey the laws of slow growth and are generally represented by the ascending branch of the "softened" parabola (Figure 2).
Figure 2. Dependence of the aboveground biomass of winter wheat at the ear formation period on the density of plant standing.

An increase in the density of standing of winter wheat plants causes a natural increase in its aboveground mass. At the same time, each subsequent increment of planting density leads to successively decreasing biomass increases. The experiment area covers the limiting zone (up to 350...400 plants/m²) with noticeable biomass increments, gradually turning into the stationary region, in which they gradually disappear. So, with plant densities of more than 400 pcs/m², almost complete “saturation” occurs on this factor. As a result, the wheat biomass, which reached its maximum values, was indifferent to a further increase in planting density.

Also, during the period of winter wheat ear formation, simultaneously with the registration of aboveground biomass of cultivated plants, we carried out the related surveys of the aboveground weed biomass. Based on a generalization and analysis of the data on the weediness of crops in the experiments, we obtained an equation describing the dependence of weed biomass on the density of winter wheat plants (3).

\[
W = -868 + 21.69P^{0.5} + 11681.47P^{-0.5}
\]  

where \(W\) is the aboveground weed biomass in the ear formation phase of wheat, g/m²; 
\(P\) is the standing density of winter wheat plants, pcs/m².

Regression is significant at the 1% level and controls the main part of the variability of weed biomass in the experimental variants (\(R^2=0.93\)). The theoretical response curve of the aboveground mass of weeds to the increasing standing density of winter wheat plants corresponds to the laws of slowed down decline and is represented by a descending branch of the hyperbola (Figure 3).
Figure 3. Aboveground biomass of weeds during the period of winter wheat ear formation depending on the standing density of cultivated plants.

In general, the response curve of weed biomass to thickening of crops in the first approximation is mirror symmetric to similar responses of winter wheat biomass, although it is characterized by a more pronounced slope of the effects (see Figure 2). At the same time, in the field of the number of cultivated plants from 400 pcs/m$^2$ and higher, the minimum values of the aboveground mass of weeds are observed, which practically does not respond to changes in planting density in the region of medium and high values. Against the background of low standing density of winter wheat plants - below 200 pcs/m$^2$, there is a significant increase in sowing weediness. A further decrease in the density of winter wheat plants (below 150...100 pcs/m$^2$) leads to a sharp, avalanche-like growth of weed biomass, which on a rare crop (at 50 plants/m$^2$) becomes almost 7 times greater than in crops with 550 winter wheat plants per 1 m$^2$.

Comparing the curves of the dependence of the biomass of wheat and weeds on the standing density of cultivated plants, we can conclude that they, mutually supplementing each other, form a generally close to linear biomass function of the entire agrophytocenosis on the number of winter wheat plants per 1 m$^2$.

From a scientific and practical point of view, it is important to identify the degree of suppression of weeds by wheat culture, depending on the density of its sowing. The denser the plants of winter wheat are located, the more intense the competitive relations in sowing, the narrower the ecological niche for weeds, the worse the conditions for their growth and development. This process can be reflected on the basis of a quantitative description of the suppression dynamics of weed biomass in successively thickened winter wheat crops compared to rare ones with a density of 100 pcs/m$^2$. In our experiments, such an increase in planting density was accompanied by a regular decrease in the aboveground weed mass of weeds (Figure 4).
Figure 4. Reduction of weed biomass in relation to the basis in depending on the standing density of winter wheat plants (1 - theoretical curve; 2.3 - 95% confidence limits for average and individual observations, respectively).

In particular, in thickened crops (500...600 pcs/m²), the reduction of aboveground weed biomass reached 90...95%. In crops with a standing density of wheat plants from 400 plants per square meter, the weight loss of weeds exceeded 80% in comparison with rare crops. The standing density of cultivated plants of 300 pcs/m² corresponds to a reduction of weed biomass at the level of 60%. Consequently, the formation of winter wheat crops with phytocenotically optimal plant density, higher than necessary to obtain maximum productivity, is the primary task of herbicide-free agricultural technology. A necessary condition for obtaining crops of such density is the use of elevated, phytocenotically optimal seeding rates. In turn, the standing density of winter wheat is also significantly affected by the sowing period, which, as was previously noted, also requires some correction to reduce the initial weediness of the sowing. It should be noted that such changes in agricultural technology will not remain without consequences in terms of their effect on the value of grain productivity. It should be considered that weed control in crops is not an end in itself, and the main criterion for the effectiveness of the technology is the productivity level. From this point of view, it is advisable to establish how the combined effect of increasing seeding rates with successive sowing periods affects grain productivity. An important circumstance is the assessment of the possibility of obtaining winter wheat productivity using a non-herbicidal technology, comparable in magnitude to the yield obtained using chemical weed control measures. To solve this problem, based on the results of our experiments, a multivariate regression analysis of the effect on the grain productivity of a complex of agrotechnical methods (sowing time × seeding rate) was carried out using chemical weeding and on a herbicide-free background when growing winter wheat by surface tillage (4).

\[
Y = 58.7 + 1.62A + 3.25B + 1.24C - 1.30A^2 - 1.73B^2 + 0.26A^2B - 0.39AC - 0.76BC
\]  
(4)

Where Y – yield, c/ha; A – sowing period, code (decoding in Figure 5); B – seeding rate, code (decoding in Figure 5); C – herbicide treatment, code (decoding in Figure 5).
Having data on the dynamics of winter wheat productivity depending on the action of the factors under consideration, taking into account the resolution of the experiment, we identified four yield areas and established the corresponding agrotechnical parameters. They are presented in the form of contour diagrams describing the “relief” of productivity similar to how the terrain is shown on geodetic maps (Figure 5).

**Figure 5.** Winter wheat yield depending on the sowing period, seeding rate and treatment of crops with herbicides, c/ha.
The area of maximum productivity (95...100% of the maximum in the experiment) is represented by values not lower than 58.2 c/ha. It covers limited intervals of seeding rate and sowing time. In particular, the use of a sowing rate of 5.5 million/ha made it possible to obtain the maximum productivity in a very narrow segment of the sowing period - only about three days, from October 6 to 9. An increase in the seeding rate of 2 million/ha expanded this period to 11 days - from October 2 to October 13 (Figure 3a). Submaximal productivity, provably lower than maximum and concentrated in the range of 58.1...55.7 kg/ha. As can be seen from the figure, significantly lower seeding rates and a wider range of sowing dates are sufficient for its formation. Beyond it lies an area of average productivity limited by a lower level of 50 c/ha.

The analysis of the revealed patterns showed that in fields clear of perennial weeds, sowing in a short time (October 3...11) using a sowing rate of 6...6.5 million of germinating seeds per hectare allows to get the maximum productivity of winter wheat grain without the use of herbicides. Consequently, the use of increased seeding rates of winter wheat - 6.5 million/ha or more, promotes phytocenotic suppression of weeds and creates the prerequisites for a reasonable refusal to use herbicides.

4. Conclusions
The technology of growing winter wheat on a non-herbicidal basis is capable of providing productivity at the level of zonal technology capabilities using chemical weeding of crops. In order to achieve a positive result, winter wheat sowings must be placed on the precursors with the used steam and corn for silage, using surface tillage, should be sowed in the second half of the optimal terms with seed rates raised to 6.0...6.5 million of germinating seeds per hectare.

Herbicide-free cultivation of winter wheat makes its production technology more environmentally friendly, safe and less energy-intensive, reduces not only the cost of grain but also environmental pollution, while increasing the environmental cleanliness of the products.

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