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EFFICACY OF WEED CONTROL BY HERBICIDES DIFLUFENICAN, METRIBUZIN AND CARFENTRAZONE WHEN APPLIED IN WINTER WHEAT CROPS IN AUTUMN

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For the purpose of development anti-resistant herbicide compositions for the protection of winter wheat crops, field trials of weed control efficiency and crop selectivity were performed during three growing seasons, when tank mixtures of herbicides diflufenican, carfentrazone and metribuzine were applied in the autumn at the stage of 2—3 leaves. For comparison as a standard, herbicides Marathon (pendimethalin, 250 g/l + isoproturon, 125 g/l) and GF-2202 (diflufenican, 100 g/l + florasulam, 3.75 g/l + penoxsulam, 15 g/l) were used. Weed control was found to be most effective throughout the growing season with application of a triple mixture of diflufenican, metribuzin, and carfentrazone. The use of carfentrazone increased the effectiveness of protection exactly in the autumn, because in the spring and summer the action of a mixture of diflufenican with metribuzin and complex herbicide GF-2202 was not inferior to the action of the triple mixture. In the 2018—2019, the use of herbicides was not effective due to low weediness, but the trend of winter wheat grain yield increase with herbicides was evidence of their crop selectivity. Manifestations of phytotoxic effects on the culture were observed only in autumn 2020 in variants with the use of carfentrazone alone and in mixtures. The phytotoxic effect of carfentrazone was the appearance of chlorotic spots on the leaves of winter wheat plants shortly after treatment. However, this effect of carfentrazone did not affect the further growth and development of winter wheat and the formation of grain yield. The highest values of grain yield in the experiments of 2019—2020 and 2020—2021 were obtained in variants using a mixture of diflufenican with metribuzin, triple mixture of diflufenican, carfentrazone and metribuzin, as well as with the application of complex herbicides GF-2202 and Marathon. It was concluded that when used in autumn in winter wheat, the tank mixture of diflufenican with metribuzin and triple tank mixture of diflufenican, metribuzin and carfentrazone are not inferior to the effectiveness of protection against weeds and yield preservation of the complex herbicides GF-2202 and Marathon. The main advantage of using mixtures of diflufenican with metribuzin, and a triple mixture of diflufenican, metribuzin and carfentrazone over the complex herbicide GF-2202 is that the use of these mixtures provides high efficiency of winter wheat protection without the use of herbicides ALS inhibitors. It has been stated that the use of diflufenican and metribuzin herbicides, and triple mixture of diflufenican, metribuzin and carfentrazone in winter wheat crops in autumn is an effective means of preventing the emergence of herbicide-resistant biotypes of weeds including weed biotypes resistant to ALS inhibitors.

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Traditionally, the main measures to protect winter wheat crops from weeds are carried out in the spring after the growth resumption. However, due to global climate change, in particular through rising average temperatures, the length of the autumn growing season continues, which highlights the need to control weeds during this period. The difference between autumn and spring herbicide applications is that in autumn the treatment of winter wheat crops should be carried out at the earlier stages of crop development, which puts forward additional requirements for the herbicides selectivity. Herbicides inhibitors of acetolactate synthase (ALS) are highly selective for wheat. However, the permanent use of this class herbicides in winter wheat and other crops has already led to the mass emergence of weed biotypes resistant to ALS inhibitors [1]. In addition, winter wheat crops can be infested with previous crops, such as sunflower or winter oilseed rape, many of which are hybrids resistant to herbicides ALS inhibitors.

The main effective means of preventing the emergence of resistance is the joint use of herbicides with different modes of action (MOA) [2—4]. In the spring, in order to prevent the emergence of resistance and control the previous ALS-resistant crops in winter wheat crops, the tank mixtures or complex herbicides containing ALS inhibitors and synthetic auxins 2.4-D or dicamba are widely used [5, 6]. However, the use of 2.4-D or dicamba in winter wheat crops in autumn is problematic because, firstly, the application period of these herbicides is limited by the tillering stage of wheat, and secondly, these herbicides are practically ineffective at low temperatures. In addition, to control weeds resistant to ALS inhibitors emergence, it would be desirable to limit the use of this class of herbicides, and to ensure high protection efficiency through the complex application of herbicides with other MOA. The latter condition is achieved by the complex herbicide Marathon, which is recommended for autumn use in winter wheat crops [6].

The active ingredients of Marathon herbicide are pendimethalin, microtubule polymerization inhibitor, and isoproturon, electron transport inhibitor (ET) in photosystem II (PSII) of chloroplasts. However, the disadvantages of this preparation are, firstly, the very high application rate, and secondly, the low effectiveness of the action on growing weeds, because both active substances act mainly as soil herbicides. Another complex herbicide recommended for autumn use in winter wheat crops Trinity differs from Marathon in containing three active substances: pendimethalin, chlortoluron — another inhibitor of ET in PSII, and inhibitor of phytoendesaturases diflufenican. The third component with a different MOA clearly increases the effectiveness of resistance controlling and, in addition, due to the high efficacy of diflufenican, especially for dicotyledonous weeds, reduces the Triniti application rate compared to Marathon. However, because diflufenican also acts mainly as a soil herbicide, the high effectiveness of Trinity herbicide on growing weeds is achieved only at the early stages of their development. Besides, the herbicidal load on the agrophytocenosis when using the herbicide Trinity still significantly exceeds the load when using the herbicides based on ALS inhibitors. A compromise option is possible, which involves the combined use of diflufenican with ALS inhibitors. In particular, Bayer has registered a complex herbicide Checker Xtend 39 WG for autumn use in winter wheat crops, the active ingredients of which are diflufenican and ALS inhibitors amidosulfuron and iodosulfuron [7]. Corteva is testing the complex herbicide GF-2202, in which diflufenican is complexed with ALS inhibitors florasulam and penoxsulam. However, increasing the effectiveness through the use of ALS inhibitors reduces the effectiveness of these herbicides to prevent resistance.

At the same time, it is possible to fulfill the requirements of high effectivity of the counteraction against resistance, crop protection and environmental safety if partners for diflufenican joint application will be found that are selective for winter wheat, exceed pendimethalin, chlorotoluron and isoproturon in efficiency or have a synergistic character of interaction with diflufenican. Protoporphyrinogen oxidase (PPO) inhibitor carfentrazone (Aurora 40), and inhibitor of ET in PSII metribuzin (Zenkor Liquid), which are approved for use in winter wheat crops, can be used as such potential partners [6]. The choice of these herbicides was based on the following considerations. The phytotoxic action of these three herbicides is due to the disruption of photosynthesis and mediated by the formation of reactive oxygen species (ROS) [8]. Because diflufenican inhibits carotenoid biosynthesis, one of the physiological functions of which is to protect the photosynthetic apparatus from ROS damage [9], the interaction of diflufenican with metribuzin and carfentrazone was expected to be additive or even synergistic [10]. To test this assumption, the effects of diflufenican, carfentrazone, and metribuzin herbicides interactions in binary and ternary mixtures were investigated in greenhouse experiments on the model objects. It was found that in the mixture of canfentrazone with metribuzin the interaction had signs of antagonism, and in other binary combinations, as well as in the ternary mixture, the interaction was additive. It was concluded that a mixture of diflufenican with metribuzin, and a triple mixture with the addition of carfentrazone to metribuzin and diflufenican are promising for use [10].

In this regard, the aim of this study was to test in field experiments on real objects the nature of interaction, weed control efficiency and crop selectivity of herbicides diflufenican, carfentrazone and metribuzin mixtures for autumn use in winter wheat crops to select the optimal anti-resistant composition of herbicides, which could be the basis for the creation of a complex herbicide or used in the form of a tank herbicides mixture.

Materials and methods

Field experiments were conducted during 2018—2021 in the fields of the research farm of the Institute of Plant Physiology and Genetics of the National Academy of Sciences of Ukraine (Glevakha village, Fastiv district, Kyiv region, 50°16'N, 30°18'E). The research farm is located on the border of Polissya and Forest-Steppe zones. The climate is temperate, the annual rainfall is from 520 to 645 mm. Soil is sod-podzolic, loamy in mechanical composition, humus content 1.6 %, pH 5.6. The experiments were carried out in winter wheat crops of the varieties Zoloto Ukrayiny, predecessor sunflower (2018—2019); Natalka, predecessor mustard (2019—2020); Snihurka (2020—2021), predecessor mustard.

The following herbicides were used in the studies: Zencor Liquid, SC, (metribuzin, 600 g/l); Aurora 40, WG (carfentrazone, 400 g/l); Diflufenican (diflufenican, 500 g/l), Marathon, SC (pendimethalin, 250 g/l + isoproturon, 125 g/l), GF-2202 (diflufenican, 100 g/l + florasulam, 3.75 g/l + + penoxsulam, 15 g/l).

Herbicide treatment was carried out in autumn at the stage of 2—3 leaves in winter wheat. Spraying with herbicides was carried out using a knapsack rod sprayer with compressed air, pressure 4 atm, rod length — 3 m, number of nozzles — 6, distance to the target — 50 cm, speed — 5 km/h, working fluid consumption — 300 l/ha.

The area of the experimental plot was 15 m^2 (3 × 5 m), experiments were performed in four replicates, the plots were placed randomly. Each experiment included a control variant (without herbicides).

Weed accountings were performed before herbicide treatment, 7—14 days after treatment, in the spring after growth resumption, and before harvesting. The effectiveness of herbicides was assessed for each weed species separately by reducing the number in treated areas compared to control [11] taking into account the visual assessment of the degree of suppression of herbicide-treated plants compared to the condition of these plants in control (weight and linear dimensions, leaf chlorosis, etc.). The degree of visual suppression was expressed as a percentage: 0 % — no signs of herbicide action, 100 % — complete death of weeds of this species. The effectiveness of weed control was calculated by formula:

$$E\ (\%) = 100 - B_{2\_} \times K_1 \times (1 - E_B / 100) \times 100 / (B_1 \times K_2),$$

where E (%) is the effectiveness of controlling of a particular species of weeds, taking into account the level of weediness and visual assessment of herbicide action; K_1 — the number of weeds per 1 m^2 in the first accounting in control plot (initial weediness), K_2 — the number of weeds per 1 m^2 in the control plot during the second (third) accounting, B_1 — the number of weeds per 1 m^2 in the first accounting in the treated plot (initial weediness), $B_{2\_}$ the number of weeds per 1 m^2 in the second (or third) accounting at the treated plot, E_B — visual assessment of the herbicide action (the level of damage or the degree of suppression of weed plants expressed (in %) visually compared to plants of the same species in the control plot).

The crop selectivity of herbicides was assessed by biometric measurements and phenological observations carried out in 7 days after herbicide treatment and at each weed accounting, and by determining the effect of herbicides on winter wheat grain yield.

Statistical processing of the results was performed by analysis of variance (ANOVA) using the Tukey (HSR) test. The results were presented as mean and standard errors (S±SE). Differences between data were considered significant at $p \le 0.05$.

Results and discussion

Since the period of autumn treatment of winter wheat crops is likely to fall on the development stage of 2—3 leaves, while the herbicide carfentrazone is recommended to be applied at the tillering stage, the task of the first experiment was to test the crop selectivity of herbicide carfentrazone and its mixtures with diflufenican and metribuzin when applied in the early stages of winter wheat development. To determine the culture-safe application rate, carfentrazone was used at a reduced application rate of 8 g/ha, and a recommended application rate of 16 g/ha. The experiment was established on October 16, 2018 in the crop of winter wheat of the Zoloto Ukrayiny variety (predecessor sunflower), when wheat plants were at the stage of 2 leaves (BBCH 12). At the time of treatment was sunny weather, air temperature 20 °C, wind 1.5 m/s. The surface of the soil and leaves are dry. The scheme of the experiment is given in Table 1.

Accounting conducted before herbicide treatments showed that winter wheat crops were infested mainly with sunflower plants (4—8 specimens/m^2), which are at the cotyledon stage. Infestation with other weed species — field pansy (*Viola arvensis* Murr.), black bindweed (*Polygonum convolvulus* L.), and rocket-larkspur (*Consolida regalis* SF Gray) was very low (less than 0.1 specimens/m^2), which was probably due to aftereffect of herbicides applied to protect sunflower crops. Accounting conducted in 7 days after treatment, showed that the most effective on the sunflower volunteer was herbicide carfentrazone (Table 2). This result is quite expected, as herbicides inhibitors PPO are characterized by a high velocity of phytotoxic action development. The addition of diflufenican and metribuzin enhanced the carfentrazone effect only at a lower application rate of 8 g/ha. The effect of herbicides on sunflower volunteer could not be assessed further. In autumn, sunflower plants were damaged by frost. In the spring after the restoration of vegetation, the appearance of the second

TABLE 1. Scheme of field experiment in 2018—2019

N	Variant		Application rate	
	Herbicide	Active substance	by herbicide	by active substance
1	Control	–	–	–
2	Aurora	Carfentrazone	0.02 l/ha	8 g/ha
3	Aurora	Carfentrazone	0.04 l/ha	16 g/ha
4	Diflufenican	Diflufenican	0.2 l/ha	100 g/ha
5	Zenkor Liquid	Metribuzin	0.4 l/ha	240 g/ha
6	Aurora	Carfentrazone	0.02 l/ha	8 g/ha
	Diflufenican	Diflufenican	0.2 l/ha	100 g/ha
	Zenkor Liquid	Metribuzin	0.4 l/ha	240 g/ha
7	Aurora	Carfentrazone	0.04 l/ha	16 g/ha
	Diflufenican	Diflufenican	0.2 l/ha	100 g/ha
	Zenkor Liquid	Metribuzin	0.4 l/ha	240 g/ha

TABLE 2. Effectiveness (%) of herbicide control of sunflower volunteer in 7 days after treatment of winter wheat crops

N	Variant	Sunflower volunteer
2	Carfentrazone (8 g/ha)	43±5 [b]
3	Carfentrazone (16 g/ha)	55±5 [bc]
4	Diflufenican (100 g/ha)	23±5 [a]
5	Metribuzin (240 g/ha)	18±5 [a]
6	Carfentrazone (8 g/ha) + diflufenican (100 g/ha) + metribuzin (240 g/ha)	60±4 [c]
7	Carfentrazone (16 g/ha) + diflufenican (100 g/ha) + metribuzin (240 g/ha)	63±3 [c]

Note. The difference between the means is significant at $p \leq 0.05$ in the absence of identical letters.

wave of sunflower plants was observed, which was very quickly suppressed by wheat canopy.

Considering accounting conducted before herbicide treatments no signs of phytotoxic effects of herbicides on the crop in any of the variants of the experiment were not revealed. Due to the low level of weediness, the use of herbicides did not significantly increase the grain yield of winter wheat (see Table 5). At the same time, the tendency to increase the yield is an additional indication of the lack of the studied herbicides negative impact on the growth and development of winter wheat plants.

Therefore, in subsequent experiments the recommended application rate of carfentrazone 16 g/ha was used. To compare the effectiveness of weed control with the herbicides diflufenican, carfentrazone, metribuzin, and their mixtures, the complex herbicides Marathon and GF-2202 were used as standards. The scheme of field experiments is given in Table 3. The experimente were established on October 22, 2019, when Natalka winter wheat plants reached the stage of 2—3 leaves (BBCH 12—13). At the time of treatment there was sunny weather, air temperature 20 °C, wind ≤ 0.5 m/s, the surface of leaves and soil was dry.

Accounting conducted before herbicide treatments showed that wheat crops were infested mainly with white mustard (*Sinapis alba* L.) plants (60 specimens/m^2), which were at the BBCH 12—13 stage, and scentless chamomile (*Matricaria inodora* L.) (1 specimen/m^2), which reached the stage of BBCH 10—12. Examination of crops in 7 days after treatment, as well as subsequent observations of plant growth and development throughout the growing season of winter wheat did not show signs of herbicides adverse effects on the crop in any variant of the experiments.

Accounting conducted in 14 days after treatment, found that mustard plants, which at the time of treatment reached a significant size of 5—8 cm, were poorly controlled by carfentrazone, diflufenican, and Marathon. The effect of the herbicide GF-2202 on mustard was slightly higher, but did not exceed 73 %. At the same time, metribuzin when used alone and in binary mixtures with carfentrazone and diflufenican, as well as in the ternary mixture almost completely controlled the mustard. Scentless chamomile plants were controlled at 70—75 % with diflufenican,

TABLE 3. Scheme of field experiments in 2019—2020 and 2020—2021

N	Variant		Application rate	
	Herbicide	Active substance	by herbicide	by active substance
1	Control	–	–	–
2	Aurora	Carfentrazone	0.04 l/ha	16 g/ha
3	Diflufenican	Diflufenican	0.2 l/ha	100 g/ha
4	Zenkor Liquid	Metribuzin	0.4 l/ha	240 g/ha
5	Aurora	Carfentrazone	0.04 l/ha	16 g/ha
	Diflufenican	Diflufenican	0.2 l/ha	100 g/ha
6	Aurora	Carfentrazone	0.04 l/ha	16 g/ha
	Zenkor Liquid	Metribuzin	0.4 l/ha	240 g/ha
7	Diflufenican	Diflufenican	0.2 l/ha	100 g/ha
	Zenkor Liquid	Metribuzin	0.4 l/ha	240 g/ha
8	Aurora	Carfentrazone	0.04 l/ha	16 g/ha
	Diflufenican	Diflufenican	0.2 l/ha	100 g/ha
	Zenkor Liquid	Metribuzin	0.4 l/ha	240 g/ha
9	GF-2202	Diflufenican	1 l/ha	100 g/ha
		Florasulam		3.75 g/ha
		Penoxsulam		15 g/ha
10	Marathon	Pendimethalin	4 l/ha	1 kg/ha
		Isoproturon		0.5 kg/ha

metribuzin, and a mixture of carfentrazone and diflufenican. In other variants, chamomile plants were controlled almost completely.

In the spring of 2020, after the growth resumption, the accounting conducted in 170 days after the application of herbicides, when winter wheat plants reached the tillering stage (BBCH 20—21), showed weediness with annual dicotyledons in control variant: scentless chamomile (1.5 specimens/m^2), common crowfoot (*Erodium cicutarium* (L.) L'Her.) (1.5 specimens/m^2), field pansy (*Viola arvensis* Murr.) (5 specimens/m^2), sow thistle (*Sonchus oleraceus* L.) (1.5 specimens/m^2), chickweed (*Stellaria media* (L.) Vill.) (0.5 specimens/m^2); as well as annual cereal silky wind grass (*Apera spica-venti* (L.) Pal. Beauv.) (2 specimens/m^2).

The results of determining the effectiveness of herbicides weed control are given in Table 4. It can be seen that almost complete controlling of the whole spectrum of weed species was achieved with mixtures of diflufenican with metribuzin, triple mixture of diflufenican, metribuzin and carfentrazone, and complex herbicides Marathon and GF-2202. Common crowfoot, scentless chamomile, and sow thistle were effectively controlled by carfentrazone applied alone by 99, 30 and 75 %, respectively, and field pansy, chickweed, and silky wind grass practically did not suffer from herbicide influence. Diflufenican when applied separately effectively controlled scentless chamomile, field pansy, sow thistle and chickweed; and silky wind grass and common crowfoot — by 70 and 74 % respectively. Metribuzin when applied separately effectively controlled common crowfoot and chickweed; sow thistle and silky wind grass were controlled by

TABLE 4. Effectiveness (%) of herbicide controlling of weeds in autumn in 14 days after treatment (DAT) and in spring at the tillering stage of winter wheat in 170 days after treatment (2019—2020 and 2020—2021)

N	2019—2020							
	14 DAT		170 DAT					
	White mustard	Scentless chamomile	Scentless chamomile	Common crowfoot	Field pansy	Sow thistle	Chickweed	Silky wind grass
2	34±5^{a}	99±1^{b}	30±10^{a}	99±1^{b}	0^{a}	75±10^{a}	0^{a}	0^{a}
3	32±2^{a}	74±5^{a}	90±7^{c}	74±8^{a}	99±1^{b}	99±1^{b}	99±1^{b}	70±5^{b}
4	99±1^{c}	75±5^{a}	18±10^{a}	99±1^{b}	18±9^{a}	75±10^{a}	99±1^{b}	82±8^{b}
5	45±6^{a}	70±5^{a}	92±5^{c}	99±1^{b}	99±1^{b}	99±1^{b}	99±1^{b}	70±5^{b}
6	99±1^{c}	99±1^{b}	80±10^{b}	99±1^{b}	15±10^{a}	94±5^{b}	99±1^{b}	95±5^{c}
7	99±1^{c}	99±1^{b}	97±2^{c}	99±1^{b}	99±1^{b}	99±1^{b}	99±1^{b}	97±2^{c}
8	99±1^{c}	99±1^{b}	97±2^{c}	99±1^{b}	99±1^{b}	99±1^{b}	99±1^{b}	99±1^{c}
9	45±5^{a}	99±1^{b}	99±1^{c}	99±1^{b}	99±1^{b}	99±1^{b}	99±1^{b}	99±1^{c}
10	73±8^{b}	99±1^{b}	92±7^{c}	99±1^{b}	92±7^{b}	99±1^{b}	99±1^{b}	92±5^{c}

N	2020—2021							
	14 DAT				170 DAT			
	White mustard	Scentless chamomile	Cornflowers	Field pansy	Scentless chamomile	Cornflowers	Field pansy	Silky wind grass
2	13±8^{a}	90±4^{c}	68±8^{a}	94±1^{c}	75±5^{a}	0^{a}	90±2^{a}	0^{a}
3	50±3^{b}	63±5^{a}	50±2^{a}	66±4^{a}	68±3^{a}	0^{a}	91±1^{a}	0^{a}
4	88±5^{c}	61±9^{a}	65±9^{a}	51±8^{a}	75±2^{a}	25±10^{ab}	90±7^{a}	80±10^{b}
5	35±9^{b}	93±1^{c}	68±9^{a}	95±1^{c}	94±2^{b}	42 ±10^{b}	95±3^{ab}	13±8^{a}
6	83±5^{c}	95±1^{c}	87±5^{b}	95±1^{c}	94±2^{b}	87 ±5^{c}	96±2^{bc}	98±1^{c}
7	78±4^{c}	80±2^{b}	80±3^{ab}	73±8^{b}	99±1^{b}	92 ±5^{cd}	99±1^{c}	97±2^{c}
8	89±4^{c}	95±2^{c}	90±2^{b}	95±1^{c}	96±2^{b}	99±1^{d}	99±1^{c}	98±1^{c}
9	55±5^{b}	64±4^{a}	53±3^{a}	63±7^{a}	99±1^{b}	99±1^{d}	99±1^{c}	98±1^{c}
10	58±9^{b}	70±7^{a}	68±7^{b}	74±8^{b}	92±5^{b}	13±8^{ab}	96±2^{bc}	80±10^{b}

N o t e . The difference between the means is significant at $p \leq 0.05$ in the absence of identical letters.

75 % and 82 %, respectively, and scentless chamomile and field pansy were resistant to this herbicide. A mixture of carfentrazone and diflufenican effectively controlled dicotyledonous species, but only 70 % of silky wind grass were controlled. The mixture of carfentrazone and metribuzin effectively controlled common crowfoot, sow thistles, chickweed and silky wind grass, but only by 80 % controlled chamomile, and had little effect on field pansy. Pre-harvest accounting did not reveal significant changes in the nature of weediness in control variant and the effectiveness of herbicides.

The following year, the experiment was established on October 22, 2020, when the winter wheat plants of the Snihurka variety reached the BBCH 12—13 stage. At the time of treatment there was variable cloudiness (50 %), air temperature 12 °C, wind 5 m/s, leaf surface was dry, soil surface was moist.

Accounting conducted before herbicide treatments showed that the main crop contaminants were white mustard (4 specimens/m^2), scentless chamomile (20 specimens/m^2), cornflowers (*Centaurea cyanus* L.) (2 specimens/m^2), and field pansy (20 specimens/m^2). In 7 days after application of herbicides, in all variants with the use of carfentrazone in a significant number of wheat plants (up to 30 %) the appearance of chlorotic spots on the leaves was observed (Fig. 1). After the growth resumption in the spring, no signs of negative effects of herbicides on the crop were detected.

In 14 days after application of herbicides, scentless chamomile and field pansy plants, which at the time of treatment were at the early stages of development and their linear size did not exceed 1 cm, were effectively controlled in all variants using carfentrazone (Table 4). Mustard plants, which at the time of treatment were at the stage of BBCH 12—14 and had a height of 5 cm, were most effectively controlled in variants using metribuzin. Cornflowers, which at the time of treatment were at the BBCH 12—13 stage and had a height of 4 cm, were most effectively controlled in variants using mixtures of metribuzin with diflufenican and carfentrazone, as well as under the action of a triple mixture of diflufenican, carfentrazone and metribuzin. For the entire spectrum of weed species, the highest efficacy, which on the 14th day after treatment significantly exceeded the action of the complex herbicides Marathon and GF-2202, was observed with the use of a triple mixture of diflufenican, carfentrazone and metribuzin.

After overwintering in 170 days after treatment of crops with herbicides, wheat plants reached stage 4 leaves (BBCH 14). The control variant was littered with scentless chamomile (25 specimens/m^2), cornflowers (2 specimens/m^2), field pansy (20 specimens/m^2) and silky wind grass (2 specimens/m^2). The greatest effectiveness of protection against all weed species

Fig. 1. Damage to winter wheat plants by the herbicide carfentrazone in 7 days after treatment

in the crop was observed in the variants using mixtures of metribuzin with diflufenican, triple mixture of diflufenican, carfentrazone and metribuzin, as well as the complex herbicide GF-2202. The mixture of metribuzin with carfentrazone effectively controlled chamomile, field pansy and silky wind grass, but was somewhat inferior in the effectiveness of cornflowers controlling. A mixture of diflufenican with carfentrazone effectively controlled chamomile and field pansy, but had little effect on cornflower and silky wind grass. The complex herbicide Marathon effectively controlled chamomile and field pansy; it controlled 80 % of the silky wind grass, but this herbicide had almost no effect on cornflowers. Further no significant changes in weed control and herbicide efficacy were observed until the time of harvest.

Thus, the obtained data show that when treating winter wheat crops in autumn, the greatest effectiveness of weed control during the entire growing season was achieved with the use of a triple mixture of diflufenican, metribuzin and carfentrazone. The addition of carfentrazone increased the effectiveness of protection exactly in the autumn, because in the spring and summer the effect of a mixture of diflufenican with metribuzin and complex herbicide GF-2202 was not inferior to the action of the triple mixture. Effective protection of crops from weeds ensured reliable preservation of winter wheat grain harvest (Table 5).

As mentioned above, herbicides were not effective in 2018—2019 due to low weediness. However, the tendency to increase yields with the use of herbicides is evidence of their selectivity for the crop. In the following years, a significant increase in yield compared to control was observed in all variants with the use of herbicides. The highest values of grain yield in the experiments of 2019—2020 and 2020—2021 were obtained in variants using a mixture of diflufenican with metribuzin, triple mixture of diflufenican, carfentrazone and metribuzin, as well as with the application of complex herbicides Marathon and GF-2202. In 2019—2020, the yield in the variant using a mixture of diflufenican with carfentrazone was not significantly inferior to the maximum value.

TABLE 5. Grain yield (t/ha) of winter wheat varieties Zoloto Ukrayiny (2019), Natalka (2020) and Snihurka (2021) with the use of herbicides in the autumn

N	Variant	2019	2020	2021
1	Control	5,03 [a]	3,12 [a]	2,84 [a]
2	Carfentrazone (16 g/ha)	5,22 [a]	3,72 [b]	3,81 [b]
3	Diflufenican (100 g/ha)	5,19 [a]	3,70 [b]	3,63 [b]
4	Metribuzin (240 g/ha)	5,11 [a]	3,53 [b]	4,19 [bc]
5	Carfentrazone (16 g/ha) + diflufenican (100 g/ha)	5,27 [a]	3,95 [bc]	4,20 [bc]
6	Carfentrazone (16 g/ha) + metribuzin (240 g/ha)	5,37 [a]	3,63 [b]	3,96 [bc]
7	Diflufenican (100 g/ha) + metribuzin (240 g/ha)	5,41 [a]	3,98 [bc]	4,52 [cd]
8	Carfentrazone (16 g/ha) + diflufenican (100 g/ha) + + metribuzin (240 g/ha)	5,68 [a]	4,18 [c]	4,62 [cd]
9	GF-2202 (1 l/ha)	–	4,15 [bc]	4,81 [d]
10	Marathon (4 l/ha)	–	3,94 [bc]	4,27 [cd]

The data obtained on the effectiveness of winter wheat grain preservation in different herbicide applications are generally well correlated with the effectiveness of weed control by herbicides. The results obtained in field experiments confirmed the data of greenhouse experiments about the greatest prospects for the use of diflufenican with metribuzin and triple mixture of diflufenican, metribuzin and carfentrazone for autumn application in winter wheat crops. Although antagonism was not observed in field experiments with metribuzin and carfentrazone, which took place in greenhouse experiments at model objects [10], the effectiveness of weed control with this mixture, as well as a mixture of diflufenican and carfentrazone was clearly inferior to the effects of a mixture of diflufenican with metribuzin, and a triple mixture of diflufenican, metribuzin and carfentrazone. It should be noted that although during the two growing seasons the differences between the diflufenican and metribuzin variant, and the triple mixture variant were not significant, however, there was a tendency to exceed the yield value in the triple mixture variant. This trend is probably due to the fact that through the high rate of carfentrazone action, weed controlling occurs earlier than with a mixture of diflufenican and metribuzin. However, although in the automn of 2020 there were manifestations of phytotoxic effects of carfentrazone on winter wheat plants in the form of chlorotic spots on the leaves, it did not affect the crop yield formation in the variant using a triple mixture.

The obtained data allow us to conclude that the mixture of diflufenican with metribuzin, and the triple mixture of diflufenican, metribuzin and carfentrazone when applied in automn is not inferior to the action of complex herbicides Marathon and GF-2202 on crop protection and yield preservation. It should be noted that when using these mixtures, the herbicidal load on the agrophytocenosis is less than when using the herbicide Marathon, but exceeds the load when applying the herbicide GF-2202. At the same time, the main advantage of using mixtures of diflufenican with metribuzin, and a triple mixture of diflufenican, metribuzin and carfentrazone over the complex herbicide GF-2202 is that the use of these mixtures provides high efficiency of winter wheat crops protection without the use of ALS inhibitors. Because these mixtures meet all the requirements for herbicide-resistant herbicide compositions [2, 3, 4], there is every reason to believe that the use of tank mixtures of diflufenican and metribuzin, and a triple mixture of diflufenican, metribuzin and carfentrazone in winter wheat crops in autumn can be an effective means of preventing the emergence of herbicide-resistant weed biotypes, including biotypes resistant to herbicides ALS inhibitors.

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ЕФЕКТИВНІСТЬ КОНТРОЛЮВАННЯ БУР'ЯНІВ ПРИ ЗАСТОСУВАННІ В ПОСІВАХ ОЗИМОЇ ПШЕНИЦІ ВОСЕНИ ГЕРБІЦИДІВ ДИФЛУФЕНІКАНУ, МЕТРИБУЗИНУ ТА КАРФЕНТРАЗОНУ

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З метою розробки антирезистентних композицій гербіцидів для захисту посівів озимої пшениці протягом трьох вегетаційних періодів проводили польові випробування ефективності контролювання бур'янів та селективності щодо культури при застосуванні восени у фазу 2—3 листків у рослин озимої пшениці бакових сумішей гербіцидів дифлуфенікану, метрибузину та карфентразону. Для порівняння як еталон використовували комплексні гербіцидні препарати марафон, КС (пендиметалін, 250 г/л + ізопротурон,125 г/л), GF-2202 (дифлуфенікан, 100 г/л + флорасулам, 3,75 г/л + пеноксулам, 15 г/л). Було встановлено, що найбільша ефективність контролювання бур'янів протягом усього вегетаційного періоду досягалася при застосуванні потрійної суміші дифлуфенікану, метрибузину та карфентразону. При цьому застосування карфентразону підвищувало ефективність захисту саме в осінній період, оскільки у весняно-літній період дія суміші дифлуфенікану з метрибузином та комплексного гербіциду GF-2202 не поступалася дії потрійної суміші. У досліді, який проводили у 2018—2019 рр., внаслідок низького рівня забур'янення застосування гербіцидів не було ефективним, однак тенденція до зростання врожаю зерна озимої пшениці при застосуванні гербіцидів була свідченням їхньої селективності щодо культури. Прояви фітотоксичного впливу на культуру спостерігали лише восени 2020 р. у варіантах із застосуванням карфентразону окремо та у сумішах. Проявом фітотоксичного впливу карфентразону була поява через короткий час після обробки хлоротичних плям на листках рослин озимої пшениці. Однак ця дія карфентразону не вплинула на подальший ріст і розвиток озимої пшениці та формування врожаю зерна. Найбільший урожай зерна у дослідах 2019—2020 та 2020—2021 рр. було отримано у варіантах із застосуванням суміші дифлуфенікану з метрибузином, потрійної суміші дифлуфенікану, карфентразону та метрибузину, а також із внесенням комплексних гербіцидних препаратів GF-2202 та марафон. Зроблено висновок, що при застосуванні восени в посіві озимої пшениці бакова суміш дифлуфенікану з метрибузином та потрійна бакова суміш дифлуфенікану, метрибузину та карфентразону не поступаються за ефективністю захисту та збереженням урожаю дії комплексних гербіцидних препаратів GF-2202 та марафон. Головною перевагою застосування сумішей дифлуфенікану з метрибузином та потрійної суміші дифлуфенікану, метрибузину та карфентразону над комплексним гербіцидним препаратом GF-2202 є те, що застосування цих сумішей забезпечує високу ефективність захисту посіву озимої пшениці без використання інгібіторів АЛС. Констатовано, що застосування восени в посівах озимої пшениці бакових сумішей гербіцидів дифлуфенікану та метрибузину та потрійної суміші дифлуфенікану, метрибузину та карфентразону є ефективним засобом попередження виникнення резистентних до гербіцидів біотипів бур'янів, у тому числі біотипів, резистентних до гербіцидів інгібіторів АЛС.

Ключові слова: Triticum aestivum L., гербіциди, резистентність, дифлуфенікан, метрибузин, карфентразон.