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Autumn Application of Synthetic Auxin Herbicide for Weed Control in Cereals in Poland and Germany

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Abstract: The biological efficacy of herbicides MCPA+tribenuron-methyl (code name: MT-565 SG) and diflufenican+chlorotoluron (Legato Pro 425 SC) was estimated in eighteen field experiments on winter cereals in Poland and Germany to control broadleaf weeds. Postemergence application of tribenuron-methyl in combination with MCPA, applied at the 3-leaf stage to 3 tillers detectable in autumn in winter cereals, resulted in the majority of weed species occurring in autumn being effectively eliminated with MCPA+tribenuron-methyl applied at 1.0 kg·ha^{-1}. It also provided an acceptable (82.4–94.1%) and comparable level of control to commonly occurring weeds *Brassica napus*, *Capsella bursa-pastoris*, *Centaurea cyanus*, *Lamium purpureum*, *Tripleurospermum inodorum*, *Stellaria media*, and *Thlaspi arvense*. A satisfactory level of control of 66.3 to 88.3% was confirmed for *Veronica persica*, *Viola arvensis*, and *Galium aparine*. According to these results, the formulation of tribenuron-methyl combined with MCPA can be recommended for application in winter cereals in the autumn as an alternative to commonly available herbicides.

Keywords: MCPA; tribenuron-methyl; winter cereals; weed control; autumn application

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1. Introduction

One of the most important areas of plant production in the Europe are cereals, occupying a third of EU's agricultural area, growing on half of the European Union's farms and accounting for a quarter of its crop production value. In Europe, the total cereal production accounts for 20% of the global scale, with great importance in human nutrition (24%), but also in the feeding of farm animals (61%), alcoholic beverages (5%), bio-energy (4%), and seeds (3%) [1].

Crop yields can be significantly reduced due to weeds [2]. The introduction of herbicides has become a very effective and relatively cheap way of weed control, significantly contributing to the increase in average yield during the period of their adoption and improving crop quality [3,4]. Thus far, herbicides are the most effective weed control tools developed, controlling 90 to 99% of the weeds targeted [5–7]. Therefore, control of weeds largely depends on chemical methods [8], and herbicides are an integral part of any weed management system and play an important role in producing high-yielding crops and maintaining the stability of agricultural production. However, Rahman [9] pointed out that herbicides cause many environmental and health hazards.

Cereals are most sensitive to competition from weeds (weed community composition) in their early stages of growth, especially in autumn-sown crops, and particularly in cereals established with reduced cultivation [10,11]. Weeds start to grow at the same time as the crop, if not earlier, affecting growth, competing with the crop for water, light, soil nutrients, space, and CO_2, and reducing the potential crop yield [12]. Moreover, weed control in the autumn is usually much better than that applied in the spring [13], because weeds are generally smaller and autumn application controls weeds that would normally survive during the winter, thus providing better conditions for competition by the crop when vegetative growth begins in the spring [14].

The dominant role of herbicides as a convenient tool used for weed control in modern agriculture has led to the rapid evolution of herbicide-resistant (HR) weeds [15–17]. One of the key components of an integrated weed management approach that may reduce the risk of the evolution of resistance in weeds are herbicide mixtures and herbicide rotations [18]. Combining herbicides with different modes of action is also one of the useful methods used to safely reduce herbicide rates, control a wider spectrum of weeds, and reduce production costs, while maintaining weed control at acceptable levels [19,20].

The aim of the field experiments carried out in Poland and Germany was to examine the potential of herbicide combination as soluble granules (SG) containing 15 g/kg of tribenuron-methyl (ALS-inhibitor) and 550 g/kg of MCPA (synthetic auxin) applied in autumn for the control of dicotyledonous weeds already emerged in winter cereals.

2. Materials and Methods

Field experiments were conducted in 2016 and 2017 in Poland and Germany. A total of 18 efficacy trials were carried out on a range of several cultivars for winter wheat, winter barley, winter rye, and winter triticale (Figure 1, Table 1). Field experiments were implemented in fields sown with commercial cereal cultivars, where crops are produced commercially, and in fields with a known history of weed infection. In all experiments, the infestation was natural. Sites were selected to represent the range of agricultural and environmental conditions (including climatic conditions) likely to be encountered in practice in potential use.

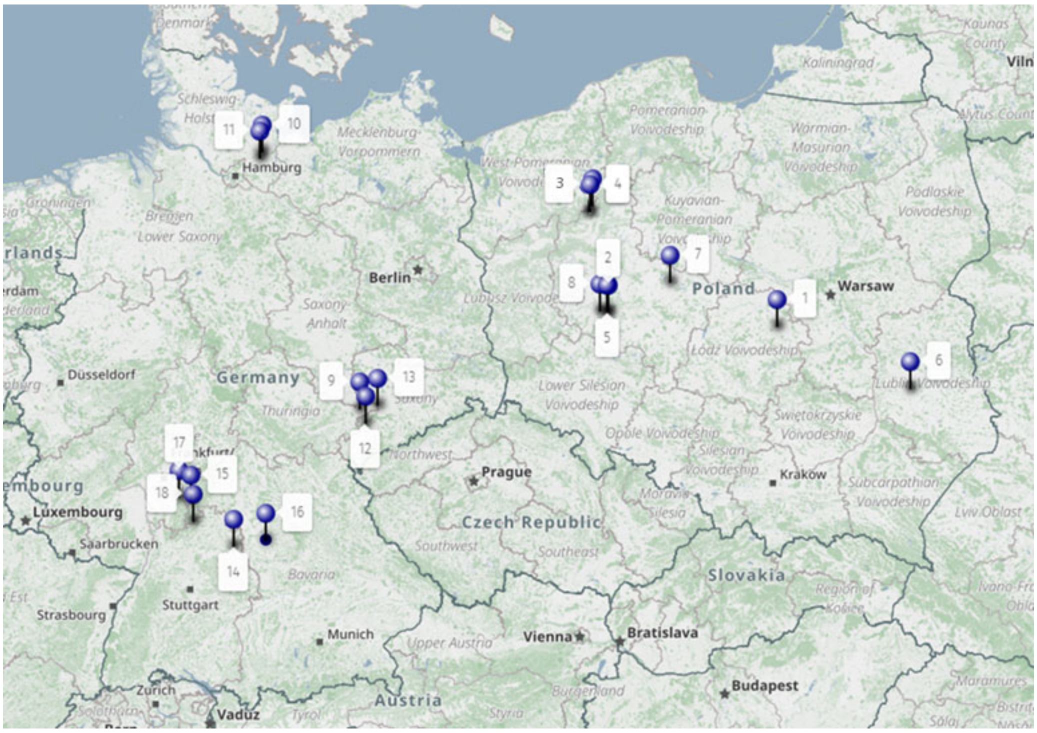

Figure 1. Locations of the experimental fields in Germany and Poland.

Table 1. Experimental site descriptions and application details are presented.

Trial No.	Country	GPS	Crop and Variety (var.)	Application Date; Crop Stage (BBCH)	Soil	Soil pH	Water Volume at Application (L ha^{-1})
1	Poland	51.87723 N 20.01983 E	Winter wheat var. Muszelka	15/11/16; 13	Sandy clay loam	5.8	300
2	Poland	52.03594 N 16.89602 E	Winter wheat var. Hondia	15/11/16; 15	Sandy clay	5.8	200
3	Poland	53.15822 N 16.54780 E	Winter wheat var. Ostroga	21/11/16; 24	Clay loam	7.1	200
4	Poland	53.15891 N 16.54822 E	Winter triticale var. Twingo	09/11/16; 16	Sandy loam	5.3	200
5	Poland	52.05919 N 16.75175 E	Winter triticale var. Twingo	23/11/16; 15	Sandy loam	6.2	200
6	Poland	51.16363 N 22.47511 E	Winter barley var. Meridian	26/10/17; 13	Clay	5.5	200
7	Poland	52.37013 N 18.03480 E	Winter barley var. Zenek	4/11/17; 22	Sandy clay	6.1	300
8	Poland	52.05919 N 16.75175 E	Winter barley var. Gloria	17/11/17; 23	Sandy clay	6.1	400
9	Germany	50.93083 N 12.29472 E	Winter wheat var. Pamier	22/11/16; 13	Silt loam	6.5	200
10	Germany	53.81500 N 10.49416 E	Winter wheat var. Ritmo	26/10/16; 12	Loamy sand	6.3	300
11	Germany	53.74694 N 10.46833 E	Winter wheat var. Edgar	16/11/16; 21	Loamy sand	6.3	300
12	Germany	50.76138 N 12.41000 E	Winter wheat var. Baranco	22/11/16; 22	Silty clay	6.6	300
13	Germany	50.97055 N 12.63555 E	Winter triticale var. Agostino	22/11/16; 22	Loam	6.8	200
14	Germany	49.30416 N 9.97555 E	Winter rye var. Protector	24/11/16; 13	Silty clay loam	7.8	200
15	Germany	49.84027 N 9.17861 E	Winter rye var. SU Forsetti	25/10/16; 13	Silty sand	6.7	300
16	Germany	49.38583 N 10.57222 E	Winter barley var. Malwinta	22/11/16; 23	Loamy sand	5.7	200
17	Germany	49.89416 N 8.95388 E	Winter barley var. Sandra	22/11/16; 13	Loamy silt	6.4	300
18	Germany	49.60861 N 9.21805 E	Winter barley var. Sandra	22/11/16; 13	Loamy sand	5.6	300

All trials were carried out in accordance with the principles of good experimental practices (GEP). MT-565 SG was applied by broadcast foliar spraying at the doses of 0.8 kg ha^{-1} (440 g a.i. ha^{-1} of MCPA and 12 g a.i. ha^{-1} of tribenuron-methyl) and 1.0 kg ha^{-1} (550 g a.i. ha^{-1} of MCPA and 15 g a.i. ha^{-1} of tribenuron-methyl) compared to the reference product at 2.5 L ha^{-1} (Legato Pro 425 SC, 62.5 g a.i. ha^{-1} of diflufenican and 1000 g a.i. ha^{-1} of chlortoluron) already registered to control weeds in winter cereals. Herbicides were sprayed using backpack plot sprayers with flat fan nozzles, calibrated to deliver water volumes ranging from 200 to 400 L ha^{-1} aqueous solution, and the plot size of trials varied between 10 and 21 m^{-2}. The experiments were organized as a complete randomized block design with four replications, and the untreated control was included in the experimental design. Herbicides were applied at the 3-leaf stage to 3 tillers detectable in autumn. Crop stages at application, experimental site descriptions and application details presented in this study are presented in Table 2.

Table 2. Weed species growth stages (BBCH) during herbicide application at individual locations.

Trial No.	Country	GPS	Weed Species									
			CAPBP	CENCY	LAMPU	MATIN	STEME	VIOAR	BRSNN	GALAP	THLAR	VERPE
			BBCH									
1	Poland	51.87723 N 20.01983 E	12	12	12	11	12	11	-	-	-	-
2	Poland	52.03594 N 16.89602 E	12	13	13	-	-	12	13	12	12	-
3	Poland	53.15822 N 16.54780 E	-	12	-	12	12	11	12	-	12	-
4	Poland	53.15891 N 16.54822 E	-	-	-	11	12	11	12	-	12	-
5	Poland	52.05919 N 16.75175 E	12	13	13	-	-	12	23	-	12	-
6	Poland	51.16363 N 22.47511 E	16	-	13	-	13	13	-	-	-	-
7	Poland	52.37013 N 18.03480 E	14	-	14	14	14	-	15	-	15	15
8	Poland	52.05919 N 16.75175 E	12	-	12	-	-	-	12	-	13	-
9	Germany	50.93083 N 12.29472 E	-	-	-	-	-	-	-	31	-	-
10	Germany	53.81500 N 10.49416 E	14	-	-	-	-	13	-	-	-	-
11	Germany	53.74694 N 10.46833 E	-	-	-	-	-	-	-	14	-	-
12	Germany	50.76138 N 12.41000 E	-	-	-	-	-	-	-	31	-	-
13	Germany	50.97055 N 12.63555 E	-	-	12	-	14	-	-	-	-	-
14	Germany	49.30416 N 9.97555 E	-	-	-	-	-	-	-	-	-	14
15	Germany	49.84027 N 9.17861 E	-	-	-	-	-	12	13	-	-	-
16	Germany	49.38583 N 10.57222 E	-	-	-	-	-	12	-	-	-	12
17	Germany	49.89416 N 8.95388 E	-	-	-	-	-	-	-	12	-	12
18	Germany	49.60861 N 9.21805 E	-	-	-	-	12	-	-	-	-	-

CAPBP: *Capsella bursa-pastoris*; CENCY: *Centaurea cyanus*; LAMPU: *Lamium purpureum*; MATIN: *Tripleurospermum inodorum*; STEME: *Stellaria media*; VIOAR: *Viola arvensis*; BRSNN: *Brassica napus*; GALAP: *Galium aparine*; THLAR: *Thlaspi arvense*; VERPE: *Veronica persica*.

Before application and during efficacy assessments, the weed population in untreated control plots was recorded in absolute terms by recording the density (number of plants m^{-2}) of each weed. Analyses of the plant communities were carried out before the herbicide application on permanent research plots, which were homogeneous plant patches of cereals. The total number of species in all plots was determined, and the weed species in the studied areas were marked. The species composition of weed communities and the number of plants of each species from the untreated control plots were used to assess the biodiversity by means of the Simpson (D), Shannon-Wiener (H′), Margalef's (K) [21,22], and Berger-Parker (d) [23] indexes according to formulas: $D = 1 - \sum p_i$; $H' = -\sum H' = -\sum_{i=1}^{k} p_i \ln p_i$ where k is the number of categories and p_i is the share of each species in the sample; and K = logS/logN where S is the number of species and N is the total number of individuals in the sample. Nmax is the number of individuals of the most abundant species. Frequency (F) and relative frequency (RF) were calculated based on formulas: F (%) = (number of sampling units in which species occurred/total number of sampling units) × 100; RF = (number of target species occurred/number of all species occurred) × 100. The similarity in field species composition between Poland and Germany was computed using the Sorensen coefficient of similarity (Ss) index [24]: Ss = 2a/(2a + b + c), where a = number of species common to both sites, b = number of species in site 1, and c = number of species in site 2.

The efficacy of the tested herbicides was visually assessed in each treated plot by comparison to the untreated control plot. The results were expressed simply as a percentage according to an inverted scale to express percent weed control (0% = no weed control, 100% = full weed control). The autumn assessment before the end of vegetation growth (about 24 days after treatment) to evaluate short-term effects and the spring assessment (about 150 days after application), when the leaves were sprouting, to evaluate the long-term effect (persistent effect) of the test product on weeds were selected and presented in this study.

All statistical procedures were conducted using Statistica 13 software (StatSoft Poland). Tukey's honest significant difference test was used to separate treatment means (p = 0.05). The percent rating of weed control was arc-sine transformed prior to analysis to correct for unequal variance. The data in tables are reported and are non-transformed. The random effects of treatment, year, and their interactions were not significant; therefore, data were pooled only by treatment.

3. Results

A total of 10 weed species from Polish and German experimental fields were identified (Tables 2 and 3). Similarity in weed species composition: of the total species identified, 10 species were found in Poland and 7 in German fields. The similarity in species composition (Ss) between Poland and Germany was 0.45 (maximum is 1.0), this means that there is a low degree of similarity among countries and that each of them has its own characteristic species.

Table 3. Indicates of weed community biodiversity at individual locations.

Trial No.	Country	GPS	Scientific Name	RF (%)	D_{Mg}	H′	D	d
1	Poland	51.87723 N 20.01983 E	*Capsella bursa-pastoris*	18.7	3.12	0.775	0.85	0.187
			Centaurea cyanus	17.5				
			Lamium purpureum	18.2				
			Tripleurospermum inodorum	13.2				
			Stellaria media	15.0				
			Viola arvensis	17.5				
2	Poland	52.03594 N 16.89602 E	*Brassica napus*	14.1	3.48	0.839	0.87	0.179
			Capsella bursa-pastoris	15.6				
			Centaurea cyanus	10.0				
			Galium aparine	13.2				
			Lamium purpureum	15.6				
			Thlaspi arvense	13.7				
			Viola arvensis	17.9				
3	Poland	53.15822 N 16.54780 E	*Brassica napus*	13.6	3.19	0.755	0.84	0.293
			Centaurea cyanus	13.0				
			Tripleurospermum inodorum	13.6				
			Stellaria media	13.6				
			Thlaspi arvense	17.1				
			Viola arvensis	29.3				
4	Poland	53.15891 N 16.54822 E	*Brassica napus*	21.2	2.33	0.620	0.73	0.449
			Tripleurospermum inodorum	11.2				
			Stellaria media	10.6				

			Thlaspi arvense	12.1				
			Viola arvensis	44.9				
5	Poland	52.05919 N 16.75175 E	*Brassica napus*	15.3	3.01	0.773	0.85	0.214
			Centaurea cyanus	14.2				
			Capsella bursa-pastoris	18.6				
			Lamium purpureum	16.4				
			Thlaspi arvense	14.2				
			Viola arvensis	21.4				
6	Poland	51.16363 N 22.47511 E	*Capsella bursa-pastoris*	22.6	2.11	0.599	0.78	0.293
			Lamium purpureum	26.3				
			Stellaria media	29.3				
			Viola arvensis	21.8				
7	Poland	52.37013 N 18.03480 E	*Brassica napus*	15.3	3.49	0.842	0.87	0.172
			Capsella bursa-pastoris	13.4				
			Lamium purpureum	13.0				
			Stellaria media	14.3				
			Tripleurospermum inodorum	11.5				
			Thlaspi arvense	15.3				
			Veronica persica	17.2				
8	Poland	52.05919 N 16.75175 E	*Brassica napus*	21.9	1.92	0.528	0.76	0.295
			Capsella bursa-pastoris	29.5				
			Lamium purpureum	26.0				
			Thlaspi arvense	22.7				
9	Germany	50.93083 N 12.29472 E	*Galium aparine*	100.0	0.0	0.0	0.0	1.0
10	Germany	53.81500 N 10.49416 E	*Capsella bursa-pastoris*	2.8	0.42	0.055	0.05	0.972
			Viola arvensis	97.2				
11	Germany	53.74694 N 10.46833 E	*Galium aparine*	100.0	0.0	0.0	0.0	1.0
12	Germany	50.76138 N 12.41000 E	*Galium aparine*	100.0	0.0	0.0	0.0	1.0
13	Germany	50.97055 N 12.63555 E	*Lamium purpureum*	36.4	0.74	0.285	0.48	0.636
			Stellaria media	63.6				
14	Germany	49.30416 N 9.97555 E	*Veronica persica*	100.0	0.0	0.0	0.0	1.0
15	Germany	49.84027 N 9.17861 E	*Brassica napus*	17.9	0.54	0.204	0.30	0.821
			Viola arvensis	82.1				
16	Germany	49.38583 N 10.57222 E	*Veronica persica*	86.2	0.55	0.175	0.24	0.862
			Viola arvensis	13.8				
17	Germany	49.89416 N 8.95388 E	*Galium aparine*	13.5	0.46	0.172	0.23	0.865
			Veronica persica	86.5				
18	Germany	49.60861 N 9.21805 E	*Stellaria media*	100.0	0.0	0.0	0.0	1.0

RF: relative frequency; DMg: Margalef diversity index; H': Shannon index; D: Simpson`s index of diversity; d: Berger-Parker dominance index.

Relative frequency (RF) determines the result of competition. RF of *C. bursa-pastoris* in polish fields varied from 13.4 to 29.5%, *C. cyanus* 10.0-17.5%, *L. purpureum* 13.0-26.3%, *T. inodorum* 11.2-13.6%, *S. media* 10.6-29.3%, *V. arvensis* 17.5-44.9%, *B. napus* 13.6-21.9%, *G. aparine* 13.2%, *T. arvense* 12.1-22.7%, and *V. persica* 17.2%, compared to 2.8% of *C. bursa-pastoris*, *L. purpureum* 36.4%, *S. media* 63.6-100%, *V. arvensis* 13.8-97.2%, *B. napus* 17.9%, *G. aparine* 13.5-100%, and *V. persica* 86.2-100% in Germany (Table 3).

Values of Margalef index (DMg) measuring the evenness, ranged in Poland from 3.01 to 3.49, and in three places 1.92-2.33, in Germany 0.0-0.74 (Table 3).

The value of the Shannon diversity index (H') varied widely from Poland to Germany, ranging from 0.528-0.842 and 0.0-0.285, respectively (Table 3). The data indicate a much greater diversity of weed communities in Poland than in Germany.

To describe the evenness (the share of individual species ine the community), the Simpson index (D) was used. Index D expresss the probability of meeting two individuals belonging to the same species. The values of the D index in Poland range from 0.73 to 0.87; in Germany, they range from 0.0 to 0.48 (Table 3). The higher the D value (1 = maximum diversity), the greater the diversity, and it should be concluded that the results obtained indicate a rather more diverse weed community in cereals in Poland compared to poor diversity in Germany.

The Berger-Parker index (d) measures the dominance of the most abundant species. The value closer to 0 corresponds to higher diversity, and the value of 1 reveals monoculture. Our results indicated that much higher diversity was observed in Poland than in Germany, respectively 0.172-0.449 and 0.636-1.0 (Table 3).

The frequency shows species that occurred in the observed area. The frequencies of CENCY, LAMPU, MATIN, STEME, VIOAR, BRSNN, GALAP, and THLAR in Poland were between 44 and 67%; VERPE was purely 11%. In Germany, the value of the indicator was only 0–33% (Figure 2). Weed species were grouped into five frequency classes: A = ≥80, B = 61-80.9; C = 41-60.9; D = 21-40.9; E = ≤20% (Figure 3). Five species from Poland were recorded in frequency class B (the most frequent species recorded in the study), four in C, and one in E. In Germany, four species were recorded in class D and three in class E.

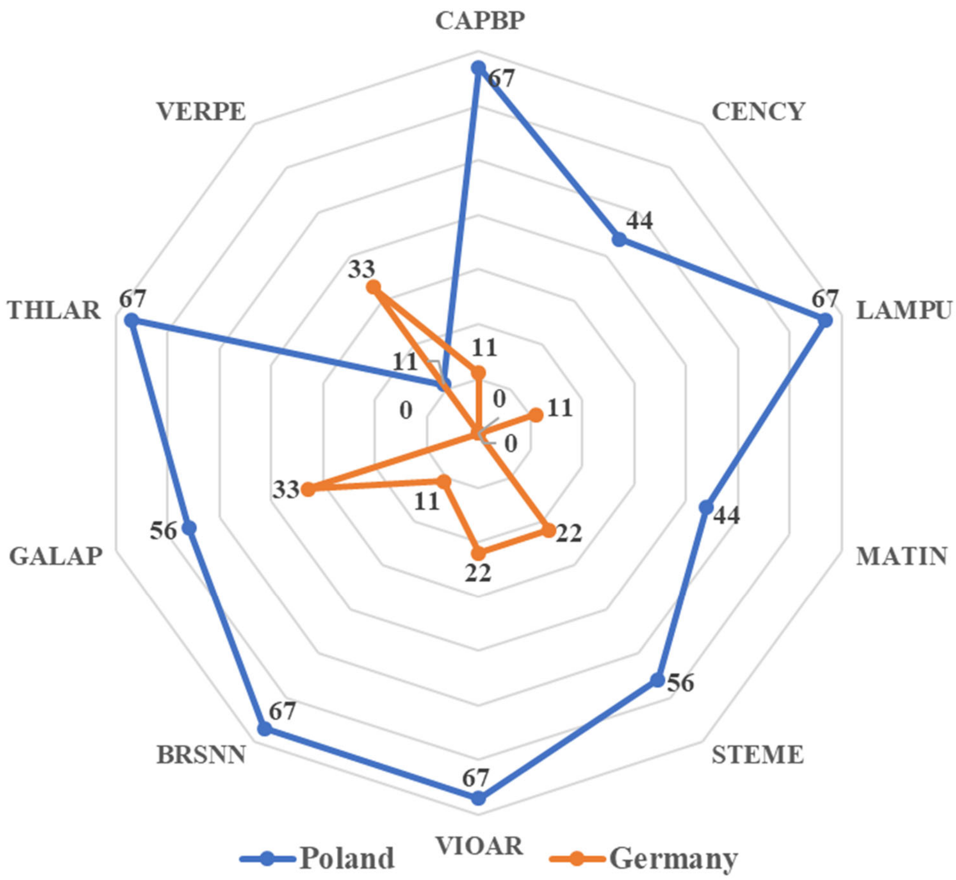

Figure 2. Frequency (%) of weed species in winter cereals in Poland (wheat, triticale, barley)and Germany (wheat, triticale, barley, rye). CAPBP: *Capsella bursa-pastoris*; CENCY: *Centaurea cyanus*; LAMPU: *Lamium purpureum*; MATIN: *Tripleurospermum inodorum*; STEME: *Stellaria media*; VIOAR: *Viola arvensis*; BRSNN: *Brassica napus*; GALAP: *Galium aparine*; THLAR: *Thlaspi arvense*; VERPE: *Veronica persica.*

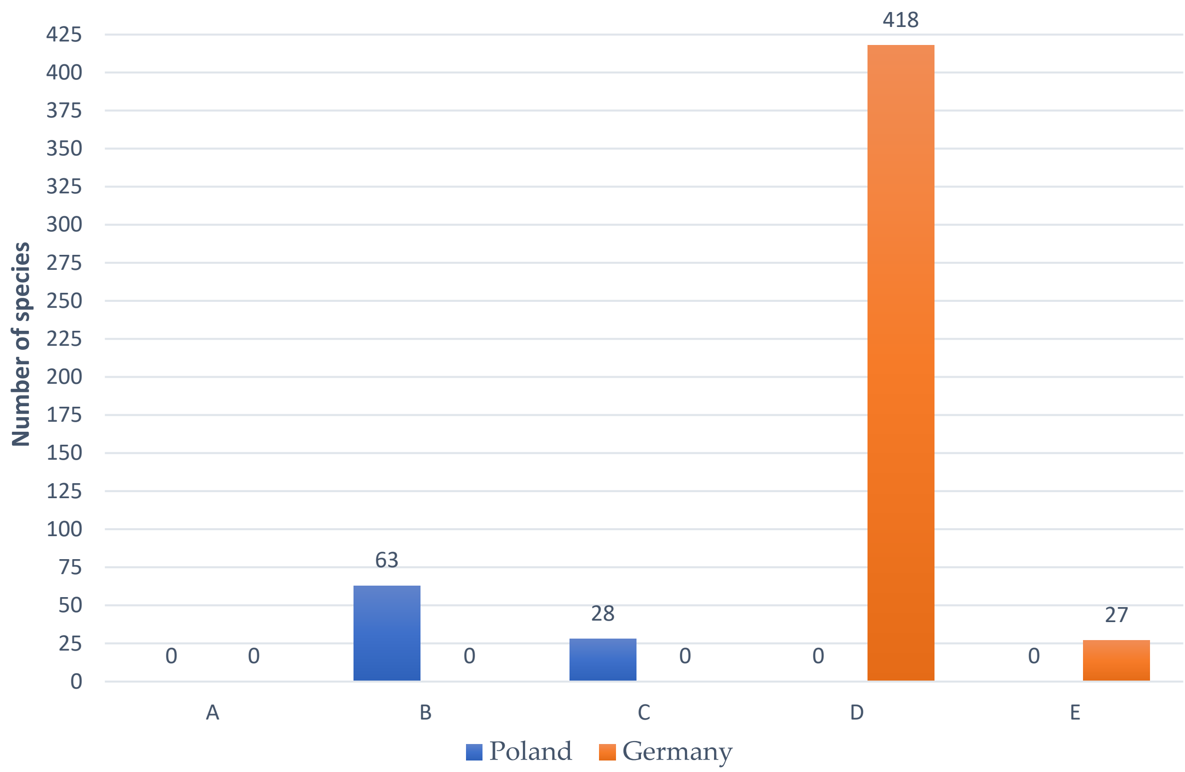

Figure 3. Frequency class distribution of weed species in winter cereals in Poland and Germany (frequency classes: A = ≥80, B = 61-80.9; C = 41-60.9; D = 21-40.9; E = ≤20%).

In the field experiments conducted in Poland and Germany (Tables 4 and 5), ten species of broadleaved weeds occurred. Considerably better control of VIOAR was observed in both assessments after use of reference product diflufenican+chlorotoluron. A similar relationship can be observed in the case of the control *Veronica persica,* VERPE. *Galium aparine* (GALAP) was not satisfactorily controlled by both doses of MCPA+tribenuron-methyl. This weed was considerably more effectively controlled by diflufenican+chlorotoluron. During the assessment performed in the spring, Stellaria media STEME was well controlled by both herbicides, MCPA+tribenuron-methyl at 1.0 kg ha^{-1} and diflufenican+chlorotoluron. Another broadleaved weed species (BRSNN, CAPBP, LAMPU, MATIN, and THLAR) were well controlled by MCPA+tribenuron-methyl at 1.0 kg ha^{-1} and comparable to diflufenican+chlorotoluron. Only the control of CENCY by MCPA+tribenuron-methyl was considerably lower before the end of the vegetation in comparison to diflufenican+chlorotoluron. A lower dose of MCPA+tribenuron-methyl controlled fewer weeds. In addition, during the spring assessment, a similar relationship can be observed, lower doses of MCPA+tribenuron-methyl eliminate weeds less effectively in comparison to higher doses of MCPA+tribenuron-methyl and diflufenican+chlorotoluron, while the higher dose of MCPA+tribenuron-methyl provides a comparable level of herbicidal efficacy to diflufenican+chlorotoluron against BRSNN, CAPBP, LAMPU, MATIN, THLAR, and CENCY.

Table 4. Influence of herbicides MCPA+tribenuron-methyl and diflufenican+chlorotoluron applied in the autumn on broadleaved weed control in winter cereals in Poland.

No.	Treatment	Dose per Ha	Weed Species									
			BRSNN	CAPBP	CENCY	GALAP	LAMPU	MATIN	STEME	THLAR	VERPE	VIOAR
Efficacy (%)												
			1st assessment before end of vegetation period (about 24 DAT)									
1	MCPA+ tribenuron-methyl	0.8 kg	31	44	26	1	44	35	41	29	50	42
2	MCPA+ tribenuron-methyl	1.0 kg	48	67	38	2	61	47	54	57	61	54
3	diflufenican+ chlorotoluron	2.5 L	45	63	57	2	63	51	58	56	62	67
	HSD 0.05		9.7	8.7	8.8	ns	9.7	2.4	3.4	10.2	5.7	5.0
2nd assessment in the spring (about 150 DAT)												
1	MCPA+tribenuron-methyl	0.8 kg	68	72	67	47	59	70	79	62	74	66
2	MCPA+tribenuron-methyl	1.0 kg	93	90	83	75	82	89	91	89	83	83
3	diflufenican+ chlorotoluron	2.5 L	95	91	83	81	83	90	97	93	90	87
	HSD 0.05		8.1	9.1	3.8	6.7	7.2	6.0	4.4	8.8	5.4	5.8

ns: nonsignificant. BRSNN: *Brassica napus*, CAPBP: *Capsella bursa-pastoris*, CENCY: *Centaurea cyanus*, GALAP: *Galium aparine*, LAMPU: *Lamium purpureum*, MATIN: *Tripleurospermum inodorum*, STEME: *Stellaria media*, THLAR: *Thlaspi arvense*, VERPE: *Veronica persica*, VIOAR: *Viola arvensis*.

Table 5. Influence of herbicides MCPA+tribenuron-methyl and diflufenican+chlorotoluron applied in autumn on broadleaf weed control in winter cereals in Germany.

No.	Treatment	Dose Per ha	Weed Species						
			BRSNN	CAPBP	GALAP	LAMPU	STEME	VERPE	VIOAR
Efficacy (%)									
1st assessment before end of vegetation period (about 24 DAT)									
1	MCPA+tribenuron-methyl	0.8 kg	99	33	6	0	15	19	58
2	MCPA+tribenuron-methyl	1.0 kg	96	45	6	0	50	21	61
3	diflufenican+chlorotoluron	2.5 L	99	48	13	0	83	55	71
	HSD 0.05		ns	8.1	6.5	ns	23.2	15.1	11.2
2nd assessment in the spring (about 150 DAT)									
1	MCPA+tribenuron-methyl	0.8 kg	100	100	48	90	98	80	56
2	MCPA+tribenuron-methyl	1.0 kg	100	100	60	96	99	90	76
3	diflufenican+chlorotoluron	2.5 L	100	100	93	100	100	100	99
	HSD 0.05		ns	ns	18.9	ns	1.6	7.3	17.8

ns: nonsignificant. BRSNN: *Brassica napus*, CAPBP: *Capsella bursa-pastoris*, CENCY: *Centaurea cyanus*, GALAP: *Galium aparine*, LAMPU: *Lamium purpureum*, MATIN: *Tripleurospermum inodorum*, STEME: *Stellaria media*, THLAR: *Thlaspi arvense*, VERPE: *Veronica persica*, VIOAR: *Viola arvensis*.

4. Discussion

In agro-ecosystems, especially in agricultural fields, plant species have decreased in population size and species number. Meyer et al. [25] indicated many reasons for these species' decline, such as intensification of the production system, excessive use of water, nutrients, and chemicals, as well as pollution of the environment. The differentiation in these areas between Poland and Germany are likely the reason for the differences in the biodiversity of weed communities in agricultural fields between these countries. One of the conditions for the proper selection of herbicides is the knowledge of the weed community [26]. Their species composition depends on many factors, including species and varieties of cultivated plants, crop rotation, sowing date, and soil mulching [27–29]. According to Zegeye et al. [30], the frequency index gives an approximate indication of the homogeneity and heterogeneity of species, and high values in lower frequency classes and low values in higher frequency classes indicate a high degree of floristic heterogeneity [31]. In our own study, higher values were obtained in lower frequency classes, which indicates that a rather high degree of floristic heterogeneity existed in both country.

Herbicides from the group of ALS inhibitors have gained considerable importance due to their broad spectrum of target species, low dose application, and safety for animals [32]. Unfortunately, there is an increasing resistance of weeds to herbicides belonging to this group [33]. Combining herbicides, especially those with different modes of action, has a lot of advantages over using a single herbicide, including saving time and labor, reducing production costs and soil compaction, increasing weed control percentages and the spectrum of weeds controlled, and of course delaying the appearance of resistant weed species [34]. Mixing ALS inhibitors and synthetic auxins and their synergistic action has been confirmed and is currently used in practice to protect crops. This is because the mixtures of these active ingredients allow for the expansion of the spectrum of controlled weed species and improved efficacy [35–37]. In this research, postemergence application of tribenuron-methyl in combination with MCPA, provided that the majority of weed species occurring in autumn were effectively eliminated with MCPA+tribenuron-methyl applied at 1.0 kg ha^{-1}, provided an acceptable and comparable level of control to commonly registered diflufenican+chlorotoluron, particularly for weeds known to be easier to control during the vegetation period. At a rate of 1.0 kg ha^{-1}, it was more difficult to eliminate VIOAR, VERPE, and GALAP weeds, and they were less effectively controlled by a combination of MCPA and tribenuron-methyl in MCPA+tribenuron-methyl, but still delivered an acceptable level of crop protection at the beginning of the spring vegetation period, confirming good control of a wide spectrum of different broadleaved weeds.

Herbicides from the group of synthetic auxins are commonly used in the cultivation of cereals [38,39]. Their efficacy largely depends on the temperature [40,41]. In research, they are used primarily in the spring [42,43]. However, the recorded higher temperatures in the autumn [44,45] mean that herbicides belonging to the growth regulators can achieve optimal efficacy when applied in this term. According to these results, the formulation of tribenuron-methyl combined with MCPA can be recommended for application in winter cereals in the autumn as an alternative to commonly available herbicides.

5. Conclusions

The composition of the weed community is an important factor limiting yield and quality of grain, and herbicide control is still the most effective weed control method. The results of this study indicated that weed communities varied between sites in Poland and Germany. Much richer weed communities were observed in Poland, with 4-7 species in each location, compared to 1-2 in Germany. Postemergence application of tribenuron-methyl in combination with MCPA, applied at the 3-leaf stage to 3 tillers detectable in autumn in winter cereals, provided effective elimination of the majority of weed species occurring in the autumn (*Brassica napus*, *Capsella bursa-pastoris*, *Centaurea cyanus*, *Lamium purpureum*, *Tripleurospermum inodorum*, *Stellaria media*, and *Thlaspi arvense)*. A satisfactory level of control (66 to 88%) was confirmed for *Veronica persica*, *Viola arvensis,* and *Galium aparine*. According to these results, the formulation of tribenuron-methyl combined with MCPA can be recommended for application in winter cereals in the autumn as an alternative to commonly available herbicides.

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References

1. Schils, R.; Olesen, J.E.; Kersebaum, K.-C.; Rijk, B.; Oberforster, M.; Kalyada, V.; Khitrykau, M.; Gobin, A.; Kirchev, H.; Manolova, V.; et al. Cereal yield gaps across Europe. *Eur. J. Agron.* **2018**, *101*, 109–120.
2. Oerke, E.C. Crop losses to pests. *J. Agric. Sci.* **2006**, *144*, 31–43.
3. Moss, S.R.; Storkey, J.; Cussans, J.W.; Perryman, S.A.M.; Hewitt, M.V. The Broadbalk long-term experiment at Rothamsted: What has it told us about weeds? *Weed Sci.* **2004**, *52*, 864–873.
4. Popp, J.; Pető, K.; Nagy, J. Pesticide productivity and food security. A review. *Agron. Sustain. Dev.* **2013**, *33*, 243–255.
5. Délye, C.; Jasieniuk, M.; Le Corre, V. Deciphering the evolution of herbicide resistance in weeds. *Trends Genet.* **2013**, *29*, 649–658.
6. Mallory-Smith, C.; Retzinger, J. Revised classification of herbicides by site of action for weed resistance. *Weed Technol.* **2003**, *17*, 605–619.
7. Wakabayashi, K.; Boger, P. Target sites for herbicides: Entering the 21st century. *Pest Manag. Sci.* **2002**, *58*, 1149–1154.
8. Jasinskas, A.; Steponavičius, D.; Šniauka, P.; Zinkevičius, R. Weed Control by Chemical and Mechanical Means. In *Weed Biology and Control*; Pilipavičius, V., Ed.; IntechOpen: London, UK, 2015. Available online: https://www.intechopen.com/chapters/48176. https://doi.org/10.5772/60002 (accessed on 10.10.2022).
9. Rahman, M.M. Potential environmental impacts of herbicides used in agriculture. *J. Agric. Forest Meteorol. Res.* **2020**, *3*, 266–269.
10. Andrew, I.K.S.; Storkey, J.; Sparkes, D.L. A review of the potential for competitive cereal cultivars as a tool in integrated weed management. *Weed Res.* **2015**, *55*, 239–248.
11. Tottman, D.R.; Ingram, G.H.; Lock, A.A.; Makepeace, R.J.; Orson, J.; Smith, J.; Wilson, B.J. Weed control in Cereals. In *Weed Control Handbook*: *Principles*, 7th ed.; Roberts, H.A., Ed.; Blackwell Scientific Publications: Boston, MA, USA.; Melbourne, VIC, Australia, 1982; pp. 268–291.
12. Korav, S.; Dhaka, A.K.; Singh, R.; Premaradhya, N.; Reddy, G.C. A study on crop weed competition in field crops. *J. Pharmacogn. Phytochem.* **2018**, *7*, 3235–3240.
13. VanGessel, M.J.; Johnson, Q.R.; Scott, B.A. Effect of application timing on winter wheat response to metribuzin. *Weed Technol.* **2017**, *31*, 94–99.
14. Pilipavičius, V.; Aliukonienė, I.; Romaneckas, K. Chemical weed control in winter wheat (*Triticum aestivum* L.) crop of early stages of development: I. Crop weediness. *J Food Agric Environ*. **2010**, *8*, 206–209.
15. Beckie, H.J. Herbicide-resistant weeds: Management tactics and practices. *Weed Technol.* **2006**, *20*, 793–814.
16. Powles, S.B.; Yu, Q. Evolution in action: Plants resistant to herbicides. *Annu. Rev. Plant Biol.* **2010**, *61*, 317–347.
17. Baucom, R.G. Evolutionary and ecological insights from herbicide resistant weeds: What have we learned about plant adaptation, and what is left to uncover? *New Phytol.* **2019**, *223*, 68–82.
18. Beckie, H.J.; Harker, K.N. Our top 10 herbicide-resistant weed management practices. *Pest Manag. Sci.* **2017**, *73*, 1045–1052.
19. Shaw, D.R.; Arnold, J.C. Weed control from herbicide combinations with glyphosate. *Weed Technol.* **2002**, *16*, 1–6.
20. Zhang, J.; Hamill, A.S.; Weaver, S.E. Antagonism and synergism between herbicides: Trends from previous studies. *Weed Technol.* **1995**, *9*, 86–90.
21. Pawlonka, Z.; Rymuza, K.; Starczewski, K.; Bombik, A. Biodiversity of segetal weed communities when chlorsulfuron-based weed control is being used on continuous winter wheat. *J. Plant Prot. Res.* **2014**, *54*, 300–305.
22. Iglesias-Rios, R.; Mazzoni, R. Measuring diversity: Looking for processes that generate diversity. *Nat. Conserv.* **2014**, *12*, 156–161.
23. Lakicevic, M.; Srdjevic, B. Measuring biodiversity in forest communities—A role of biodiversity indices. *Contemp. Agric.* **2018**, *67*, 65–70.
24. Yakob, G.; Fekadu, A. Diversity and Regeneration Status of Woody Species: The Case of Keja Araba and Tula Forests, South West Ethiopia. *Open Access Libr. J.* **2016**, *3*, 1.

25. Meyer, S.; Wesche, K.; Krause, B.; Leuschner, C. Dramatic losses of specialist arable plants in Central Germany since the 1950s/60s—A cross-regional analysis. *Divers. Distrib.* **2013**, *19*, 1175–1187.
26. Kudsk, P. Optimising herbicide dose: A straightforward approach to reduce the risk of side effects of herbicides. *Environmentalist* **2008**, *28*, 49–55.
27. Locke, M.A.; Reddy, K.N.; Zablotowicz, R.M. Weed management in conservation crop production systems. *Weed Biol. Manag.* **2002**, *2*, 123–132.
28. Płaza, A.; Ceglarek, F.; Królikowska, A.; Próchnicka, M. Działanie następcze wsiewek międzyplonowych i słomy jęczmienia jarego na plonowanie i elementy struktury plonu pszenżyta ozimego. *Folia Pomer. Univ. Technol. Stetin. Agric. Aliment. Pisc. Zootech.* **2010**, *276*, 31–38.
29. Gaweda, D.; Cierpiała, R.; Harasim, E.; Haliniarz, M. Effect of tillage systems on yield, weed infestation and seed quality elements of soybean. *Acta Agrophys.* **2016**, *23*, 175–187.
30. Zegeye, H.; Teketay, D.; Kelbessa, E. Diversity, regeneration status and socio-economic importance of the vegetation in the islands of Lake Ziway, south-central Ethiopia. *Flora-Morphol. Distrib. Funct. Ecol. Plants* **2006**, *201*, 483–498.
31. Dibaba, A.; Soromessa, T.; Kelbessa, E.; Tilahun, A. Diversity, structure and regeneration status of the woodland and riverine vegetation of Sire Beggo in Gololcha District, Eastern Ethiopia. *MEJS* **2014**, *6*, 70–96.
32. Brown, H.M. Mode of action, crop selectivity, and soil relations of the sulfonylurea herbicides. *Pestic. Sci.* **1990**, *29*, 263–281.
33. Tranel, P.; Wright, T.R. Resistance of Weeds to ALS-Inhibiting Herbicides: What Have We Learned? *Weed Sci.* **2002**, *50*, 700–712.
34. Damalas, C.A. Herbicide tank mixtures: Common interactions. *Int. J. Agric. Biol.* **2004**, *6*, 209–212.
35. Isaacs, M.A.; Hatzios, K.K.; Wilson, H.P.; Toler, J. Halosulfuron and 2,4-d mixtures' effects on common lambsquarters (*Chenopodium album*). *Weed Technol.* **2006**, *20*, 137–142.
36. Morderer, Y.Y.; Sychuk, A.M.; Rodzevych, O.P.; Pavlenko, V.V.; Sarbash, O.M. Effectiveness of auxin-like herbicide halauxifen-methyl mixtures with other herbicides for canada thistle (*Cirsium arvense*) control in wheat crops. *Fiziol. Rastenij Genet.* **2018**, *50*, 508–516.
37. Hollaway, K.L.; Hallam, N.D.; Flynn, A.G. Synergistic joint action of MCPA ester and metsulfuron-methyl. *Weed Res*. **1996**, *36*, 369–374.
38. Curran, W.S.; Wallace, J.M.; Mirsky, S.; Crockett, B. Effectiveness of Herbicides for Control of Hairy Vetch (*Vicia villosa*) in Winter Wheat. *Weed Technol.* **2015**, *29*, 509–518.
39. Grossmann, K. Auxin herbicides: Current status of mechanism and mode of action. *Pest. Manag. Sci.* **2010**, *66*, 113–120.
40. Silva, D.R.O.D.; Aguiar, A.C.M.D.; Basso, C.J.; Muraro, D.S. Application time affects synthetic auxins herbicides in tank-mixture with paraquat on hairy fleabane control. *Rev. Ceres Viçosa* **2021**, *68*, 194–200.
41. Lang, J.; Zikmundová, B.; Hájek, J.; Barták, M.; Váczi, P. The Effects of Foliar Application of Phenoxy and Imidazoline Family Herbicides on the Limitation of Primary Photosynthetic Processes in Galega orientalis L. *Agronomy* **2022**, *12*, 96.
42. Messelhäuser, M.; Saile, M.; Sievernich, B.; Gerhards, R. Effect of cinmethylin against Alopecurus myosuroides Huds. in winter cereals. *Plant Soil Environ.* **2021**, *67*, 46–54.
43. Pawlonka, Z.; Skrzyczyńska, J.; Ługowska, M. Rozwój *Apera spica-venti* (L.) Beauv. w pszenżycie ozimym w warunkach różnej uprawy roli i nawożenia. *Fragm. Agron*. **2010**, *27*, 94–101.
44. Le Gouis, J.; Oury, F.-X.; Charmet, G. How changes in climate and agricultural practices influenced wheat production in Western Europe. *J. Cereal Sci.* **2020**, *93*, 102960.
45. Ruosteenoja, K.; Markkanen, T.; Räisänen, J. Thermal seasons in northern Europe in projected future climate. *Int. J. Climatol.* **2020**, *40*, 4444–4462.