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Interactive effect of tank-mixed post emergent herbicides and plant growth regulators on corn yield

Yu.I. Tkalich[1]*, A.I. Tsyliuryk[1], S.V. Masliiov[2], V.I. Kozechko[1]

[1] Dniprovskyi State Agrarian and Economic University, st. Serhii Yefremov, 25, Dnipro, Ukraine, 49027
[2] Luhansk National Taras Shevchenko University, sq. Hohol, 1, Starobelsk, Ukraine, 92703
Corresponding author E-mail: tkalich_yuriy@ukr.net, Tel.: +38050-575-22-72
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We proved that tank mixture (Task Extra 440 g ha^{-1} + Par Trend 0.2L ha^{-1} + Vympel 1000 g ha^{-1}) had the maximum efficiency in corn protection against the weeds in the conditions of Northern Ukrainian Steppe. This mixture had high index of herbicide technical efficiency (96.6%) and contributed to a steady tendency to increase the plant height by 5-7 cm (2.1-2.8%), the leaf surface area by 5-6%, structure elements of the yield (cob length by 13.6 cm (5.1%), cob graininess by 18 pieces (3.9%), weight of 1000 grains by 29 g (9.1%) and grain yield by 0.33 t ha^{-1} (5.3%) compared to control. The tank mixture of the herbicide Titus Extra with the plant growth regulator Vympel (Titus Extra 50 g ha^{-1} + Par Trend 0.2L ha^{-1} + Pennant 500g ha^{-1}) has also positive effect and was slightly lower than Task Extra 440 g ha^{-1} + Par Trend 0.2L ha^{-1} + Vympel 1000 g ha^{-1}) for the grain yield by 0.12 t ha^{-1} (1.9%).
Key words: corn, weeds, herbicides, tank mixture, plant growth regulator, Vympel, Extra Task, Titus Extra, biometric indicators, yield structure elements.

Introduction

At present stage of development of the plant-growing industry, the introduction of the newest corn-growing technologies with the use of modern means of plant protection from weeds becomes of great importance with the purpose of a steady increase in the volumes of grain production.

The constant spreading of negative factors in the farming of the Steppe zone, namely the violation of crop rotations, the excessive man-caused impact and the growth of corn infestation, limits the level of grain production, which makes it necessary to improve the elements of corn-growing technology in the direction of leveling the aforementioned negative factors and improve the plant protection system by optimizing the weed control using, in addition to modern herbicides, also tank mixtures with plant growth regulators (Krut', Benedichuk, Shvets, 1979; Kiver, Melua, Pilipenko, 1979; LeBaron, 1982; Mayor, Dessaint, 1998; Hrytsayenko, 2005; Matyukha et al. 2005; Barz, Edvards, Campbell, Hood, 2006; Knezevic, 2007; Lebid, Tsyliuryk, 2014; Tsyliuryk, Sudak, Shapka, 2015; Tsyliuryk, Desyatnik, 2014, 2016; Shcherbak, 1979; Tsyliuryk, Kozechko, 2017; Tsyliuryk, Shevchenko et al.).

For the protection of corn from weeds in unfavorable meteorological conditions of the Steppe zone (droughts, dry winds, high temperatures, etc.), it has recently become increasingly important to use tank mixtures of herbicides and physiologically active substances which effectively destroy weeds and are able to regulate growth processes, contribute to raising the level of grain yield, its quality indicators and are environmentally friendly for the environment and human health. In recent years, considerable attention has been paid to substances that are used to activate and stimulate seed material and spray vegetating plants. Among plant growth regulators (PGR) the most common and topical is Vympel (Tsykov, 2006; Tsykov, Matyukha, Tkalic, 2012).

Considering the urgency and importance of the introduction of these herbicides into production against the background of the contradictory attitude of various scientists and commodity producers to them, in our opinion, further studies should be continued to determine their effectiveness in order to identify the optimal use of herbicide tank mixtures and plant growth stimulants. Therefore, the main objective of our work was to determine the technical efficiency of the herbicides Task Extra, Titus Extra and PGR Vympel on the growth and development of plants, elements of the crop structure and the yield of corn grain.

The aim of the work is to establish the effectiveness of weed control and increase the productivity of the corn hybrid DN Galatea using modern herbicides and plant growth regulators.

Methods

Experimental studies were carried out on the pilot field of the experimental farm of Dnipro of the State Institute of Agriculture of the Steppe zone of National Academy of Sciences of Ukraine (now the Institute of Grain Cultures of Ukrainian Academy of Sciences of Ukraine) during 2013-2015.

Agrotechnics for growing corn (the hybrid DN Galatea) corresponded to the generally accepted recommendations of the Steppe zone. The precursor of corn was winter wheat, the main tillage (plowing) was carried out to a depth of 23-25 cm. In the spring, the soil was leveled with tooth harrows, and under pre-sowing cultivation fertilizers were applied in a dose of $N_{30}P_{50}$. Herbicides and plant growth regulators in the experiment were introduced by the sprayer OM-6 in the unit with a tractor T-25. Sowing was carried out by a VEGA 8 PROFI seed drill.

The experimental scheme included the following options for the application of herbicide tank mixtures (Task Extra, Extra Titus) and the plant growth regulator (Vympel), which were introduced into the phase of 3-6 actual leaves of corn:

1. Control. Task Extra - 440 g ha^{-1} + Par Trend - 0.2L ha^{-1}.
2. Task Extra - 440g ha^{-1} + Par Trend - 0.2L ha^{-1} + Vympel - 500 g ha^{-1}.
3. Task Extra - 440g ha^{-1} + Par Trend - 0.2L ha^{-1} + Vympel - 1000 g ha^{-1}.
4. Control. Titus Extra - 50 g ha^{-1} + Par Trend - 0.2L ha^{-1}.
5. Titus Extra - 50g ha^{-1} + Par Trend - 0.2L ha^{-1} + Vympel - 500g ha^{-1}.

In all versions of the experiment the sticking agent Par Trend was also used - 0.2L ha^{-1} for fixing herbicides on weed leaves, to improve the contact of leaf tissue cells with active substances of herbicides.

Herbicide Task Extract consists of three active substances (rimsulfuron - 23 g kg^{-1}, nicosulfuron - 92 g kg^{-1}, dicamba - 550 g kg^{-1}). High efficiency of the drug is achieved due to the enhanced herbicidal effect, the synergistic effect of the three components related to different chemical classes. Rimsulfuron and nicosulfuron are mainly absorbed by leaves and move to the growth points of weeds. They block cell division in areas of growth of shoots and roots, because of which the growth of weeds ceases within several hours after the treatment. Dicamba penetrates the leaves and root system of weeds and can migrate in all directions: from the roots to the growth points and from the ground part of the plant to the root hairs, which is especially effective for controlling perennial dicotyledonous weeds.

Herbicide Titus Extra consists of two active substances such as nicosulfuron - 750 g kg^{-1} and rimsulfuron - 250 g kg^{-1}. Nicosulfuron and rimsulfuron belong to the class of sulfonylureas and are highly selective in relation to corn, have a systemic effect and quickly penetrate weed plants. After the treatment rimsulfuron and nicosulfuron penetrate mainly into the leaves and within a few hours they move around the plant, which leads to a stop of cell division at the growth points of shoots and roots. The drug stops the growth and development of weeds by blocking the acetyl synthetase enzyme, necessary for the synthesis of essential amino acids: valine, leucine and isoleucine. As a result, the growth and development of sensitive species of weeds ceases, the visible symptoms of the herbicide action appear in 3-10 days as growth cessation, redness, chlorosis and leaf necrosis. The death of weeds occurs in15 days after treatment.

These herbicides could control the main dicotyledonous weeds (various types of thistles) and cereal weeds (all types of mice, common millet, barnyard grass, etc.) effectively. That is, in the technology of growing corn it is possible to abandon the use of soil herbicides preferring post-emergence drugs capable of controlling practically all biological groups of weeds in agrophytocenoses.

The plant growth regulator PGR Vympel includes polyethylene oxides (PEO-1500 - 54% and PEO-400-23%) and salts of humic acids. PEO-400 has a low molecular weight, so it easily penetrates tissues fulfilling the role of a transport agent for all drugs shared with plant growth regulators.

The drug structures free intracellular water, increases its biological activity, accelerates the process of photosynthesis, transformation and intensity of mineral nutrition. PEO-1500 has a high film-forming ability, and therefore PGR Vympel can be used in tank mixtures along with plant protection products and microfertilizers as a sticking agent. Substances that are part of PGR Vympel, reinforce each other and provide multifunctionality, so it has the properties of a growth stimulant, adaptogen, antidepressant, cryoprotector, sticking agent and disease inhibitor.

The soil cover of the experimental plot is represented by ordinary low-humus and full-profile chernozems with a content of humus of 3.14%. Potential soil contamination in the areas where experiments were carried out by vegetative reproduction organs of perennial root sprout weeds was: 27-44 thousand pcs/m^2 (medium level) and seeds of juvenile weeds: 300-450 million pcs ha^{-1} in the arable layer (high level).

The weather conditions for corn growing in general were favorable during the growing season of 2013-2015. The hydrothermal coefficient during the period of the highest water consumption of plants (July - first half of August) was equal to: 2013 – 0.7, in 2014 – 0.9, 2015 - 0.8. The hydrothermal coefficient indicator of less than 0.7 points out the presence of soil-air drought, which negatively affects the formation and grain filling.

Results and discussion

Before the introduction of herbicides into the phase of 3-6 corn leaves, the general background of the contamination of crops was at the level of 51.8-79.4 pcs./m^2, in particular, the most common weeds were ragweed (*Ambrosia artemisiifolia* L.), which was in the phase of cotyledons, thistle pink (*Cirsium arvense* L.) had a height of 8-10 cm and barnyard grass (*Echinochloa crus-galli* L.) had 1-2 leaves (table 1).

Table 1. Dynamics of weed contamination in corn crops (2013-2015)

Variants of tank mixes of drugs	Number of weeds in biological groups, pcs/m^2												Underground biomass of weeds in air-dry condition, g / m^2	Technical efficiency of herbicides, %
	before applying herbicides				25-30 days after spraying				before harvesting					
	juvenile				juvenile				juvenile					
	double-flowered	cereals	root and sprout	in all	double-flowered	cereals	root and sprout	in all	double-flowered	cereals	root and sprout	in all		
1. *Control.* Task Extra – 440 g/ha + Par Trend – 0.2l ha^{-1}	45.5	3.5	2.8	51.8	1.0	0	0	1.0	15.0	0.0	1.0	16.0	18.4	98.1
2. Task Extra – 440 g ha^{-1} + Par Trend – 0.2l ha^{-1} + Vympel – 500 g ha^{-1}	72.3	4.2	2.9	79.4	2.0	1.4	0	3.4	22.0	2.5	0.0	24.5	35.6	95.7
3. Task Extra – 440 g ha^{-1} + Par Trend – 0.2l ha^{-1} + Vympel − 1000 g ha^{-1}	57.2	3.8	1.8	62.8	0.1	2.0	0	2.1	20.1	4.3	0.0	24.4	46.4	96.6
4. *Control.* Titus Extra – 50 g ha^{-1} + Par Trend – 0,2l ha^{-1}.	63.7	5.7	2.0	71.4	4.6	0	0.8	5.4	26.2	2.8	0.0	28.2	33.6	92.4
5. Titus Extra – 50 g ha^{-1} + Par Trend – 0.2l ha^{-1} + Vympel – 500 g ha^{-1}	60.8	7.3	2.5	70.6	7.3	0	0.4	8.1	17.3	3.2	0.4	20.5	41.8	88.5

Note: Double-flowered juvenile weeds are preferably represented in the experiment: ragweed, pig weed, bindweed fallopia, amaranthus retroflexus, bindweed bitterling. Cereal weeds: yellow and green foxtail grass; barnyard grass. Root and sprout weeds: perennials (thistle pink, birch field).

After application of herbicides and 25 days from the date of introduction, the weediness of crops was significantly reduced. Thus, after the introduction of herbicide Task Extra, almost complete destruction of weed vegetation was observed, and its technical efficiency was at the level of 98.1%. There was a significant inhibition of cultivated plants by this herbicide in corn crops, so the plant growth regulator Vympel was used to remove stress from cultivated plants.

By joint application of such drugs as Task Extra + Vympel - 500 g ha^{-1}, inhibition and twisting of leaves was observed in only 3.6% of plants, and in the case with the application of Task Extra + Vympel – 1000 g ha^{-1} this indicator even decreased to 2.3%. That is, the drug Vympel was not only the growth regulator but also an antidepressant, which had a positive effect on the partial removal of stress in corn. The technical efficiency of mentioned tank mixtures was also high and amounted 95.7 and 96.6% of the destroyed weeds, respectively. A small amount of remaining (not destroyed) weeds did not cause significant damage to corn plants, because it was in a depressed, underdeveloped state (Table 1).

In the variants where the herbicide Titus Extra was introduced, the technical efficiency of herbicides was also high and amounted in the control (Titus Extra – 50 g ha^{-1} + Par Trend) 92.4%, and in the tank mixture (Titus Extra – 50 g ha^{-1} + Par Trend – 0,2l ha^{-1} + Vympel - 500 g ha^{-1}) – 88.5%.

The reduction of technical efficiency here in all experimental variants compared to the herbicide of Task Extra by 5.8-7.5% should be noted, which is probably due to the presence of only two active substances in the composition of this herbicide and their low phytotoxic effect on some types of weeds. For example, the technical efficiency of the herbicide in relation to different weeds was as follows: ragweed (*Ambrosia artemisiifolia* L.) - 96%, pink thistle (*Cirsium arvense* L.) - 80%, black nightshade (*Solanum nigrum* L.) - 28%, corn bindweed *(Convolvulus arvensis* L.) - 41%, bindweed bitterling (*Polygonum convolvulus L.*) – 49%, pig weed *(Chenopodium album* L.) - 15%, yellow foxtail grass *(Setaria glauca* L.) and barnyard grass *(Echinochloa crus-galli* L.) - 100%.

Tank mixture Titus Extra with Vympel improved the appearance of corn, the plants were more tolerant to the herbicidal load and more developed with a bright green color, which further affected its productivity.

At the time of corn harvest, the number of weeds in all experimental variants was naturally increased due to the appearance of their new shoots after the treatment, but in general, the above-ground mass of wild plants was negligible and varied from 18.4 to 46.4 g/m^2. The appearance of weed shoots after treatment with herbicides is due to rainfall at the beginning of vegetation and increased temperature regimes, which positively affected the germination of the second wave of weeds.

The use of plant growth regulators positively affected the growth trend of height and leaf surface area of corn plants (Table 2). Thus, when using Task Extra + Vympel (500 g ha^{-1}), the height in the phase of 13-14 leaves was increased by 2 cm (1.0%), and in detasseling stage - by 6 cm (2.4%). The leaf surface area was increased by 5-6%. When using the drug Vympel (1000 g ha^{-1}) the

plant height was increased by 5-7 cm (2.1-2.8%) compared to the control. In the variant with Titus Extra - 50 g ha^{-1} + Par Trend - 0.2l ha^{-1} + Vympel - 500 g ha^{-1} the height of corn plants in the phase of detasseling was 245 cm, which was 3 cm (1.2%) higher than in the control.

Similarly to the height of plants the leaf surface area of corn plants was increased. This, in turn, enabled corn plants to obtain photosynthetic active radiation to a greater extent, and in the future, it was positively reflected on the productivity of this grain crop.

Table 2. Height and leaf surface area of one corn plant, depending on the mixtures of herbicides and growth stimulants on the average for 2013-2015.

Drug variants	Plant height, cm		Leaf surface area of one plant, cm²	
	stage of 13-14 leaves	stage of detasseling	Stage of 13-14 leaves	stage of detasseling
1. *Control.* Task Extra – 440 g ha^{-1} + Par Trend – 0.2l ha^{-1}	228	240	3409	3967
2. Task Extra – 440 g ha^{-1} + Par Trend – 0.2l ha^{-1} + Vympel – 500 g ha^{-1}	230	246	3560	4140
3. Task Extra – 440 g ha^{-1} + Par Trend – 0.2l ha^{-1} + Вимпел − 1000 g ha^{-1}	233	247	3632	4367
4. *Control* Titus Extra – 50 g ha^{-1} + Par Trend – 0.2l ha^{-1}	228	242	3427	3998
5. Titus Extra – 50 g ha^{-1} + Par Trend – 0.2l ha^{-1} + Vympel – 500 g ha^{-1}	230	245	3457	4079

The indicated peculiarities of the formation of assimilation leaf surface, growth of plants and weediness of crops were significantly reflected on the elements of the yield structure and corn productivity (Table 3). Indicators of the structure elements of the corn yield using herbicide Task Extra, namely, the cob length was naturally minimal in the control variant (Task Extra - 440 g ha^{-1} + Par Trend - 0.2l ha^{-1}) - 12.9 cm, using the PGR Vympel (500 g ha^{-1}) this indicator increased to 13.2 cm (2.3%), and Vympel (1000 g ha^{-1}) to 13.6 cm (5.1%). As for the cob graininess in corn plants with the application of the PGR Vympel (500 g ha^{-1}), it grew by 5 pieces (1.1%), and in the version with the PGR Vympel (1000 g ha^{-1}) by 18 pieces (3.9%) compared to the control.

One of the important elements in the formation of corn grain yield is also a mass of 1000 grains, which had a noticeable tendency to vary, depending on the factors studied. So, the mass of 1000 grains in the experiment variants using plant growth regulators also tended to increase compared to the control without their application. Thus, in the second variant (Task Extra - 440 g ha^{-1} + Par Trend - 0.2l ha^{-1} + Vympel - 500 g ha^{-1}), this indicator was 306 g, while in the third (Task Extra - 440 g ha^{-1} + Par Trend - 0.2l ha^{-1} + Vympel - 1000 g ha^{-1}) - 317 g, which was more than control for 18 and 29 g, or 5.8 and 9.1%, respectively. Spraying corn plants with herbicide Titus Extra together with PGR Vympel in the phase of 3-6 leaves of the plant contributed to an increase in the cob length to 0.6 cm (4.7%), cob graininess - 12 pcs. of grains (2.7%), weight of 1000 grains - 18 g (6.1%) compared to the control (Titus Extra - 50 g ha^{-1} + Par Trend - 0.2l ha^{-1}). Based on the above analysis it can be stated that there is a steady tendency to an increase in the graininess and size of corn grain when using tank mixtures of herbicides and plant growth regulators, which ultimately contributes to the growth of the grain yield.

Table 3. Elements of the yield structure and productivity of corn hybrid DN Galatea on the average for 2013-2015.

Drug variants	Cob length, cm	Cob graininess, pcs. grains	Weight of 1000 grains, g	Grain yield, t / ha
1. ***Control.*** Task Extra – 440 g ha^{-1} + Par Trend – 0.2l ha^{-1}	12.9	438	288	5.85
2. Task Extra – 440 g ha^{-1} + Par Trend – 0.2l ha^{-1} + Vympel – 500 g ha^{-1}	13.2	443	306	6.06
3. Task Extra – 440 g ha^{-1} + Par Trend – 0.2l ha^{-1} + Вимпел − 1000 g ha^{-1}	13.6	456	317	6.18
4. ***Control*** Titus Extra – 50 g ha^{-1} + Par Trend – 0.2l ha^{-1}	12.0	429	277	5.90
5. Titus Extra – 50 g ha^{-1} + Par Trend – 0.2l ha^{-1} + Vympel – 500 g ha^{-1}	12.6	441	295	6.19

According to the studies on the elements of corn growing technology, the formation of the maximum grain yield of corn is only possible if life-support factors are optimized at all stages of the organogenesis of the crop. With the current amplitude development of climatic elements during the crop vegetation, the efficiency of technological methods is determined by the ability to optimize agroecological regimes in agrocenoses.

In the areas with the herbicide Task Extra, the highest yield was recorded using a tank mixture with PGR Vympel (1000 g ha^{-1}) – 6.18 t ha^{-1}, which exceeded the variant with PGR Vympel (500 g ha^{-1}) by 0.12 t ha^{-1} (1.9%), and control without plant growth

regulators by 0.33 t ha^{-1} (5.3%). The increment in the grain yield from the use of Titus Extra in the tank mixture with PGR Vympel was 0.29 t ha^{-1} (4.6%) compared to the control, where this indicator was 5.90 t ha^{-1}.

Conclusions

The maximum efficiency in the technology of corn growing for grain is provided by a tank mixture (Task Extra - 440 g ha^{-1} + Par Trend – 0.2l ha^{-1} + Vympel - 1000 g ha^{-1}), which besides the high indicator of technical efficiency of the herbicide 96,6%, also contributes to a steady tendency to increase the plant height by 5-7 cm (2.1-2.8%), the leaf surface area by 5-6% and the elements of the yield structure (cob length by 13.6 cm (5.1%), cob graininess by 18 pieces (3.9%), the weight of 1000 grains by 29 g (9.1%)) and the grain yield by 0.33 t ha^{-1} (5.3%) compared to the control without the growth of regulating substances.
The tank mixture of herbicide Titus Extra with PGR Vympel (Titus Extra - 50 g ha^{-1} + Par Trend - 0.2l ha^{-1} + Vympel - 500 g ha^{-1}) compared to Task Extra - 440 g ha^{-1} + Par Trend - 0.2l ha^{-1} + Vympel - 1000 g ha^{-1}, in particular, for the grain yield by 0.12 t ha^{-1} (1.9%) is slightly lower than all the above-mentioned efficiency indicators.

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