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CHEMICAL PLANT PROTECTION AGENTS CHANGE THE YIELD STRUCTURE AND THE GRAIN QUALITY OF WINTER WHEAT (*TRITICUM AESTIVUM* L.)

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Abstract: *The purpose of this work was to identify the optimal combinations of different chemicals to provide a balance between their cost, crop yield, grain quality and the possible negative consequences. The highest individual herbicide effectiveness was ensured by the action of Monitor, Lontrel Grand, and Starane Premium (91, 79, and 77%, respectively) while the most effective complex treatment was provided by Monitor and Lontrel Grand (100 and 83%). The best way to eliminate the pathogenic fungi was the joint application of the Monitor and Falcon. The most economic return was in the cases of herbicides Lontrel Grand and Monitor both at the independent exposure, and in combination with the fungicide and insectoacaricide.*

Key words: *fungicide, grain quality, herbicide, insectoacaricide, winter wheat.*

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1. Introduction

According to the long-term forecasts [15], in 2050, to meet the nutritional needs of 9 billion people on our planet, a 70% increase in food production will be required. The solution to this problem is complicated by the ongoing climate change, making it necessary to create the cultivars that are resistant to the extreme weather conditions. There is no doubt that the food resources of humanity today are linked, directly or indirectly, with the four main cereal crops, including wheat, barley, maize and rice [1].

Winter wheat has advantages over the other crops in terms of predicted rainfall reduction, as the yield matures before the summer drought, but it can be reduced because of the influence of the high temperatures during the winter wheat flowering [13]. This difficulty entails the need to create the high-yielding varieties of winter wheat using the different approaches, including mutagenesis [9-10] and the effect of chemical growth regulators [14]. A successful result would be the formation of winter wheat varieties that are tolerant to the influence of a range of adverse environmental conditions, including herbicides in the case of intensive land use in the agrocenoses [11].

According to the recent data [1], to date, herbicides account for 37% of all pesticides in the world, which cost 38 billion euro per year. At the same time, the current situation in the world economy, agronomy and environmental issues dictates the need to reduce the use of herbicides [16]. Herbicides belong to exosestrogens and ultimately affect the animals [4] and human state [5].

The simple solutions are hardly possible here, because the loss of crop yields due to competition with the weed plants may be too great. For instance, in the field experiments, the influence of weed species *Gallium aparine* and *Alopecurus myosuroides* reduced the yield of winter wheat by 17.5 and 12.4 kg per ha, respectively [3]. In addition, one cannot ignore the fact that over the past few decades, some weeds have lost or reduced susceptibility to certain herbicidal modes of action, creating a global problem of herbicide resistance [2], [7-8], [17].

In Ukraine, winter wheat accounts for 42% of the total acreage of cereals (about 7 million hectares), and its average yield is 3.98 tons per ha. The yield rate can be higher, but, unfortunately, the wheat is sensitive not only to the weeds, but also to a wide range of fungal and other diseases. The most notable damage to the winter wheat is caused by fungal diseases such as yellow and brown rust, septoriosis, fusariosis, powdery mildew; the causative agents of these diseases are fungi of genera *Puccinia*, *Septoria*, *Fusarium*, and species *Erysiphe graminis*, respectively. Many pathogenic fungi affect the leaves of wheat, reducing the assimilative surface, destroying chlorophyll and other pigments, thereby reducing the intensity of photosynthesis, violating the physiological and biochemical processes in plants.

No less significant damage to wheat yield is caused by insect pests, among which the most common are Swedish (frit) fly (*Osinosoma frit* L.), ground beetle (*Zabrus tenebricides* Goeze), and corn bug (*Eurygaster integriceps* Put). These insects damage the winter wheat seedlings and leaves, as well as the grains at different stages of formation, including full

ripeness.

All these negative events result in the losses of winter wheat yield in the range from 3 to 1 - 2 tons per ha and to the deterioration of grain quality indicators as well. Thus, overcoming these numerous obstacles to obtain the high yields of crops, the land users are faced with the need for rational use of pesticides and the integration of environmental effects. The purpose of this study was to identify the combinations of different plant protection chemicals that provide a balance between costs, crop yields, grain quality and the compliance with environmental safety requirements during the treatment of the winter wheat plantings.

2. Material and Methods

The work was carried out in 2016-2017 at the experimental sites of the Institute of Grain Crops (Dnipropetrovs'k province, Ukraine). The study area is located in the geographical region of the Northern Steppe Dnieper, where the climate is of continental nature, including low precipitation (average 472 mm), high evaporation, frequent seasonal droughts along with high air temperature and dry winds. Previous studies [6] have shown that climatic changes in the region have manifested themselves, in particular, as an increase in air temperature in the early spring period, affecting the phenology of plants. During the winter wheat vegetation, several dry periods were noted (Table 1).

Weather conditions during the growing season of winter wheat Table 1

Weather metrics		September 2016			June 2017		
		I decade	II decade	III decade	I decade	II decade	III decade
Precipitation [mm]	norm	17.8	15.3	13.0	14.0	27.0	18.0
	in fact	14.0	10.0	12.0	0.3	17.1	19.7
Air temperature [°C]	norm	17.8	15.3	13.0	19.1	19.1	20.6
	in fact	20.5	16.0	10.8	20.1	19.0	23.2

In addition, in 2017, the weather was characterized by the abnormal precipitation of 4 cm of snow with the simultaneous decrease in the temperature to 3-6 °C from April 19 to 22.

The soil of the experimental sites is the ordinary medium-loamy low-humus chernozem, containing 3.1 - 3.2% humus in the plowing layer. The preceding crop in the rotation was the sunflower. Soil potential infestation was caused by the presence of vegetative reproduction organs of perennial weeds (*Cirsium arvense*, *Sonchus arvensis*, *Convolvolus arvensis*, and *Lactuca tatarica*) at the level of 35 t pcs. per m^2. Soil contamination by the seeds of the annual and biennial weeds (*Setaria glauca*, *Setaria viridis*, *Echinochloa crus-galli*, *Chenioidium album*, *Ambrosia artemisiifolia*, and *Amaranthus retroflexus*) was 53-60 pcs. per m^2.

The test object was the winter wheat (cultivar Podolyanka), which was shown on September 16, 2016, observing the norm of 4.5 mln. seeds per ha of the conditional seeds. Granular compound fertilizers (NPK) were introduced simultaneously with the sowing at a dose

of 10-12 kg/ha of active substance phosphorus. Ammonium nitrate was used for the spring top dressing of the winter wheat plants in early March 2017, when the projective cover of the crop was 87%.

Herbicide treatment was carried out at the beginning of May in the phase of the complete tillering of winter wheat. The herbicides Lancelot, Lontrel Grand, Starane Premium, Monitor, and Peak were applied, observing the norm of 250-300 L/ ha of the herbicide working solutions. The effectiveness of herbicides (in %) was calculated by the formula:

$$E = 100 - \frac{K_2}{K_1} \cdot 100 \quad [\%]$$

where:

E is the efficiency;

K_2 – number of weeds before treatment;

K_1 – number of weeds 25 days after the treatment with the herbicides.

Other pesticides (Nurel D insectoacaricide and Falkon fungicide) were introduced on May 26, 2017 after an appropriate survey of the sown areas. No pesticides were applied to the control sites. The yield of winter wheat was harvested in early July in phase of complete ripeness of grain (moisture content of 14.0 %). The qualitative parameters of wheat grain were determined in accordance with accepted methods [12]. In our study, each variant of pesticide treatment was performed in three replicates with a random arrangement of the experimental sites, and the results are averages of three measurements.

3. Results and Discussion

The effectiveness of herbicides in the experiment varied over a wide range reaching 100% (Table 2).

Effect of pesticides on the number of weeds and the productivity Table 2

Treatment option	Processing efficiency [%]	Yield [t/ha]	Payback [UAH]
Lancelot (33 g/ha) + Trend 90* (0.3 L/ha)	66.2±2.1	3.5±0.2	4.64
Lancelot (33 g/ha) + Trend 90 (0.8 L/ha) + Falcon (0.6 L/ha) + Nurel D (075 L/ha)	81.4±2.3	3.5±0.2	3.07
Lontrel Grand (120 g/ha) + Trend 90 (0.3 L/ha)	78.8±2.2	3.6±0.1	9.64
Lontrel Grand (120 g/ha) + Trend 90 (0.3 L/ha) + Falcon (0.6 L/ha)	82.6±2.5	3.4±0.1	4,98
Starane Premium (0.3 L/ha) + Trend 90 (0.3 L/ha)	76.7±2.4	3.5±0.2	5.21
Starane Premium (0.3 L/ha) + Trend 90 (0.3 L/ha) + Nurel D (075 L/ha)	76.3±2.0	3.4±0.3	3.84
Monitor (20 g/ha) + Trend 90 (0.3 L/ha)	91.1±2.5	3.6±0.1	8.12
Monitor (20 g/ha) + Falcon (0.6 L/ha)	98.9±2.4	3.9±0.2	4.53
Monitor (20 g/ha) + Falcon (0.6 L/ha) + Nurel D (075 L/ha)	100.0±2.5	4.0±0.2	4.01
Peak (20 g/ha)	50.9±1.7	2.9±0.1	4.08
Peak (20 g/ha) + Falcon (0.6 L/ha) + Nurel D (075 L/ha)	77.7±2.1	3.4±0.1	3.78
Control (without pesticides)	-	2.7±0.2	-

Individual action of sulfonylurea herbicide Peak as well as of bicomponent herbicide Lancelot showed surprisingly low efficacy (50.9 and 66.2%, respectively), which could be due to the several factors, including sensitivity to exceeding the optimum air temperature during the application of herbicides and the insufficient adhesion to the leaves of weeds as well.

Effectiveness of the auxin-like herbicides Lontrel Grand and Starane Premium was higher, accounting for 79 and 77%, respectively. The action of sulfonylurea herbicide Monitor was the most effective, extending both to the hard-to-perish perennial weeds (*C. arvence* and C*. arvensis*) and an allergenic plant species *A. artemisiifolia.*

The productivity of winter wheat in all tre The efficacy of all herbicides, excluding Starane Premium, increased markedly if the sites were additionally treated with Nurel D insectoacaricide and Falkon fungicide. The highest amplification of herbicidal effect was noted for the herbicides Peak and Lancelot (respectively, 26.8 and 15.2% higher than their individual action), whereas the increase in the effects of the herbicides Lontrel and Monitor after application of the fungicide and insectoacaricide did not exceed 10%. Probably, the effect of Falkon and Nurel D did not directly influence the weeds, but was mediated. The decrease in the number of pathogens and pests increased the potential of winter wheat plants in competing with the weeds, the abundance of which was inevitably reduced. The most significant decrease in the number of weeds was found on the sites that were processed by Falcon and Nurel D after the application of the sulfonylurea herbicide Monitor (complete weed removal).

Tested areas exceeded the control value by 0.2-1.3 t/ha. The maximum productivity of the crop in 2017 was ensured by the individual action of the herbicide Lontrel Grand, and the herbicide Monitor, both in the case of an independent and complex action.

Infection of the winter wheat plants with the fungal diseases before the treatment with the fungicide was of different degrees depending on the studied area (Table 3).

The complete elimination of all fungal pathogens was detected only at the sites treated with the herbicide Monitor and fungicide Falcon. Effectiveness of the fungicide on the sites treated with herbicide Lontrel Grand was low only in relation to septoria, whose infection decreased by only 57%. Simultaneous application of the fungicide Falcon and insecticacaricide Nurel D on the sites treated with Lancelot herbicide reduced fusariosis infection by 50% and septoria by 74%, but did not affect powdery mildew. Similar results were found in the both areas treated with herbicides Monitor and Peak together with the application of Falcon and Nurel D; the difference was that the septoria infection was most effectively reduced (by 78 and 59%, respectively). The study results showed that simultaneous application of Falcon and Nurel D led to a decrease in the effectiveness of the fungicide.

Effect of the pesticides on pathogens in the winter wheat plantings Table 3

Treatment option	The degree of wheat plants infestation, % (averaged data, ± st. deviation)					
	Before fungicide treatment			25 days after treatment		
	Fusariosis	Septoria	Powdery mildew	Fusariosis	Septoria	Powdery mildew
Lancelot + Falcon + Nurel D	0.30± 0.05	0.95± 0.08	0.15± 0.01	0.15± 0.01	0.25± 0.02	0.15± 0.01
Lontrel Grand + Falcon	0.20± 0.02	0.35± 0.06	0.30± 0.02	0.0	0.15± 0.01	0.0
Monitor + Falcon	0.30± 0.03	1.0± 0.07	0.15± 0.01	0.0	0.0	0.0
Monitor + Falcon+ Nurel D	0.15± 0.01	0.90± 0.07	0.25± 0.01	0.15± 0.01	0.20± 0.01	0.20± 0.02
Peak + Falcon+ Nurel D	0.30± 0.04	0.85± 0.07	0.15± 0.01	0.15± 0.01	0.35± 0.03	0.15± 0.01
Control	0.30± 0.01	1.05± 0.1	0.35± 0.07	0.65± 0.05	1.30± 0.11	0.75± 0.01

Number of the insect pests on the winter wheat plants before the treatment varied (Table 4). The effectiveness of insectoacaricide Nurel D reached 100% at all the treated sites, except for those where the herbicide Peak was introduced. In these areas, such insects as the ground beetles and imago of corn bug were preserved, but their numbers were significantly reduced (by 56 and 69 %, respectively).

The growth and development of winter wheat plants, as well as the crop yield were greatly influenced by the cenotic relationships with weeds, the damaging effect of pathogens and pests, and the weather conditions during the vegetation period. The most negative phenomena were snowfall in April and drought in the first and second decades of June 2017 (Table 1). Nevertheless, the height of winter wheat plants on all sites treated with pesticides exceeded the control level by an average of 4.8%, and the excess of the control area of the leaf surface averaged 2.0 cm^2 (Table 5).

The smallest excess of the height of the control winter wheat plants was at the sites treated with herbicide Peak (only 0.5 cm), while the largest - at the sites where the herbicide Monitor was used with a Falcon (8.7 cm), and also with fungicide Falcon and insectoacaricide Nurel D simultaneously (9.1 cm). Similar dependencies were found when determining the area of a wheat leaves, and the lowest and the highest morphometric parameters were measured on the plots treated with the herbicides Peak and Monitor, respectively.

Table 4

Effect of the pesticides on the insect pests in the winter wheat plantings

Treatment option	Number of insects, specimen/m^2 (averaged data, ± st. deviation)					
	Before treatment			25 days after treatment		
	Frit fly	Ground beetle	Corn bug	Frit fly	Ground beetle	Corn bug
Lancelot + Falcon + Nurel D	0.25± 0.02	0.55± 0.04	0.15± 0.01	0.0	0.0	0.0
Starane Premium + Nurel D	0.45± 0.03	0.40± 0.04	0.25± 0.02	0.0	0.0	0.0
Monitor + Falcon+ Nurel D	0.15± 0.01	0.25± 0.02	0.15± 0.01	0.0	0.0	0.0
Peak + Falcon+ Nurel D	0.15±0.01	0.45± 0.04	0.65± 0.05	0.0	0.20± 0.02	0.20± 0.02
Control	0.45±0.03	0.30± 0.02	0.25± 0.02	0.90± 0.07	0.80± 0.06	0.65± 0.05

Table 5

Effect of pesticides on the winter wheat plants growth and the seed quality

Treatment option*	Height of wheat plant [cm]	Leaf area [cm^2]	Spike grain content [pcs.]	Seed germination [%]	Protein content [%]
Lancelot	64.0±2.1	10.19±0.9	37±4	86.2±2.1	13.0±0.5
Lancelot + Falcon + Nurel D	64.9±1.7	10.06±1.1	40±3	86.8±2.1	13.2±0.2
Lontrel Grand	64.8±1.8	10.17±0.8	38±3	96.2±2.3	14.3±0.2
Lontrel Grand + Falcon	65.1±1.3	10.33±0.7	40±3	89.1±2.0	13.7±0.4
Starane Premium	64.9±1.1	10.28±0.6	39±4	95.0±1.5	13.5±0.4
Starane Premium + Nurel D	65.4±1.8	10.29±0.7	40±3	94.4±1.7	13.9±0.3
Monitor	65.2±1.7	10.86±0.8	40±3	96.2±1.7	14.9±0.4
Monitor+ Falcon	65.8±1.7	11.26±1.1	43±3	96.1±1.7	15.2±0.4
Monitor + Falcon + Nurel D	66.2±1.5	11.58±0.8	45±3	94.3±0.9	15.2±0.4
Peak	57.4±1.5	8.54±0.4	43±3	94.2±2.3	14.7±0.3
Peak + Falcon + Nurel D	64.1±1.4	9.79±0.7	39±2	94.0±0.5	13.1±0.4
Control (without pesticides)	57.1±1.9	8.04±0.7	31±4	94.0±0.4	10.0±0.2

The number of grains in the ear of winter wheat after application of the Falcon and Nurel D increased in comparison with the independent action of herbicides in all areas, especially in areas treated with the herbicide Peak (by 18.2%). It should be noted a significant increase in all the studied parameters of wheat plants on the plots treated with herbicide Peak, followed by the application of fungicide Falcon and insectoacaricide Nurel D. Nevertheless, the increased growth of the winter wheat plants did not exceed the average level, while the treatment costs became too large.

The content of gluten in wheat grain exceeded the control value by 3.0 – 5.2%. Gluten content was the highest due to the treatment with herbicide Monitor followed by the introduction of Falcon and Nurel D, exceeding the effect of the independent action of the Monitor by 0.3%. At the same time, the addition of Falcon and Nurel D led to the decrease in gluten content by 1.6% in the wheat grains from the sites, treated with herbicide Peak. So, the effect of complex action of the pesticides on the bakers' quality of grain was not determined by mode of action of the herbicides, and needs further study.

The sowing quality of the winter wheat seed from the sites treated with all herbicides, excluding Lancelot, exceeded the control value by 0.2 – 2.2%. However, complex application of the pesticides led to a decrease in the germination of wheat seeds, especially noticeable in the areas treated with the herbicide Lontrel Grand together with fungicide Falcon (7.1%), as well as the herbicide Monitor with Falcon and Nurel D insectoacaricide (by 1.9%). As for the herbicide Lancelot, its joint action with Falcon and Nurel D ensured an increase in the germination of wheat seeds by 0.6%. Thus, taking into account the aftereffects of complex pesticide treatment of crops for the quality of winter wheat grain is a necessary measure.

4. Conclusions

The effect of the independent action of the herbicides Lancelot, Lontrel Grand, Starane Premium, Monitor, and Peak as well as complex action together with the fungicide Falcon and insectoacaricide Nurel D on the winter wheat growth, yield and quality of seeds were studied in the unfavorable weather conditions during the growing season in 2016 – 2017. The highest individual herbicide effectiveness was found due to the action of Monitor, Lontrel Grand, and Starane Premium, while the most effective complex treatment was provided by Monitor and Lontrel Grand. The best way to eliminate the pathogenic fungi from the wheat crops was the joint application of the herbicide Monitor and fungicide Falcon. Effective decrease in the number of pest insects was ensured by complex treatment with herbicides Monitor, Starane Premium and Lancelot with insectoacaricide Nurel D. The economic return was the highest in the cases of herbicides Lontrel Grand and Monitor both at the independent exposure, and in combination with the fungicide Falcon and with insectoacaricide Nurel D.

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