

Article

Rationalizing Herbicide Use in Maize within the Framework of Climatic Change and Extreme Hydrometeorological Phenomena

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Abstract: The aim of this study was to investigate specific management methods for controlling weeds under different climate conditions by reducing the risk of herbicide resistance in maize. Herbicide trials were placed at two locations during 2017 and 2018 and organized in a randomized block design with four replicates of all herbicide combinations (terbuthylazine—pre-emergence and mesotrione post-emergence treatment, terbuthylazine + mesotrione in post-emergence treatment, and terbuthylazine—pre-emergence and dicamba in post-emergence treatment). In the trials, 13 specific weeds were observed. High effectiveness was achieved when using commercial preparations with two active ingredients (terbuthylazine and mesotrione) in both years of research. As the year 2018 featured a higher amount of precipitation, uneven weed sprouting occurred, which resulted in a large number of *Setaria glauca* (18.50 No m⁻²), *Solanum nigrum* (16.50 No m⁻²), *Datura stramonium* (13.75 No m⁻²), and *Chenopodium hybridum* (10.50 No m⁻²) plants. Herbicide phytotoxicity was not expressed in maize. *Ambrosia artemisiifolia*, *Solanum nigrum*, and *Datura stramonium* had the highest competitive index (CI 10). The highest maize yield was observed under the application of terbuthylazine + mesotrione in post-emergence (14.223 t/ha). This combination led to the highest weed control costs (35.60 EUR/ha) in 2018, while in 2017, the yield was 12.829 t/ha, with a control cost of 33.99 EUR/ha.

Keywords: climate; crop yield; herbicides; weed management; *Zea mays* L.



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1. Introduction

Maize (*Zea mays* L.) is the most important cereal crop worldwide [1], with an average harvested area of 198,869,908.20 ha and production of 1,154,945,359.65 t from 2017 to 2021 [2]. In the Republic of Serbia, maize is the most important arable crop [3] and provides staple food to a large portion of the human population [4]. As a cereal, maize dominates, comprising 53.0% of the harvested area. Moreover, maize is grown on over 35% of arable land, and the main economic importance of this crop arises from its diverse uses [5]. Maize is a source of fiber, animal feed, and fuel that demands a notable quantity of water, sunlight, and other agronomic resources to achieve the maximum potential yield and total dry matter [6,7]. Although maize yield can be affected by a number of factors, including moisture stress, low soil fertility [8], pests, cultivated hybrids, and environmental conditions, weeds are one of the most important factors limiting yield in maize production [9]. These effects can be quite variable, but the most common is competition for nutrients, water, and light, leading to a drastic reduction in yield [10–12].

During the most critical period of maize competition, yield loss by weeds, in some cases, can exceed 30%, depending on climatic conditions and management techniques [13,14]. Maize crops should be maintained without weeds for the first 6 to 8 weeks after sowing to maximize yield [15] and are often characterized by complexes of weed flora, broad-leaf weeds, and grass weeds [16]. According to Lehoczy et al. [17], weed competition reduced maize biomass by 64% in weedy plots.

The economic feasibility and selection of weed management strategies during the season of the crop could be crucial for maximizing yields [18]. Weed management in annual crops, as with maize, has become necessary to increase and improve the quality of maize grain yield. The application of herbicides is the most effective and economical practice for weed management in all major crops [12]. To reduce application costs and optimize weed control efficacy, it is essential to use combinations of pre- and post-emergence herbicides, preferentially during the critical period of competition. This measure can also reduce the risk of weed resistance against herbicides evolving in the crop but requires certain information to assist farmers with the process of herbicide and dosage selection, depending on the floristic situation. The benefits of utilizing herbicide mixtures include saving time, costs, and control efforts [10,16]. Weed management has historically aimed to control weeds through herbicide treatments or tillage, primarily to reduce yield losses through competition. Therefore, weed control decision-making frameworks with a strong herbicide focus, such as the economic threshold (ET), have been developed. The ET concept has been widely accepted by weed science as a decision-making framework for rationalizing herbicide use to minimize costs and environmental pollution and increase economic returns in a variety of enterprises, including forestry and intensive horticulture, as well as field crops in many countries [19]. Today, the aim of this sector is to develop more sustainable production models for exploring the economic injury level (EIL) of crops in order to reduce environmental impacts. Therefore, it is necessary to combine technical knowledge with economic factors [20]. Knowledge of EIL can enable a farmer to verify what weed-density maize crops can tolerate in competition without great losses, thereby determining the most appropriate control measure to adopt [21].

In the last 25 years, the yield of maize has increasingly depended on meteorological conditions during the growing season, which are often characterized by the occurrence of “extreme climate events” [22–24]. Future weather is expected to be more variable and significantly impact global maize yields [25]. The global average annual air temperature is expected to increase by 2.0–5.0 °C by 2100 [26]. Higher temperatures anticipated by the end of the century are predicted to cause maize yield losses of between 9% and 28% [25].

Weeds compete with crops for water, light, and nutrients and significantly reduce yield and product quality. Therefore, crop–weed interactions and management under climate change should be more comprehensively analyzed to ensure sustainable agricultural production [27]. Climate change can affect weed biology, weed dynamics, phenology, and management by affecting various physiological and biochemical processes. Weed plants react to the changing climate, which has serious consequences for weed management, especially using herbicides [28,29].

Changes in atmospheric CO₂ levels, precipitation, temperature, and other growing conditions can affect the distribution of weed species and their competitiveness within the weed population and corresponding crop [30]. Factors of global climate change have serious implications for not only crop growth and productivity but also herbicide performance and the effectiveness of chemical weed management. Current weed management strategies that rely heavily on the use of herbicides may have different effects on these aggressively growing weeds under future climates [31].

Among the climatic factors, precipitation and air temperature are of particular importance for the success of maize production. The amount of water in the soil depends on the rainfall, which should ensure a constant inflow of water in an accessible form for normal plant growth and development. The high fertility potential of maize hybrids can be best observed when plants are in the growing season and supplied with 550–700 mm of water sediments [32].

This research was undertaken to explore the efficacy of different herbicide combinations over two years at two localities, with a native maize hybrid used for grain production (FAO maturity group 640). We also sought to assess the economic feasibility of chemical weed control under specific agroecological conditions based on the yield over a year and climate change.

2. Materials and Methods

The two field experiments on maize were conducted in 2017 and 2018 at Ruski Krstur (the first location, 45°34'12" N; 19°24'22" E; altitude 81 m) and Kruščić (the second location, 45°37'16" N; 19°22'26" E; altitude 81 m) in the Republic of Serbia. Ruski Krstur and Kruščić are villages in the Autonomous Province of Vojvodina, located in the West Bačka District in the northernmost part of Serbia. At both localities, the preceding crop was winter wheat, while conventional soil preparation included mineral fertilization of NPK 16:16:16 (Elixir Zorka, Šabac, Serbia) at a rate of 300 kg/ha. The soil was plowed to a depth of 30 cm with a Class Arion 630c tractor and Vogel MX 1050 plow. In spring, the soil was leveled with a ridged roller, and before sowing, nitrogen fertilizer was spread in the form of urea (220 kg/ha). The maize hybrid AS 72 (FAO 640; Chemical Agrosava, Belgrade, Serbia) was sown on 6 and 24 April in 2017 and 2018, respectively. The experimental trial was set up using a random block system with four replications, according to the standard EPPO/OEPP methods [33,34]. Untreated plots were also included at both localities. Herbicides were applied at the 3–6 leaf growth stage of maize, with post-emergence (post-em) herbicides. Treatments with herbicides included the application of four preparations based on one or two active ingredients but with different amounts of herbicides. Investigated herbicides included mesotrione, 50 g/L + terbuthylazine, 125 g/L (Tvister; Chemical Agrosava, Belgrade, Serbia), followed by a combination of two herbicides: terbuthylazine, 500 g/L (Zeazin; Chemical Agrosava, Belgrade, Serbia) and mesotrione, 480 g/L (Intermezzo; Chemical Agrosava, Belgrade, Serbia); terbuthylazine, 500 g/L (Zeazin; Chemical Agrosava, Belgrade, Serbia); and dicamba, 578 g/L (Colosseum; Chemical Agrosava, Belgrade, Serbia) (Table 1). Combinations of herbicides were applied to expand the spectrum of action. Herbicide application was carried out using an AgM 2200 trailed field sprayer with a water consumption of 200 L per hectare. Two assessments of herbicide effectiveness were carried out. The first assessment was performed at 15 days after treatment and the second 30 days after treatment. An assessment of phytotoxicity was carried out at the same time. The intensity of weed density was determined with a quantitative method of squares by counting the number of weeds per m². Based on the obtained data, the coefficient of efficiency Ce (%) of herbicides was calculated with the formula given by Dodel cited in Janjić [35] and represented a relative ratio between the number of destroyed weeds and the weed number in the control. Visual assessment of herbicide phytotoxicity was evaluated by using the European Weed Research Council (EWRC) scale from 1 to 9.

Table 1. Herbicide treatments.

Variants	Preparation	Active Ingredient (AI)	Applied Doses	Time of Application
1	Control	-	-	-
2	Tvister	mesotrione (50 g/L) + terbuthylazine (125 g/L)	2.3 L/ha	post-em
3	Zeazin + Intermezzo	terbuthylazine (500 g/L) + mesotrione (480 g/L)	0.6 + 0.25 L/ha	pre-em post-em
4	Zeazin + Colosseum	terbuthylazine (500 g/L) + dicamba (578 g/L)	0.6 + 0.6 L/ha	pre-em post-em

pre-em—pre-emergence application, before weed emergence; post-em—post-emergence, after weed emergence.

During the growing season, the crops were not irrigated. Maize was harvested by hand at the end of September and the beginning of October.

2.1. Meteorological Conditions

To ensure normal growth and development of maize plants and achieve high and stable yields of good quality, optimal soil moisture is required during the entire growing season. Due to climate change and the effects of population growth on water demands

for agricultural irrigation, water shortages are becoming a problem in many parts of the world. Without excess water in the soil profile, which occurs increasingly often due to hydro-meteorological extremes under climate change, the yield of maize can be significantly reduced [36,37]. Data on the deficits of readily available soil water in the vegetative and off-vegetative seasons (Table 2) and mean monthly precipitation and air temperatures during the maize vegetative season at the Sombor measuring station (Figure 1) are presented in the following.

Table 2. Deficit of readily available soil water in the vegetative and off-vegetative seasons [38].

Year	Water Deficit (mm)		Excess Water (mm)	
	Vegetative Season	Off-Vegetative Season	Vegetative Season	Off-Vegetative Season
2017	262	0	0	48
2018	195	0	0	149

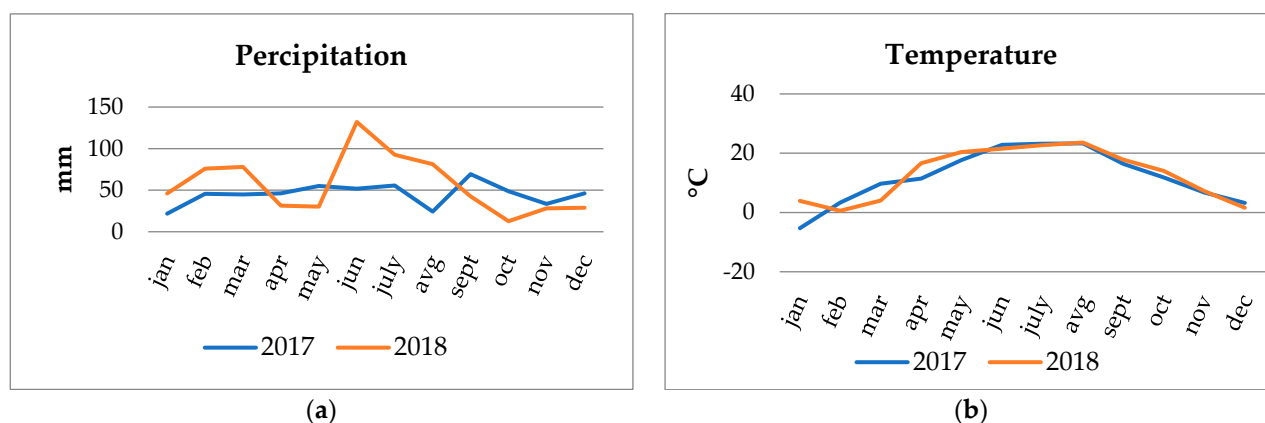


Figure 1. Mean monthly precipitation (a) and air temperatures (b) during the maize vegetative season at the Sombor measuring station.

2.2. Data Analysis

The significant differences in the average number of weeds between the control, treated plots, localities, and years of research were assessed through a *t*-test using the software STATISTICA 13.2 (University License, Novi Sad, Serbia).

An economic threshold (ET) for agricultural weed management can be described as the point at which the cost of weed control equals the value of crop yield attributed to that control [18,39].

The economic threshold and economic injury level were calculated using the following equations (Equations (1) and (2)) [40]:

$$ET(\text{weed m}^{-2}) = C \div (V \times D) \quad (1)$$

where ET (weed/m²) represents the economic thresholds, C is the control costs, with the application (€/ha), V is the crop value (€/t), and D is weed damage (t/ha for each weed m⁻²).

$$EIL(\text{weed m}^{-2}) = C \times N \div (V \times I) \quad (2)$$

where EIL (weed m⁻²) is the economic injury level, C is the costs of weed control, N is the number of weeds per unit area, V is the market value per output unit, and I is the yield loss percentage.

The following equation (Equation (3)) was used to calculate control costs (CC):

$$CC = NA \times (AC + IC) \quad (3)$$

where CC stands for control costs (€/ha), NA represents the number of herbicide applications, AC represents application costs (€/ha per application), and IC represents herbicide costs per application (€/ha).

Using Equation (4), the CI (competitive index) values for broadleaf weed species were calculated based on weed emergence:

$$CI = \left(\frac{A}{B}\right) \times K \quad (4)$$

where CI is the competitive index of the target weed species, A is the measured variable (weed emergence), B is the measured variable of the most competitive weed, and K is a constant with a value of 10 [18,41].

On a scale of 1 to 10, weeds were graded, with a score of 10 for the most competitive weed. The competitive load (CL) for each weed in the maize was calculated using this index.

3. Results and Discussion

As well-adapted plant species, weeds can dominate and colonize an agroecosystem through competitiveness, aggressiveness, adaptability, and high fecundity, as well as survive a wide range of environmental conditions in crop fields [42]. Oerke [43] estimated that weeds can cause approximately 34% yield loss in crops.

During a two-year survey at two locations, weed vegetation was determined to establish the herbicides' efficacy against certain weed species. Numerous weed species, including annual, perennial broadleaf, and grass weeds, were present in the experimental field. To compare the data, the paper presented data for the 13 weed species observed in both localities during their two-year research project (Tables 3–6).

Table 3. Efficacy and phytotoxicity of herbicides used at the first location in 2017.

Weed Species	First Assessment						
	1	2	3	4			
	No m ⁻²	No m ⁻²	Ce (%)	No m ⁻²	Ce (%)	No m ⁻²	Ce (%)
<i>Abutilon theophrasti</i>	1.50	0	100	0	100	0	100
<i>Amaranthus retroflexus</i>	6.50	0	100	0	100	0	100
<i>Ambrosia artemisiifolia</i>	17.00	1.25	92.64	3.50	88.23	0	100
<i>Chenopodium album</i>	13.25	1.75	86.79	2.00	84.90	1.50	88.67
<i>Chenopodium hybridum</i>	3.75	0.50	86.67	0	100	0	100
<i>Cirsium arvense</i>	1.25	0	100	0.50	60.00	0	100
<i>Convolvulus arvensis</i>	1.75	0.75	57.14	1.00	42.85	1.00	42.85
<i>Datura stramonium</i>	5.25	0.50	90.47	0	100	0	100
<i>Setaria glauca</i>	2.75	0	100	0	100	1.00	100
<i>Solanum nigrum</i>	8.75	0	100	0	100	1.00	100
<i>Sorghum halepense</i> (s)	3.50	0	100	0	100	1.00	71.42
<i>Veronica persicaria</i>	1.25	0	100	0	100	0	100
<i>Xanthium strumarium</i>	6.75	0	100	0	100	0	100
Total number of weeds	73.25	4.75		7.00		5.50	
Total efficacy	-	93.51%		90.44%		92.49%	
Phytotoxicity	-	1		1		1	

Table 3. Cont.

Weed species	Second Assessment						
	1	2	3	4			
	No m ⁻²	No m ⁻²	Ce (%)	No m ⁻²	Ce (%)	No m ⁻²	Ce (%)
<i>Abutilon theophrasti</i>	1.75	0	100	0	100	0	100
<i>Amaranthus retroflexus</i>	5.50	0	100	0	100	0	100
<i>Ambrosia artemisiifolia</i>	13.25	0	100	0.50	96.22	0	100
<i>Chenopodium album</i>	10.75	1.50	86.04	0.50	95.34	0	100
<i>Chenopodium hybridum</i>	2.00	0	100	0	100	0	100
<i>Cirsium arvense</i>	1.75	0	100	0	100	0	100
<i>Convolvulus arvensis</i>	1.75	0.25	85.71	0	100	0	100
<i>Datura stramonium</i>	6.00	0	100	0	100	0	100
<i>Setaria glauca</i>	10.25	0	100	0	100	1.00	90.24
<i>Solanum nigrum</i>	2.75	0	100	0	100	0	100
<i>Sorghum halepense</i>	3.50	0	100	0	100	1.00	71.42
<i>Veronica persicaria</i>	1.25	0	100	0	100	0	100
<i>Xanthium strumarium</i>	10.00	0	100	0	100	0	100
Total number of weeds	61.50	1.75		1.00		2.00	
Total efficacy	-	97.15%		98.37%		96.74%	
Phytotoxicity	-	1		1		1	

1—Control. 2—mesotrione + terbuthylazine. 3—terbuthylazine + mesotrione. 4—terbuthylazine + dicamba. Ce (%)—efficacy coefficient.

Research found to be *Abutilon theophrasti* Medik, *Amaranthus retroflexus* L., *Ambrosia artemisiifolia* L., *Chenopodium album* L., *Chenopodium hybridum* L., *Cirsium arvense* (L.) Scop., *Convolvulus arvensis* L., *Datura stramonium* L., *Solanum nigrum* L., *Veronica persicaria* Poir., and *Xanthium strumarium* L., dominant broadleaf weeds, while the most common grass weeds were *Setaria glauca* (L.) Beauv. and *Sorghum halepense* (L.) Pers. The observed weed species are in accordance with other authors' research on the dominant weed species of maize [3,44–46]. We observed two perennial species (*C. arvense* and *S. halepense*) and 11 annual species (*A. theophrasti*, *A. retroflexus*, *A. artemisiifolia*, *C. album*, *C. hybridum*, *C. arvensis*, *D. stramonium*, *S. nigrum*, *V. persicaria*, *X. strumarium*, and *S. glauca*) in the experimental area.

Herbicide efficacy varied according to weed species and density, as well as by active ingredients and application times (one application in post-emergence or two applications before and after weed occurrence), as shown in Tables 3–6.

In practice, farmers extensively utilize both pre-em and post-em herbicides in maize planting regions [47]. In the case of the pre-em treatment, the maize crop was shielded from the competitive impact of weeds at the beginning of the crop's development [48]. Since pre-em herbicides are applied to the leaves, the characteristics of weed species in each area and agro-climatic conditions should be considered when choosing specific herbicides to use. On the other hand, post-em treatments enable herbicides to be adjusted based on the range of weeds present during the time of application [48].

During 2017, all examined preparations had high efficacy against all weed vegetation. Total efficacy during the first year of research was high (90–100%) at the first (Ce 90.44–98.37%) and second locations (Ce 94.91–96.92%) (Tables 3 and 4). Considering annual broadleaf weed dominance, the relative scarcity of grass (*S. glauca* and *S. halepense*) and perennial weeds (*C. arvensis* and *C. arvense*), and the application of treatments with two AIs, the result was an extended range of action and high efficacy in all variants. As a dry vegetation period followed herbicide application, there was no subsequent emergence of weeds, which enabled the maize crop to compete against the weeds and better develop.

Lower efficacy (Ce below 75%) was observed in treatment 3 (Intermezzo + Zeazin) for *C. arvense* (60%) and *C. arvensis* (42.85–62.50%) and in treatment 2 (preparation Tvister) for *C. arvensis* (57.14%). Satisfactory efficacy (Ce 75–90%) was observed after applying

the Twister preparation to *C. album* and *C. hybridum* and after applying Intermezzo + Zeazin to *A. artemisiifolia* and *C. album*. Both tested variants (treatments 2 and 3) presented results similar to those of the standard combination of weed control under treatment 4 (Colosseum + Zeazin) (Tables 3 and 4). We analyzed the effectiveness of the commercial herbicide preparation with two AIs, mesotrione and terbuthylazine (variant 2 in Table 1), and prolonged action when the same two AIs were applied separately in two treatments (variant 3 in Table 1). The third combination, terbuthylazine applied on the soil with dicamba in foliar application, was applied as the standard method for weed control in maize.

Table 4. Efficacy and phytotoxicity of herbicides used at the second location in 2017.

Weed Species	First Assessment						
	1	2		3		4	
	No m ⁻²	No m ⁻²	Ce (%)	No m ⁻²	Ce (%)	No m ⁻²	Ce (%)
<i>Abutilon theophrasti</i>	3.50	0	100	0	100	0	100
<i>Amaranthus retroflexus</i>	7.25	0	100	0	100	0	100
<i>Ambrosia artemisiifolia</i>	16.25	1.50	90.76	1.00	93.84	0	100
<i>Chenopodium album</i>	18.75	2.00	89.33	2.50	86.66	0	100
<i>Chenopodium hybridum</i>	3.25	0.50	84.61	0	100	0	100
<i>Cirsium arvense</i>	1.25	0	100	0.50	60.00	0	100
<i>Convolvulus arvensis</i>	2.00	0.50	75.00	0.75	62.50	0	100
<i>Datura stramonium</i>	7.75	0	100	0	100	1.00	87.09
<i>Setaria glauca</i>	1.50	0	100	0	100	0	100
<i>Solanum nigrum</i>	12.50	0	100	0	100	2.00	84.00
<i>Sorghum halepense</i> (s)	4.50	0	100	0	100	0	100
<i>Veronica persicaria</i>	1.25	0	100	0	100	0	100
<i>Xanthium strumarium</i>	8.75	0	100	0	100	0	100
Total number of weeds	88.50	4.50		4.75		3.00	
Total efficacy	-	94.91%		94.63%		96.61%	
Phytotoxicity	-	1		1		1	
Weed species	Second Assessment						
	1	2		3		4	
	No m ⁻²	No m ⁻²	Ce (%)	No m ⁻²	Ce (%)	No m ⁻²	Ce (%)
<i>Abutilon theophrasti</i>	4.75	0	100	0	100	0	100
<i>Amaranthus retroflexus</i>	6.25	0	100	0	100	0	100
<i>Ambrosia artemisiifolia</i>	15.25	0.50	96.72	0.50	96.72	0	100
<i>Chenopodium album</i>	11.50	1.50	86.95	0.50	95.65	0	100
<i>Chenopodium hybridum</i>	3.75	0	100	0	100	0	100
<i>Cirsium arvense</i>	1.00	0	100	0	100	0	100
<i>Convolvulus arvensis</i>	1.00	0.25	75.00	0.50	50.00	0	100
<i>Datura stramonium</i>	6.00	0	100	0	100	1.00	83.33
<i>Setaria glauca</i>	7.25	0	100	0	100	0.50	100
<i>Solanum nigrum</i>	2.75	0	100	0	100	0.75	72.72
<i>Sorghum halepense</i> (s)	3.25	0	100	0.25	92.30	0.25	92.30
<i>Veronica persicaria</i>	0.25	0	100	0	100	0	100
<i>Xanthium strumarium</i>	10.25	0	100	0.75	92.68	0	100
Total number of weeds	73.25	2.25		2.50		2.50	
Total efficacy	-	96.92%		96.58%		96.58%	
Phytotoxicity	-	1		1		1	

1—Control. 2—mesotrione + terbuthylazine. 3—terbuthylazine + mesotrione. 4—terbuthylazine + dicamba. Ce (%)—efficacy coefficient.

The highest density in the first location in 2017 was recorded for the species *A. artemisiifolia* (17.00 in the first assessment and 11.50 No m⁻² in the second assessment) and *C. album* (13.25 in the first assessment and 9.75 No m⁻² in the second assessment). Due to

specific climatic factors that yielded extremely dry weather in 2018 and the distribution of rainfall (Table 2 and Figure 1), a high density of weed species uncharacteristic of 2017 (*C. hybridum*, *D. stramonium*, *S. nigrum*, and *S. glauca*) was recorded (Tables 3 and 5). These species were followed by *S. nigrum*, *X. strumarium*, *A. retroflexus*, and *D. stramonium* (more than 5.00 plants m^{-2}).

Table 5. Efficacy and phytotoxicity of herbicides used at the first location in 2018.

Weed Species	First Assessment						
	1	2		3		4	
	No m^{-2}	No m^{-2}	Ce (%)	No m^{-2}	Ce (%)	No m^{-2}	Ce (%)
<i>Amaranthus retroflexus</i>	9.00	0.75	91.66	0	100	0	100
<i>Ambrosia artemisiifolia</i>	1.75	0	100	0	100	0	100
<i>Chenopodium album</i>	11.50	1.00	91.30	2.50	78.26	1.25	89.13
<i>Chenopodium hybridum</i>	9.25	0.50	94.59	2.50	72.97	1.50	83.78
<i>Cirsium arvense</i>	10.50	0	100	0	100	1.00	90.47
<i>Convolvulus arvensis</i>	0.75	0.25	66.66	0.25	66.66	0.25	66.66
<i>Datura stramonium</i>	0.75	0.25	66.66	0	100	0.25	66.66
<i>Setaria glauca</i>	13.75	0	100	0	100	1.00	92.72
<i>Solanum nigrum</i>	3.75	0	100	0	100	0.25	93.33
<i>Sorghum halepense</i> (s)	16.50	1.25	92.42	0.25	98.48	0.50	96.96
<i>Veronica persicaria</i>	4.00	0	100	0	100	0.25	93.75
<i>Xanthium strumarium</i>	0.50	0	100	0	100	0	100
<i>Xanthium strumarium</i>	3.75	0.25	93.33	0	100	0	100
Total number of weeds	85.75	4.25		5.50		6.25	
Total efficacy	-	95.04%		93.58%		92.71%	
Phytotoxicity	-	1		1		1	
Weed species	Second Assessment						
	1	2		3		4	
	No m^{-2}	No m^{-2}	Ce (%)	No m^{-2}	Ce (%)	No m^{-2}	Ce (%)
<i>Abutilon theophrasti</i>	4.00	0	100	0	100	0	100
<i>Amaranthus retroflexus</i>	9.75	0	100	0	100	0	100
<i>Ambrosia artemisiifolia</i>	3.50	0	100	0	100	0	100
<i>Chenopodium album</i>	9.75	0	100	0	100	0	100
<i>Chenopodium hybridum</i>	11.5	0	100	0	100	0	100
<i>Cirsium arvense</i>	4.75	0	100	0	100	0	100
<i>Convolvulus arvensis</i>	0.50	0.25	50.00	0	100	0.25	50.00
<i>Datura stramonium</i>	11.00	0.25	97.72	0.50	95.45	1.00	90.90
<i>Setaria glauca</i>	18.50	2.25	87.83	3.25	82.43	2.75	85.13
<i>Solanum nigrum</i>	10.00	0	100	1.00	90.00	2.00	80.00
<i>Sorghum halepense</i> (s)	5.75	0	100	0	100	0	100
<i>Veronica persicaria</i>	3.75	0	100	0	100	0	100
<i>Xanthium strumarium</i>	1.00	0	100	0	100	0	100
Total number of weeds	93.75	2.75		4.75		6.00	
Total efficacy	-	97.06%		94.93%		93.60%	
Phytotoxicity	-	1		1		1	

1—Control. 2—mesotrione + terbuthylazine. 3—terbuthylazine + mesotrione. 4—terbuthylazine + dicamba. Ce (%)—efficacy coefficient.

The highest density of weeds (Table 4) was recorded for the species *A. artemisiifolia* (16.25 in the first assessment and 15.25 No m^{-2} in the second assessment), *C. album* (18.75 in the first assessment and 11.50 No m^{-2} in the second assessment), *S. nigrum* (12.5 No m^{-2} in the first assessment), and *X. strumarium* (8.75 in the first assessment and 10.25 No m^{-2} in the second assessment).

Table 6. Efficacy and phytotoxicity of herbicides used at the second location in 2018.

Weed Species	First Assessment						
	1	2	3	4			
	No m ⁻²	No m ⁻²	Ce (%)	No m ⁻²	Ce (%)	No m ⁻²	Ce (%)
<i>Abutilon theophrasti</i>	16.25	0	100	0	100	0	100
<i>Amaranthus retroflexus</i>	6.50	0	100	0	100	0	100
<i>Ambrosia artemisiifolia</i>	11.50	2.00	82.60	0	100	0	100
<i>Chenopodium album</i>	13.75	2.50	81.81	3.50	74.54	2.75	80.00
<i>Chenopodium hybridum</i>	18.50	0	100	0	100	0	100
<i>Cirsium arvense</i>	1.50	0	100	0.50	66.66	0	100
<i>Convolvulus arvensis</i>	0.50	0	100	0	100	0	100
<i>Datura stramonium</i>	19.25	0	100	1.75	90.90	1.50	92.20
<i>Setaria glauca</i>	3.00	0	100	0	100	0	100
<i>Solanum nigrum</i>	14.25	0	100	0	100	1.00	92.98
<i>Sorghum halepense</i> (s)	1.50	0	100	0	100	0	100
<i>Veronica persicaria</i>	0.25	0	100	0	100	0	100
<i>Xanthium strumarium</i>	3.75	0	100	0	100	0.25	93.33
Total number of weeds	110.50	4.50		5.75		5.50	
Total efficacy		95.92%		94.79%		95.02%	
Phytotoxicity	-	1		1		1	
Weed species	Second Assessment						
	1	2	3	4			
	No m ⁻²	No m ⁻²	Ce (%)	No m ⁻²	Ce (%)	No m ⁻²	Ce (%)
<i>Abutilon theophrasti</i>	21.75	0.50	97.70	0.50	97.70	0.75	96.55
<i>Amaranthus retroflexus</i>	10.50	0	100	0	100	0	100
<i>Ambrosia artemisiifolia</i>	13.75	0.50	96.36	1.00	92.72	0.25	98.18
<i>Chenopodium album</i>	18.25	1.00	94.52	0.75	95.89	1.00	94.52
<i>Chenopodium hybridum</i>	21.25	1.25	94.11	1.75	91.76	1.25	94.11
<i>Cirsium arvense</i>	0.75	0	100	0	100	0	100
<i>Convolvulus arvensis</i>	0.75	0	100	0	100	0	100
<i>Datura stramonium</i>	21.50	1.00	95.34	1.00	95.34	1.25	94.18
<i>Setaria glauca</i>	17.25	0.25	98.55	0.25	98.55	0.50	97.10
<i>Solanum nigrum</i>	3.50	0	100	0	100	0.50	85.71
<i>Sorghum halepense</i> (s)	1.00	0	100	0	100	0.25	75.00
<i>Veronica persicaria</i>	0.75	0	100	0	100	0	100
<i>Xanthium strumarium</i>	2.75	0	100	0	100	0	100
Total number of weeds	133.75	4.50		5.25		5.75	
Total efficacy		96.63%		96.07%		95.70%	
Phytotoxicity	-	1		1		1	

1—Control. 2—mesotrione + terbuthylazine. 3—terbuthylazine + mesotrione. 4—terbuthylazine + dicamba. Ce (%)—efficacy coefficient.

During 2018, all herbicide treatments were highly effective against established weed species. Total efficacy during the second year of research was also high (90–100%) at the first (Ce 92.71–97.06%) and second location (Ce 94.79–96.63%) (Tables 5 and 6).

Lower efficacy (Ce below 75%) was observed under treatment 3 (Intermezzo + Zeazin) against the weed species *C. arvense* (66.66%) and *C. album* (72.97–74.54%) and in treatment 2 (preparation Tvister) against *C. arvense* (66.66%) and *C. arvensis* (50.00–66.66%). Satisfactory efficiency (Ce 75–90%) against the following species was determined via a Tvister preparation: *A. artemisiifolia*, *C. album*, *S. glauca*, and the combination of Intermezzo + Zeazin against *A. artemisiifolia*, *C. album*, and *C. arvense*. Both tested variants (treatment 2 and 3) presented results at the level of the standard combination used in treatment 4 (Colosseum + Zeazin) (Tables 5 and 6).

As the year 2018 had a higher amount of precipitation, there was uneven and ongoing weed species growth, which resulted in a large number of *S. glauca* (18.50 No m⁻²), *S.*

nigrum (16.50 No m⁻²), *D. stramonium* (13.75 No m⁻²), and *C. hybridum* (10.50 No m⁻²) plants in the area.

The preparation Tvister consists of a combination of two AIs that complement each other in the spectrum of action against weed species. Mesotrione, from the triketone group, is absorbed through the leaves and part of the root system, as is terbuthylazine from the triazine group. Terbuthylazine forms a herbicidal film on the soil surface that prevents the germination and sprouting of weeds. This activity makes it possible to replace two treatments (pre- and post-emergence) with one foliar application and thus support a more economically profitable weed control strategy.

As in the first location, during the second year of research, the following weed species were dominant: *A. theophrasti*, *C. hybridum*, *D. stramonium*, and *S. nigrum*. These species were followed by *A. retroflexus* (more than 5.00 plants m⁻²). The weed density and weed species identified in this study are very similar to the findings of other authors [45,49]. Due to subsequent sprouting, during the second assessment, a higher abundance of the annual grass weed *S. glauca* (17.25 No m⁻²) was observed (Table 6). Changes in climate conditions can cause some non-potent weeds to dominate in arable land due to altered crop–weed interactions that favor weeds [42]. Also, the effects of climate change are predicted to increase the competitiveness of weeds, resulting in greater production losses if weeds are not properly controlled.

Differences between weed populations during 2017 and 2018 in the investigated area can be explained by the climatic conditions, which have a significant influence on the spread, population dynamics, and weed life cycle duration [30,42]. In the context of changing climate, soil moisture and ambient temperature are the primary factors influencing the composition and distribution of weed species [42,50].

The vegetation period (April–September) in 2017 was warmer and featured less precipitation than the long-term average. From April to September, approximately 302.3 mm of precipitation was recorded in the investigated localities, which is about 20% less than the multi-year average (Figure 1). The beginning of spring 2017 (March–May) featured significantly warmer weather than usual, followed by changeable weather with large temperature changes in April and average warmth in May. This spring was followed by a warmer summer with less precipitation than the long-term average. During these three months (June–August 2017), the amount of precipitation was 131.7 mm. The last month of the growing season, September, continued with very hot weather. During this time, air temperatures were often around and above 30 °C, with very little precipitation [38].

During the spring of 2018 (March–May), the weather was colder than usual (Figure 1). March was marked by colder and wetter weather, while April and May were warmer than usual. At the time of maize sowing, the weather was extremely warm and dry, which caused uneven crop sprouting. A total amount of 224.6 mm of precipitation was recorded in June and July 2018. During June, precipitation was abundant, with 132.1 mm, while August and September were warm, with significantly less precipitation (123.7 mm). The summer period (June–August) in 2018 was warmer and featured a higher amount of precipitation than the multi-year average [38].

According to the agrometeorological conditions, 2018 was more favorable than 2017 for the development of crops and weeds, as 2017 was characterized as extremely dry due to the minimal amounts of precipitation. Climatic changes have led to the dominance of some weed species but also to much higher maize yields.

In 2017, the total number of weeds during the experiment in control (untreated plot) was 61.50–88.50 m⁻² in both localities, while in 2018, a higher number of weeds, 85.75–133.75 m⁻², was observed (Tables 3–6).

In addition, changes in weed demography lead to changes in weed management. As an unavoidable measure for weed control in maize production, herbicide application should be considered alongside an anti-resistance strategy to preemptively combat herbicide resistance, which has become a worldwide problem [51]. The agrochemical industry must comply with new rules in the continuous fight against weed adaptations

in a changeable environment where new preparations are developed based on an old practice—mixing of two active ingredients with different modes of action (MOAs) in plants. The herbicide preparation Tvister, as a formulation with AIs from mesotrione (inhibition of hydroxyphenyl pyruvate dioxygenase—HRAC MOA group 27) and terbuthylazine (photosynthesis inhibitors in PSII Serine 264 Binders—HRAC MOA group 5), was compared with the results of applying these two AIs separately in pre-emergence (Zeazin) and post-emergence treatments (Intermezzo). Phytotoxicity in maize crops was not determined.

Due to the changes in meteorological conditions during the vegetation periods of 2017 and 2018 as non-specific years (the first being extremely dry and the second having an amount of precipitation above the multi-year average), the applied herbicide treatments had a different effect on weeds (expressed as Ce (%)) and maize yield. Experimental conditions such as location, maize cultivar, AIs of the herbicides, MOAs of the herbicides, and weed species/density are also critical predictors in weed management. Significant differences were found in the average weed number between the control and treated plots before and after herbicide treatment during the research period (for 2017 and 2018) (Figure 2). The control plots (Figure 2a) had higher weediness (average number of weeds m^{-2}) than the treated plots. Increased average weediness at the control and treated plots was observed in both localities during 2018. Analysis of each applied treatment (see Figure 2b; the herbicide treatment is marked in red) indicated no significant differences in the average weed number between different plots treated with the same herbicide during the two years at both localities. An applied combination of Zeazin + Colosseum led to significantly higher average weediness in 2018 at both localities, indicating lower efficacy.

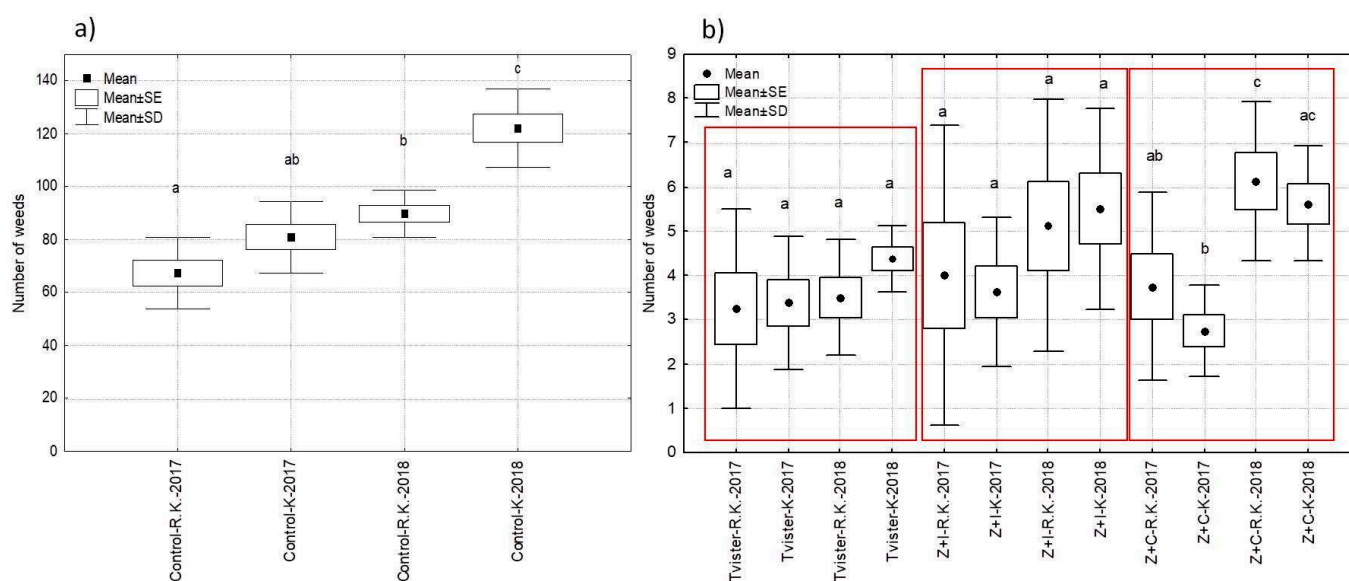


Figure 2. Significance of differences in average weed infestation between treatments in both localities during the research period (2017 and 2018) on (a) the control and (b) treated plots (*t*-test) (boxes followed by the same letter do not differ significantly according to *t*-test) (Legend: R.K.—Ruski Krstur; K—Krušić; Z + I—Zeazin + Intermezzo; Z + C—Zeazin + Colosseum).

According to the data obtained during 2017–2018, the economic injury level (EIL), control costs (CC), and competitive index (CI) for certain weeds were calculated. The competitive load (CL) is shown in Tables 7 and 8.

At the first location during 2017 in the untreated (control) plot, the maize yield was 8.711 t/ha, while in the treated plots, the yield was as follows: treatment I: 11.117 t/ha; treatment II: 10.683 t/ha; and treatment III: 10.545 t/ha. At the second location, a yield of 11.359 t/ha was achieved in the control plot, while under treatment I, the yield was 12.829 t/ha; under treatment II, the yield was 12.849 t/ha; and under treatment III, the yield was 12.525 t/ha.

Table 7. CI and CL for broadleaf weeds during 2017.

The First Location				The Second Location			
Weed Species	Average	CI	CL	Weed Species	Average	CI	CL
<i>Ambrosia artemisiifolia</i>	3.03	10	30.30	<i>Ambrosia artemisiifolia</i>	3.15	10	31.50
<i>Chenopodium album</i>	2.40	7.94	19.06	<i>Chenopodium album</i>	3.02	9.60	28.99
<i>Xanthium strumarium</i>	1.67	5.54	9.25	<i>Xanthium strumarium</i>	1.90	6.03	11.46
<i>Amaranthus retroflexus</i>	1.20	3.97	4.76	<i>Solanum nigrum</i>	1.52	4.84	7.36
<i>Solanum nigrum</i>	1.15	3.80	4.37	<i>Datura stramonium</i>	1.37	4.38	6.00
<i>Datura stramonium</i>	1.12	3.72	4.17	<i>Amaranthus retroflexus</i>	1.35	4.29	5.79
<i>Chenopodium hybridum</i>	0.57	1.90	1.08	<i>Abutilon theophrasti</i>	0.82	2.62	2.15
<i>Convolvulus arvensis</i>	0.35	1.16	0.41	<i>Chenopodium hybridum</i>	0.70	2.22	1.55
<i>Abutilon theophrasti</i>	0.32	1.07	0.34	<i>Convolvulus arvensis</i>	0.30	0.95	0.28
<i>Cirsium arvense</i>	0.30	1.00	0.30	<i>Cirsium arvense</i>	0.22	0.71	0.16
<i>Veronica persicaria</i>	0.20	0.83	0.17	<i>Veronica persicaria</i>	0.15	0.48	0.072

CI—competitive index; CL—competitive load.

Table 8. CI and CL for broadleaf weeds during 2018.

The First Location				The Second Location			
Weed Species	Average	CI	CL	Weed Species	Average	CI	CL
<i>Solanum nigrum</i>	2.65	10	26.50	<i>Datura stramonium</i>	4.07	10	40.70
<i>Datura stramonium</i>	2.47	9.34	23.07	<i>Chenopodium hybridum</i>	3.97	9.75	38.71
<i>Chenopodium hybridum</i>	2.20	8.30	18.26	<i>Abutilon theophrasti</i>	3.80	9.33	35.45
<i>Chenopodium album</i>	1.90	7.17	13.62	<i>Chenopodium album</i>	3.20	7.86	25.15
<i>Ambrosia artemisiifolia</i>	1.50	5.66	8.49	<i>Ambrosia artemisiifolia</i>	2.52	6.20	15.62
<i>Abutilon theophrasti</i>	1.20	4.53	5.44	<i>Solanum nigrum</i>	1.77	4.35	7.70
<i>Amaranthus retroflexus</i>	1.15	4.34	4.99	<i>Amaranthus retroflexus</i>	1.70	4.17	7.09
<i>Cirsium arvense</i>	0.55	2.08	1.14	<i>Xanthium strumarium</i>	0.65	1.60	1.04
<i>Xanthium strumarium</i>	0.47	1.79	0.84	<i>Cirsium arvense</i>	0.22	0.55	0.12
<i>Veronica persicaria</i>	0.42	1.60	0.67	<i>Convolvulus arvensis</i>	0.12	0.30	0.036
<i>Convolvulus arvensis</i>	0.12	0.47	0.056	<i>Veronica persicaria</i>	0.10	0.25	0.025

CI—competitive index; CL—competitive load.

According to the results in [24] from field experiments including 11 native maize hybrids (FAO maturity group: 400–600) for grain production, the average yield of maize grain for all hybrids was 4.2 t/ha in 2017 and 11.10 t/ha in 2018.

A larger and more favorable distribution of precipitation during the vegetation period in 2018 enabled a higher yield than that in 2017. Additionally, the tested hybrid AS 72 belongs to the FAO 640 group of maturity, members of which are recommended for these specific agroecological conditions [32].

Control costs in 2017 were $CC_1(\text{Twister}) = 33.99 \text{ EUR/ha}$, $CC_2(\text{Zeazin} + \text{Intermezzo}) = 24.98 \text{ EUR/ha}$, and $CC_3(\text{Zeazin} + \text{Colosseum}) = 20.82 \text{ EUR/ha}$.

The EIL results at the first and the second locations are as follows:

First location

$$\text{EIL1} = (33.99 \text{ EUR/ha} \times 1.75 \text{ weeds m}^{-2}) : (0.14 \text{ EUR/kg} \times 2.85\%) = 149.07 \text{ weeds m}^{-2}$$

$$\text{EIL2} = (24.98 \text{ EUR/ha} \times 1.00 \text{ weeds m}^{-2}) : (0.14 \text{ EUR/kg} \times 1.63\%) = 109.47 \text{ weeds m}^{-2}$$

$$\text{EIL3} = (20.82 \text{ EUR/ha} \times 2.00 \text{ weeds m}^{-2}) : (0.14 \text{ EUR/kg} \times 3.26\%) = 91.24 \text{ weeds m}^{-2}$$

Second location

$$\text{EIL1} = (33.99 \text{ EUR/ha} \times 2.25 \text{ weeds m}^{-2}) : (0.14 \text{ EUR/kg} \times 3.08\%) = 177.37 \text{ weeds m}^{-2}$$

$$\text{EIL2} = (24.98 \text{ EUR/ha} \times 2.50 \text{ weeds m}^{-2}) : (0.14 \text{ EUR/kg} \times 3.42\%) = 130.10 \text{ weeds m}^{-2}$$

$$\text{EIL3} = (20.82 \text{ EUR/ha} \times 2.50 \text{ weeds m}^{-2}) : (0.14 \text{ EUR/kg} \times 3.42\%) = 108.00 \text{ weeds m}^{-2}$$

During 2018, on untreated plots in the first location, maize yield was 10.368 t/ha, while in treated plots, the yield in treatment I was 12.643 t/ha, that in treatment II was 12.783 t/ha, and that in treatment III was 13.196 t/ha. In untreated control plots at the second location, the yield of maize was 11.293 t/ha. Under treatments I, II, and III, the yield was 14.223 t/ha, 14.006 t/ha, and 13.95 t/ha, respectively.

Control costs in 2018 were $\text{CC}_{1(\text{Twister})} = 35.60 \text{ EUR/ha}$, $\text{CC}_{2(\text{Intermezzo} + \text{Zeazin})} = 23.74 \text{ EUR/ha}$, and $\text{CC}_{3(\text{Colosseum} + \text{Zeazin})} = 20.54 \text{ EUR/ha}$, while EIL at both locations was as follows:

First location

$$\text{EIL1} = (35.60 \text{ EUR/ha} \times 2.75 \text{ weeds m}^{-2}) : (0.14 \text{ EUR/kg} \times 2.94\%) = 233.10 \text{ weeds m}^{-2}$$

$$\text{EIL2} = (23.74 \text{ EUR/ha} \times 4.75 \text{ weeds m}^{-2}) : (0.14 \text{ EUR/kg} \times 5.07\%) = 158.82 \text{ weeds m}^{-2}$$

$$\text{EIL3} = (20.54 \text{ EUR/ha} \times 6.00 \text{ weeds m}^{-2}) : (0.14 \text{ EUR/kg} \times 6.40\%) = 136.93 \text{ weeds m}^{-2}$$

Second location

$$\text{EIL1} = (35.60 \text{ EUR/ha} \times 4.50 \text{ weeds m}^{-2}) : (0.14 \text{ EUR/kg} \times 3.07\%) = 372.56 \text{ weeds m}^{-2}$$

$$\text{EIL2} = (23.74 \text{ EUR/ha} \times 5.25 \text{ weeds m}^{-2}) : (0.14 \text{ EUR/kg} \times 3.93\%) = 226.60 \text{ weeds m}^{-2}$$

$$\text{EIL3} = (20.54 \text{ EUR/ha} \times 5.75 \text{ weeds m}^{-2}) : (0.14 \text{ EUR/kg} \times 4.30\%) = 196.83 \text{ weeds m}^{-2}$$

In this study, broadleaf weeds exhibited higher competitiveness than grass weeds, resulting in higher CI values for broadleaf species. Among 13 weeds, 11 were broadleaf species, and 2 were grass species.

At the first location, the weed that displayed the highest level of competitiveness was *A. artemisiifolia*, whose CL was 10.00. Based on weed emergence, CI for *C. album*, *X. strumarium*, *A. retroflexus*, *S. nigrum*, and *D. stramonium* were 7.94, 5.54, 3.97, 3.80, and 3.72, respectively. The CI value was 1.90 for *C. hybridum*, 1.16 for *C. arvensis*, 1.07 for *A. theophrasti*, and 1.00 for *C. arvense*. The lowest CI was 0.83 for *V. persicaria* (Table 7). At the second location, the most competitive weed was *A. artemisiifolia* (CI-10.00). *C. album* had a high CI index of 9.60, while for *X. strumarium*, *S. nigrum*, *D. stramonium*, and *A. retroflexus*, the CIs were 6.03, 4.84, 4.38, and 4.29, respectively. Weeds *A. theophrasti* and *C. hybridum* had CIs of 2.62 and 2.22, respectively. The lowest CI scores were recorded for *C. arvense*, *C. Arvensis*, and *V. persicaria* at 0.95, 0.71, and 0.48, respectively.

The total competitive load (TCL) for the first location was 74.21 weeds m⁻². To determine the percentage by which competing weeds would reduce yield, the projected yield loss was calculated by dividing the TLC by 2. The projected yield loss was 37.10%. For the second location, the TCL was 95.31 weeds m⁻², while the projected yield loss was 47.65%.

Broadleaf weeds are better able to avoid the shading effects of maize and compete longer during the growing season. Fields exposed to moisture stress are also at greater risk of yield losses due to weed competition. Soils that are heavier and hold better moisture can tolerate a higher population of weeds that may impact maize yield.

During the second year of research, at the first locality, the most competitive weed was *S. nigrum* (CI-10.00), followed by *D. stramonium* with CI 9.34 and *C. hybridum* with 8.30. For *C. album*, *A. artemisiifolia*, *A. theophrasti*, *A. retroflexus*, and *C. arvense*, the CI values were 7.17, 5.66, 4.53, 4.34, and 2.08, respectively. Low CIs of 1.79, 1.60, and 0.47 were recorded for *X. strumarium*, *V. persicaria*, and *C. arvensis*.

For the second locality, the most competitive weed was *D. stramonium* (CI-10.00). *C. hybridum* and *A. theophrasti* had high competitive indexes of 9.75 and 9.33, respectively, while the CIs for *C. album*, *A. artemisiifolia*, *S. nigrum*, and *A. retroflexus* were 7.86, 6.20, 4.35, and 4.17, respectively. *X. strumarium*, *C. arvense*, *C. arvensis*, and *V. persicaria* had the lowest CIs with 1.60, 0.55, 0.30, and 0.25, respectively (Table 8). Weeds can be more competitive when they emerge with maize than when they emerge a week or two later. Zimdahl [52] found that the first three- to six-week period of maize growth is more sensitive to weed control than later growth stages, which can significantly decrease the final yield if proper management is neglected. Crop–weed competition can lead to significant reductions in crop yield, ranging from 10% to 100%, depending on the crop and associated weed flora. The extent of yield losses can vary greatly depending on the relative competitive ability between crops and weeds [53]. The TCL for the first locality was 103.08 weeds m⁻², while the projected yield loss was 51.54%. For the second locality, the TCL was 171.64 weeds m⁻², while the projected yield loss was 85.82%.

4. Conclusions

Due to the significant influence of climatic changes and extreme hydrometeorological phenomena on maize production, this research sought to rationalize the use of herbicides in controlling dominant weed species and fulfill the conditions for an anti-resistance strategy, environmental protection and economic justification. The trials were set during extremely dry (2017) and extremely wet (2018) years in the northern region of Serbia. As the focus was on 13 weed species, the most dominant 11 species were annual broadleaf weeds and 2 grass species. Due to the higher amount of precipitation during the growing season in 2018, weed species sprouted in an uneven and continuous manner. A higher density was recorded for *Setaria glauca* (18.50 No m⁻²), *Solanum nigrum* (16.50 No m⁻²), *Datura stramonium* (13.75 No m⁻²), and *Chenopodium hybridum* (10.50 No m⁻²). Moreover, the use of a commercial herbicide preparation with two AIs (terbuthylazine and mesotrione) was determined to have high efficacy. Based on a comparison of efficacy with a standard combination of terbuthylazine and dicamba, as well as the application of mesotrione and terbuthylazine in two treatments (pre-emergence and post-emergence), successful protection against weeds was realized under extreme hydrometeorological phenomena with one post-emergence application. Phytotoxicity on maize crops was not determined. According to the financial performance evaluation, the most effective variant (terbuthylazine and mesotrione) for post-emergence weed control was also economically justifiable. Compared to the control, all treatments in the study produced a higher maize yield. Higher yields in 2018 were mainly the result of a larger amount and more favorable distribution of precipitation in the second part of the vegetation period, during which the critical phases of maize development take place. High yields were recorded in the AS 72 (FAO 640) hybrid. The most competitive weeds were *Ambrosia artemisiifolia*, *Solanum nigrum*, and *Datura stramonium* (CI-10.00). The highest maize yield was determined via the application of a commercial preparation with a combination of two AIs with different MOAs (14.223 t/ha). The highest weed control costs (35.60 EUR/ha) were observed in 2018, whereas in 2017, the yield was 12.829 t/ha with a control cost of 33.99 EUR/ha. The results indicate that combinations of herbicides play an important role in weed suppression, positively impacting crop yield. Twister (terbuthylazine + mesotrione) was found to be the most effective preparation for weed control, maximizing maize yield under different agroecological conditions in the investigated region. This kind of study could be helpful in determining and designing specific management methods for controlling weeds under climate change by reducing the risk of herbicide resistance.

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