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The Evaluation of Sweetcorn (*Zea mays saccharata* Sturt.) Infestation of Barnyardgrass (*Echinochloa crus-galli*) Depending on Weather Conditions and Crop Rotation

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Abstract: This paper focuses on the weed species *Echinochloa crus-galli*, commonly known as barnyardgrass, which is a persistent threat to crop yield and quality, especially in maize (*Zea mays*) cultivation. It is one of the most problematic weeds in agricultural fields due to its aggressive growth, adaptability to different environmental conditions and prolific seed production. The incidence of *Echinochloa crus-galli* in maize fields has increased in recent years. This study aims to provide a comprehensive understanding of the characteristics and behavior of *Echinochloa crus-galli*, and to suggest effective measures to control it. This research on sweetcorn was conducted from 1992 to 2019 at the Research and Education Center Gorzyń, Złotniki branch, which belongs to the Poznań University of Life Sciences. The evaluation of weed infestation was carried out in experiments focusing on chemical weed control in maize. The experiments were designed as a one-factor randomised block design with four field replications. The condition and the degree of weed infestation (number of weeds and fresh weight of weeds) in the control plots was assessed on an annual basis at the end of June and in July. The aim of the study was to evaluate the dynamic changes in the status and extent of barnyardgrass (*Echinochloa crus-galli*) infestation in maize grown after various other crops in the Wielkopolska region, with a focus on the weather conditions. The study found that barnyardgrass was most likely to occur when maize was sown after winter wheat in a dry and warm year, and least likely when maize was grown in rotation after winter wheat in a cold year with average rainfall. The proportion of barnyardgrass weed mass in the total weed mass was significantly lower after winter rye than after winter wheat, winter oilseed rape and winter triticale. Further research into the biology and ecology of barnyardgrass is key to effectively controlling this weed and safeguarding sweetcorn yields.

Keywords: barnyardgrass; sweetcorn; weed infestation; previous crop

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1. Introduction

Contemporary challenges in agriculture necessitate continuous refinement of cultivation strategies to enhance productivity and safeguard crops against the adverse impact of external factors [1,2]. The problem of the influence of different species of weeds on the production of agricultural plants has been studied by many researchers [3–6]. The damage caused by weeds in the maize crop is mostly 30–70% or even more, and if the infestation is strong cultivation can be fully compromised [7,8]. Effective weed control is one of the crucial aspects that significantly influences the ability to cultivate useful crops. In the context of maize production, barnyardgrass (*Echinochloa crus-galli*) poses a significant challenge for farmers, negatively impacting yields and overall production efficiency [9].

Barnyardgrass (*Echinochloa crus-galli*) is a weed species belonging to the family *Poaceae* and for centuries it has posed a significant challenge for farms worldwide. Its presence in agricultural crops is often associated with yield losses, increased production costs, and the necessity to employ more intensive chemical practices for its control. Despite numerous efforts aimed at managing barnyardgrass, it remains one of the most persistent issues in agriculture [4,10]. This weed species shows a strong competitive ability against crop plants [11], and in maize it can reduce plant height, leaf length, leaf area, number of leaves, leaf fresh and dry weight, and consequently grain yield by 24–35% [12,13]. This because this weed is a large seed producer, constantly enriching its seed bank in the soil, and because it is usually found in high numbers in maize it is highly competitive with maize, especially during its early growth. Barnyardgrass also inhibits seed germination and radicle growth of maize seedlings due to its allelopathic nature [14].

In the case of annual weed species, environmental conditions are especially relevant because the particular characteristics of each season may affect the whole life cycle of the population. Each species shows different requirements for its development and, with specific reference to the sequence of processes regulating seedling emergence, the driving forces are mainly soil temperature and moisture [15,16].

This scientific publication focuses on multi-year studies concerning the presence of barnyardgrass in weed populations. Our research aims not only to comprehend the factors influencing the spread of this weed but also to analyze the effectiveness of various weed management strategies from a long-term perspective. In the context of global challenges related to sustainable agriculture and environmental conservation, it is crucial to identify effective and sustainable methods for weed control that simultaneously minimize the negative impact on agricultural ecosystems [17,18].

We believe that the findings of our research will not only provide valuable insight for farmers and plant protection specialists but will also contribute significantly to the development of sustainable weed management strategies. These strategies aim to maintain agricultural productivity while concurrently minimizing the adverse impact on the natural environment.

The study's working hypothesis assumed that the occurrence of *E. crus-galli* in sweetcorn cultivation depends on agricultural and weather conditions.

The aim of the study was to assess dynamic changes in the status and the degree of *E. crus-galli* infestation in sweetcorn that was cultivated in the Wielkopolska region in the past three decades.

2. Materials and Methods

2.1. Experimental Field

The research was conducted in the years 1992–2019 in the fields of the Research and Education Center branch Złotniki (52°29′ N, 16°49′ E) belonging to Poznań University of Life Sciences. Sugar maize was sown annually after various preceding crops: winter triticale, winter wheat, winter oilseed rape, spring barley, winter rye, and maize grown for grain harvest. The evaluation of sugar maize weed infestation was carried out in experiments related to chemical weed control in maize which were established as single-factor randomized block designs in four field replications. The study included data concerning weed infestation in control plots where no herbicide treatments were applied. The experimental plots had an area of 11.8 m^2 and consisted of four rows of maize plants. The row spacing was 70 cm and the plant spacing within the row was 25 cm, resulting in 24 plants per row. Maize seeds were sown manually with two grains per point. At the 2–3 leaf stage of maize (BBCH 12–13), thinning was performed to leave only one plant per point. The assessment of the condition and degree of weed infestation (number and fresh weight of weeds) in the control plots was carried out annually in late June and July. The evaluation involved placing frames with dimensions of 0.7×0.5 m in randomly selected locations within each plot, identifying and determining the number of all weed species present within the designated areas. After removing all weeds from the specified area, they were sorted into individual species, counted, and weighted.

Phytosociological analysis was conducted on fixed research plots where the condition and degree of weed infestation (species abundance and fresh weight) of sugar maize were determined [19]. The individual weed species were classified according to the phytosociological system developed by Matuszkiewicz et al. [20] and their participation was determined throughout the study years.

2.2. Meteorological Conditions

The course of weather conditions during the years of research was presented based on data obtained from measurements at the Meteorological Station in the Experimental and Didactic Center in Złotniki, which belongs to the Poznań University of Life Sciences.

The results in Tables 1 and 2 are presented based on the percentage share of precipitation in the months from April to June relative to the multi-year norm. The period under consideration was characterized as extremely wet, very wet, wet, dry, very dry, and extremely dry [21].

Table 1. Percentage of precipitation compared to the long-term average.

Type	% Precipitation
Extremely wet (EW)	>200
Very wet (VW)	151–200
Wet (W)	126–150
Average (A)	75–125
Dry (D)	50–74
Very dry (VD)	25–49
Extremely dry (ED)	<25

Table 2. Categorization of years according to humidity.

Humidity Categories						
ED	VD	D	A	W	VW	EW
1992, 2018	1996, 2000, 2003, 2008, 2011	2001, 2004, 2005	1994, 1997, 1998, 2006, 2007, 2015, 2019	1993, 1995, 2014, 2016, 2017	2010, 2002	1999, 2009, 2012, 2013

EW—extremely wet; VW—very wet; W—wet; A—average; D—dry; VD—very dry; ED—extremely dry.

The period under consideration was characterized in terms of temperature as warm, moderate, and extremely dry [22]. The most favorable in terms of temperature were the years 1992, 1993, 1998, 2000, 2002, 2003, 2006, 2007, 2008, 2009, and 2011, 2012, 2013, 2014, 2016, 2018, 2019. The years with moderate temperatures were 1994, 1995, 1996, 1999, 2001, 2004, 2005, and 2010, 2015, 2017, while the year 1997 was cool (Table 3).

Table 3. Categorization of years according to temperature.

Temperature Categories		
W—warm	M—moderate	C—cold
1992, 1993, 1998, 2000, 2002, 2003, 2006, 2007, 2008, 2009, 2011, 2012, 2013, 2014, 2016, 2018, 2019	1994, 1995, 1996, 1999, 2001, 2004, 2005, 2010, 2015, 2017	1997

2.3. Statistical Analysis

The assumption of analysis of variance regarding the normal distribution of data was not met (Shapiro–Wilk test). Consequently, Spearman's rank correlation coefficients between temperature and rainfall in the months of April, May, and June were calculated.

For the analysis of differences between pre-crops in terms of mass and number proportion of weed individuals in the total mass and number of weeds, excluding the influence of the continuous variables (temperature and rainfall for April, May and June), permutation analysis of covariance was employed (with 5000 permutations). This test was available also for non-orthogonal data (our data were non-orthogonal as regards number of years with different pre-crops). The mixed model was used with random years. Homogeneity of variance was assessed using the Levene test (homogeneity of variance among compared groups—pre-crops—was demonstrated). Multiple simultaneous comparisons were performed using the Bonferroni correction for the empirical significance level.

Violin plots were constructed to illustrate the distribution of mass and numerical proportion of weeds in the total mass and number of weeds according to the categorized meteorological conditions and pre-crop used. The analysis of differences between categorized weather conditions and pre-crops was conducted using permutation three-way analysis of variance (with 5000 permutations).

The probability of weed occurrence in corn after a given pre-crop and under specific meteorological conditions was determined using a generalized linear model with a logit link function for binary data (whether a plant is a weed or not). In this analysis, three factors were taken into account: categorization temperature, categorization rainfall, and pre-crop.

In all statistical analyses conducted, a significance level of 0.05 was adopted.

All computations were performed using the R platform, utilizing the following packages: stats (R Core Team) [23], permuco [24], ggplot2 [25], and car [26].

2.4. Soil Conditions

The Research and Education Center in Złotniki is located on a glacial outwash plain within the Poznań upland region, which is characterized by the granulometric composition of light clays. According to the PTG classification system [27] the soil on which the experiment were conducted can be characterized as follows:

Order fluvisols, suborder: brown soils, great group: typical brown soils, Subgroup: loamy sands, Family: medium loamy sand, lying shallow on light clay. Throughout the years of research, the soil was classified as bonitation class IV and/or IV b, belonging to the good rye complex.

3. Results

3.1. The Relationship between the Proportion of Weed Mass and Count and Pre-Crop, Rainfall, and Temperature

In the first step, a correlation analysis between the independent variables was performed (Table 4). None of the coefficients, in terms of absolute value, exceeds 0.8. All relationships are very weak, and no multicollinearity of variables was observed. Therefore, all continuous independent variables (temperature and rainfall in the months of April, May, and June) will be included in the analysis of the covariance model.

The shares of weed mass and number of individuals in total weed mass and number are very weakly correlated with precipitation and temperature in the analyzed months of the experiment (Table 4). However, the permutation analysis of covariance carried out showed a significant dependence of the weight share of weed individuals in the total weed mass on temperature and precipitation in June, and that the weed mass share depends on the previous crop (Table 5a).

Analysis of covariance of the relationship of the proportion of the number of barnyardgrass to the total number of weeds showed a significant dependence on rainfall in April, May, and June, as well as temperature in April and May. The share of the number of barnyardgrass individuals is also dependent on the previous crop (Table 5b).

Simultaneous multiple comparisons between previous crops for mass of barnyardgrass showed two homogeneous groups (Table 6a). Winter rye, spring barley, and maize constitute one homogeneous group (labeled as "a"), while spring barley and maize, winter wheat, winter oilseed rape, and winter triticale constitute the second homogeneous group (labeled as "b"). The proportion of weed mass in the total weed mass is significantly lower after winter rye than after winter wheat, winter oilseed rape, and winter triticale.

Table 4. Spearman rank correlations between meteorological conditions from April to June.

Variable		Rainfall				Temperature			
		April	**May**	**June**	**Precipitation Sum**	**April**	**May**	**June**	**Average Temperature**
Rainfall	April	1.0000	−0.3539	−0.1327	0.0505	−0.1383	−0.0131	−0.0189	0.1397
	May	−0.3539	1.0000	0.2600	0.6958	0.0641	−0.3554	−0.2087	−0.1729
	June	−0.1327	0.2600	1.0000	0.7730	−0.0899	0.1046	−0.4645	−0.2212
	Sum	0.0505	0.6958	0.7730	1.0000	−0.0813	−0.1942	−0.4364	−0.3254
Temperature	April	−0.1383	0.0641	−0.0899	−0.0813	1.0000	0.3121	0.2367	0.7235
	May	−0.0131	−0.3554	0.1046	−0.1942	0.3121	1.0000	0.2650	0.6660
	June	−0.0189	−0.2087	−0.4645	−0.4364	0.2367	0.2650	1.0000	0.7114
	Average	−0.1397	−0.1729	−0.2212	−0.3254	0.7235	0.6660	0.7114	1.0000
Proportion of barnyardgrass in the total weed mass		0.0067	−0.1191	0.2831	0.1262	0.0045	0.1721	−0.0606	0.0474
Proportion of barnyardgrass in the total number of weeds		−0.0738	−0.2968	0.1488	−0.1075	−0.1735	0.2757	−0.0282	0.0208

Table 5. (**a**) Permutational analysis of covariance on the relationship between the percentage of weed mass in the total weed population and meteorological conditions and previous crop, using 5000 permutations. (**b**) Permutational analysis of covariance on the relationship between the percentage of weed count in the total weed population and meteorological conditions and previous crop, using 5000 permutations.

(**a**)

Variable		Sum of Squares	Degrees of Freedom	F Parametric	Parametric *p*-Value P(>F)	Permutation *p*-Value P(>F)
Rainfall	April	0.0001	1	0.0016	0.9682	0.9682
	May	0.0280	1	0.5943	0.4426	0.4512
	June	0.8401	1	17.8508	0.0001	0.0002
Temperature	April	0.0348	1	0.7386	0.3922	0.3774
	May	0.0366	1	0.7766	0.3803	0.3828
	June	0.2499	1	5.3110	0.0233	0.0242
	Previous crop	0.7924	5	3.3676	0.0075	0.0090

(**b**)

Variable		Sum of Squares	Degrees of Freedom	F Parametric	Parametric *p*-Value P(>F)	Permutation *p*-Value P(>F)
Rainfall	April	0.1804	1	4.401	0.0384	0.0362
	May	0.1847	1	4.507	0.0362	0.0406
	June	0.3031	1	7.396	0.0077	0.0058
Temperature	April	0.5973	1	14.576	0.0002	0.0002
	May	0.3393	1	8.280	0.0049	0.0070
	June	0.1614	1	3.938	0.0499	0.0508
	Previous crop	0.8901	5	4.344	0.0013	0.0024

Table 6. (**a**) Simultaneous multiple comparisons of previous crop in terms share of barnyardgrass mass in the total mass of weeds, excluding the influence of meteorological conditions. (**b**) Simultaneous multiple comparisons of previous crop in terms of the proportion of the number of barnyardgrass to the total number of weeds excluding the effect of meteorological conditions.

(**a**)

Previous Crop	Lsmean	Means	Homogeneous Group
Winter Rye	−0.24935	0.0085	a *
Spring Barley	−0.00063	0.0548	ab
Maize	0.11654	0.0439	ab
Winter Wheat	0.17117	0.160	b
Oilseed Rape	0.24536	0.213	b
Winter Triticale	0.30611	0.346	b

(**b**)

Previous Crop	Lsmean	Means	Homogeneous Group
Winter Rye	−0.2006	0.0272	a *
Spring Barley	−0.0277	0.0243	a
Winter Wheat	0.1726	0.162	ab
Oilseed Rape	0.1758	0.190	ab
Maize	0.2482	0.0400	ab
Winter Triticale	0.4324	0.448	b

* The same letters indicate homogenous groups (no statistically significant difference). Lsmean—least squares mean.

Simultaneous multiple comparisons between previous crops for the number of barnyardgrass showed two homogeneous groups (Table 6b). Winter rye, spring barley, winter wheat, winter oilseed rape, and maize form one homogeneous group (letter a) and winter wheat, winter oilseed rape, maize, and winter triticale form the other homogeneous group (letter b). The share of the number of barnyardgrass individuals in the total weed number is significantly higher after winter triticale than after winter rye and spring barley.

3.2. Violin Plots of the Proportion of Barnyardgrass Weight and Number in the Total Weight and Number of Weeds

The violin plots show the distribution of observations (share of mass and number of individuals) according to the applied previous crop and degree of moisture (Figure 1), as well as the previous crop and type of thermal conditions (Figure 2).

An exploratory analysis of the violin plots allows us to see that the share of barnyardgrass number of individuals and mass in the total number and mass of weeds is influenced by the following factors: previous crop, temperature, and precipitation.

Spring barley occurred as a previous crop before average and wet years (Figure 1). The share of weed mass in years with average rainfall (P) was 0.075, while in wet years (W) it was 0.035. Average (A) and wet (W) years also occurred when maize was grown in rotation after winter oilseed rape. The proportion of barnyardgrass mass in years with average rainfall (A) was similar at 0.06 as above when maize was grown after spring barley. However, in wet years (W), barnyardgrass was absent or its proportion was at 0.75. Years with different degrees of moisture occurred after winter wheat. For each of these degrees of moisture, the mass share of barnyardgrass in the weed infestation of maize had a different distribution.

The type of thermal conditions also affects the share of barnyardgrass mass and number of individuals in the total number of weeds (Figure 2). In a temperate year (M), the share of weed mass and number was most often lower than in a warm year (W) after the previous crops: spring barley, wheat, and winter oilseed rape. However, the values of these traits vary widely, e.g., in warm years the share of the weight of individuals of barnyardgrass was in the range 0.000–0.80; the same is true for the share of the number of individuals of this weed species for winter wheat.

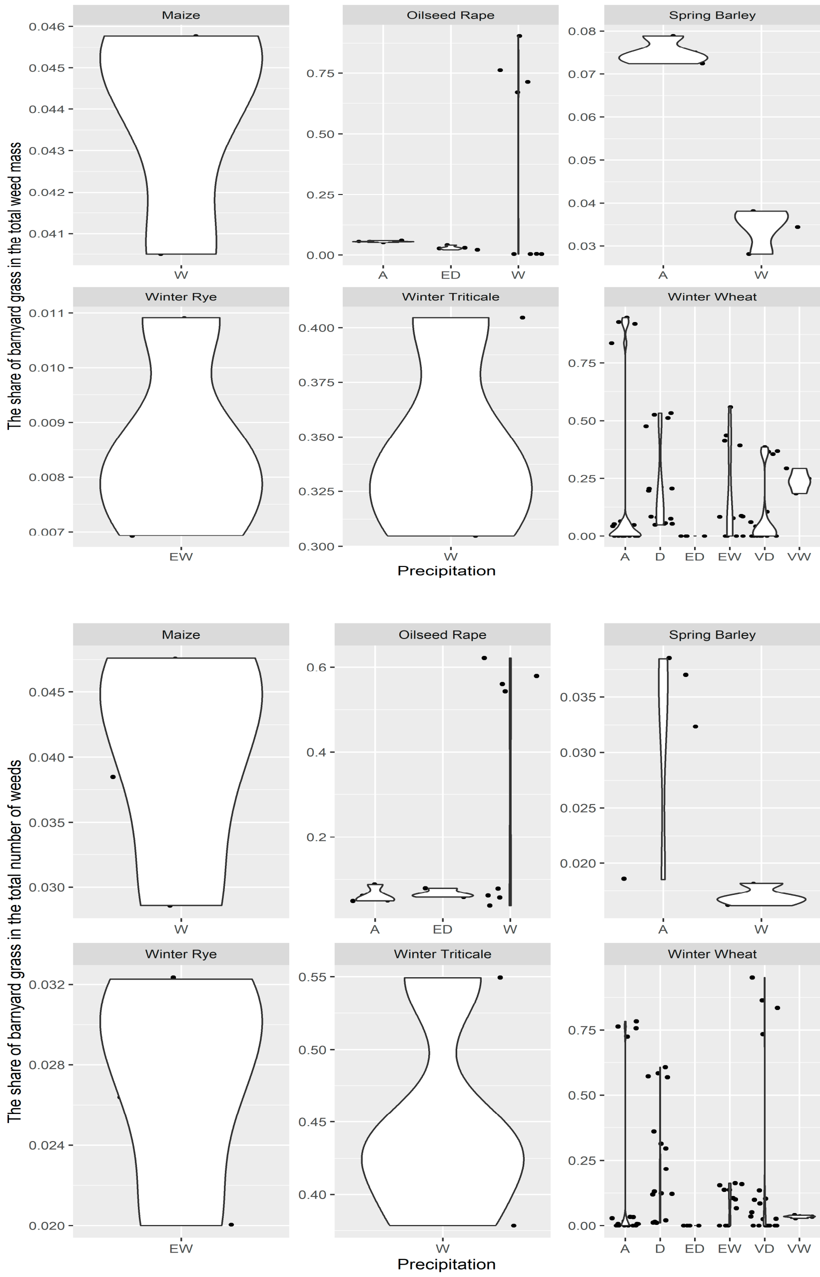

Figure 1. Violin plots of the proportion of barnyardgrass mass and number of individuals in the total mass and number of weeds depending on the previous crop used and the degree of moisture of the previous crop as well as the degree of moisture. Category of humidity: EW—extremely wet; VW—very wet; W—wet; A—average; D—dry; VD—very dry; ED—extremely dry.

Figures 1 and 2 show that the proportion of barnyardgrass mass and number of individuals to total weed mass and number of individuals is dependent on both the degree of moisture, type of thermal conditions, and previous crop. Permutation three-factor analysis of variance was used to demonstrate the significance of these relationships. First, an analysis of variance was performed taking into account all double interactions between the factors analyzed. Since for both the weight share and the number of individuals of the barnyardgrass plant all interactions were ultimately not significant, irrelevant interactions were not included in the model. The permutation test conducted for both the weight share of barnyardgrass individuals in the total weight of weeds and the share of the number of weed individuals in the total number of barnyardgrass species present showed the significance of the effect of all analyzed factors of the experiment (Table 7).

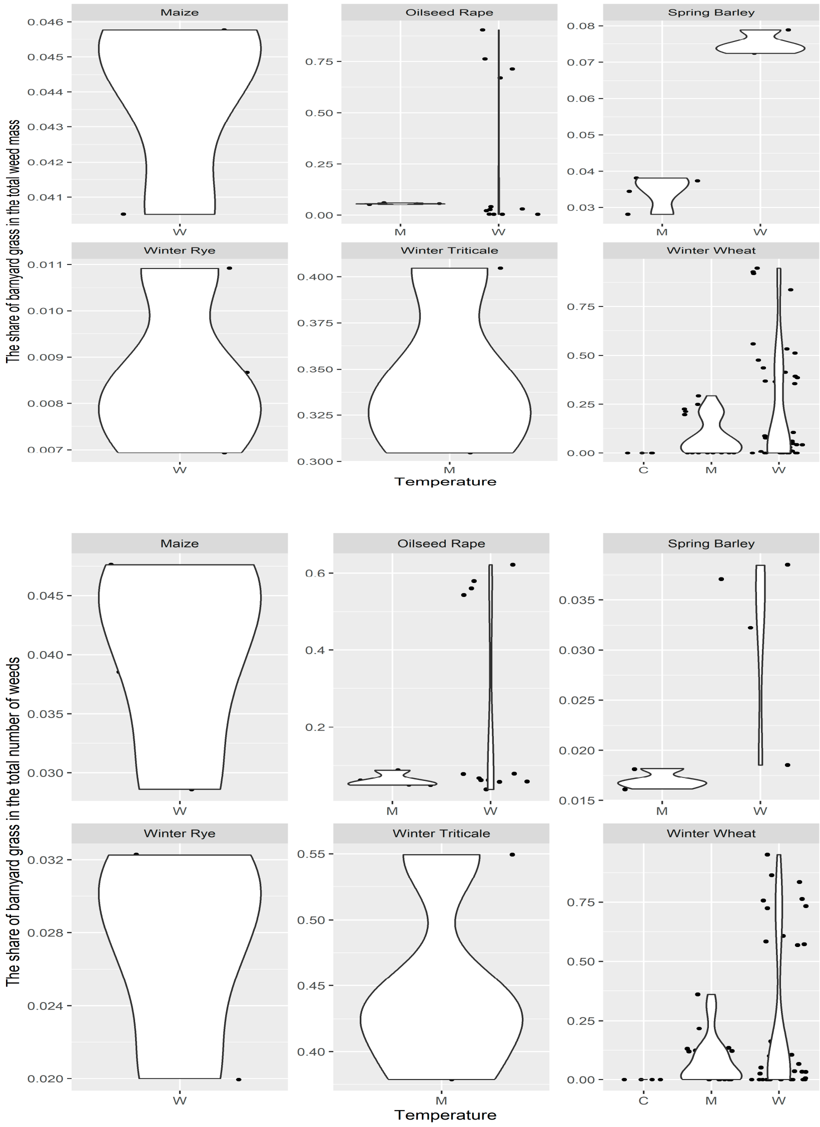

Figure 2. Violin plots of the proportion of barnyardgrass weight and number of individuals in the total weight and number of weeds depending on the previous crop used and type of thermal conditions. Temperature categories: W—warm; M—moderate; C—cold.

The multiple comparisons carried out (Table 8) showed that the share of the weight of individuals of barnyardgrass in sweet maize sown after maize differed significantly from the share of the weight of individuals of this weed species when maize was sown after winter triticale. The share of the number of individuals of the barnyardgrass species in the total number of weeds present differed significantly when sweet maize was sown after winter triticale from the share of the number of individuals when maize was grown in rotation after maize or after spring barley. These results are slightly different from those obtained from the analysis of covariance.

Table 7. Permutation analysis of variance of the dependence of the proportion of barnyardgrass mass and number of individuals in the total weed mass and number of individuals on meteorological conditions and previous crops using Freedman–Lane to handle nuisance variables and 5000 permutations.

Dependent Variable	Source of Variability	Sum of Squares	Degrees of Freedom	*F* Statistic	Parametric *p*-Value	Permutation *p*-Value
The share of barnyardgrass in the total weed mass	Rainfall	1.2138	6	4.751	0.0003	0.0006
	Temperature	1.1380	2	13.363	0.0000	0.0002
	Previous crop	0.9051	5	4.251	0.0015	0.0044
The share of barnyardgrass in the total number of weeds	Rainfall	0.8751	6	3.136	0.0074	0.0102
	Temperature	0.8400	2	9.032	0.0003	0.0020
	Previous crop	0.9174	5	3.945	0.0027	0.0044

Table 8. Simultaneous multiple comparisons of previous crop, moisture degrees, and types of thermal conditions in terms of the proportion of barnyardgrass mass and number of individuals to total weed mass and number of individuals.

The Share of Barnyardgrass in the Total Weed Mass				The Share of Barnyardgrass in the Total Weed Number			
Previous crop	Lsmean	Average	Homogeneous Group	Previous crop	Lsmean	Average	Homogeneous Group
Maize	−0.2676	0.0560	a *	Maize	−0.2098	0.0612	A
Winter Rye	−0.1420	0.0100	ab	Spring Barley	−0.0742	0.0619	A
Spring Barley	−0.0750	0.0166	ab	Winter Rye	−0.0416	0.0069	Ab
Winter Oilseed Rape	0.0914	0.1993	ab	Winter Wheat	0.0860	0.1886	Ab
Winter Wheat	0.1075	0.1824	ab	Winter Oilseed Rape	0.0925	0.1481	Ab
Winter Triticale	0.2756	0.0439	b	Winter Triticale	0.4079	0.0400	B
Rainfall Assessment	Lsmean	Average	Homogeneous Group	Rainfall Assessment	Lsmean	Average	Homogeneous Group
ED	−0.2659	0.0037	a	ED	−0.1638	0.0083	A
VD	−0.1485	0.0230	ab	EW	−0.0387	0.0608	Ab
EW	−0.0306	0.0330	abc	VD	0.0455	0.0143	Ab
A	0.0083	0.0400	abc	A	0.0495	0.0316	Ab
D	0.1044	0.0530	c	VW	0.0514	0.2542	Ab
W	0.1304	0.0595	bc	W	0.1423	0.0565	Ab
VW	0.1901	0.0622	bc	D	0.2180	0.0022	B
Temperature	lsmean	Average	Homogeneous Group	Temperature	lsmean	Average	Homogeneous Group
C	−0.1191	0.0000	a	C	−0.0486	0.0000	Ab
M	−0.0637	0.0264	a	M	−0.0154	0.0272	A
W	0.1778	0.0496	b	W	0.1944	0.0486	B

* The same letters indicate homogenous groups (no statistically significant difference). Lsmean—least squares mean.

The proportion of the weight of the barnyardgrass individuals varied significantly according to the years of the study (Table 8). The mass of individuals of this weed species occurring in extremely dry (ED) years differed significantly from those occurring in dry (D), wet (W), and very wet (VW) years, and very dry (VD) from dry (D) years. On the other hand, the number of barnyardgrass individuals present in extremely dry years (ED) was significantly different with respect to dry years (D). The weight of barnyardgrass individuals shown in warm years differed significantly from those determined in cold (C) and temperate (M) years. In contrast, the abundance of barnyardgrass individuals found in temperate years (M) was significantly different with respect to their density found in warm years (W).

3.3. Probability of Barnyardgrass Occurrence

The analysis of the dependent variable of the proportion of barnyardgrass individuals in the total number of weeds in relation to the previous crop and categorized meteorological conditions was carried out using a generalized linear model with a logit binding function. For this purpose, the dependent variable was presented in dichotomous form; each weed was defined as 1—barnyardgrass and 0—other weed species. The analysis showed that the abundance of barnyardgrass individuals was influenced by the type of meteorological conditions, the degree of moisture and the previous crop (Table 9).

Table 9. The logistic model of barnyardgrass contribution to the total number of weeds.

	Degrees of Freedom	*p*-Value Pr (>Chi)
Rainfall	6	0.0000
Temperature	2	0.0000
Previous crop	5	0.0000

The logistic model for the probability of weed emergence is as follows:

$$1 - p(Previous\ crop,\ Rainfall, Temperature) = 1 - \frac{e^{\beta X}}{1 + e^{\beta X}}, \tag{1}$$

where:

$$\begin{aligned} \beta X = 3.8686^{*} + \quad & 0.0558\ VW - 0.8195\ ^{*}\ A - 1.2887^{*}\ D + 1.8183^{*}\ EW \\ & +1.1987^{*}\ EW - 0.29277\ W - 2.13745^{*}\ M + 18.10570\ C \\ & -0.35693\ m - 2.72957^{*} ww + 5.47403 * wt - 2.63024^{*} or \\ & -1.45640^{*} wr \end{aligned}$$

m—maize, ww—winter wheat, wt—winter triticale, or—oilseed rape, wr—winter rye, the other symbols as in Tables 2 and 3.

The highest probability of barnyardgrass among all weeds is when maize is sown after winter wheat in a dry (D) and warm (W) year (Table 10), and the lowest after winter wheat in an average wet (A) and cold (C) year.

Table 10. Probability of the contribution of barnyardgrass to the total number of weeds determined from model (1).

Previous Crop	Humidity Level	Type of Thermal Conditions	Probability of Barnyardgrass Occurrence
Spring Barley	A *	W *	0.045
Spring Barley	W	M	0.003
Maize	W	W	0.038
Winter Wheat	VD	W	0.243

Table 10. *Cont.*

Previous Crop	Humidity Level	Type of Thermal Conditions	Probability of Barnyardgrass Occurrence
Winter Wheat	VD	M	0.036
Winter Wheat	VW	M	0.034
Winter Wheat	A	W	0.421
Winter Wheat	A	M	0.079
Winter Wheat	A	C	0
Winter Wheat	D	W	0.537
Winter Wheat	D	M	0.12
Winter Wheat	ED	W	0.049
Winter Wheat	EW	W	0.088
Winter Wheat	EW	M	0.011
Winter Triticale	W	M	0.44
Winter Oilseed Rape	A	M	0.072
Winter Oilseed Rape	ED	W	0.045
Winter Oilseed Rape	W	W	0.28
Winter Rye	EW	W	0.026

* Symbols as in Tables 2 and 3.

4. Discussion

The results of our study confirm the significant influence of meteorological conditions on the occurrence of barnyardgrass in maize crops. The observed differences in the amount of precipitation in each year of conducting the experiment may have been crucial for the population dynamics of barnyardgrass [28–31]. It is most likely to occur among all weed species when maize is sown after winter wheat in a dry and warm year, suggesting that wet conditions may limit its development. This result is consistent with previous studies that suggested that soil moisture can have a significant impact on the emergence and growth of weeds, including barnyardgrass [7].

In the conducted research, a significant correlation was found between the proportion of weed mass in the total weed biomass and the temperature and precipitation in June, as well as the previous crop. It was significantly lower when maize was sown in crop rotation after winter wheat compared to its cultivation after winter rye and winter oilseed rape. Studies [1,32,33] indicate the influence of the preceding crop as well as the amount of remaining crop residue on weed seedling emergence. The authors demonstrated that type and quantity of plant residues can differentiate the percentage of weed seedling emergence, and differences between individual species can range from a few to several percent. According to Nichols et al. [34], plant residues reduce weed seed germination mainly due to insufficient light availability, but this is likely not the primary advantage of plant residue retention. Surface residues decrease the maximum soil temperature during the day but have little effect on the minimum temperature, resulting in two changes: lower average soil temperatures and less drastic fluctuations. Most agronomic crops and many weeds require soil temperatures above a certain threshold to germinate—lower average soil temperatures thus delay germination of both. This delayed germination and shorter growing season of the crop can reduce yields, emphasizing that residue amounts should optimize yields rather than weed control. For some weed species, germination is increased by greater temperature fluctuations, hence buffered soil temperature can additionally reduce their germination rate [35,36].

Our findings suggest that crops rotation pays a significant role in influencing the occurrence of barnyardgrass in maize fields. Crop rotation, as a fundamental aspect of agriculture management, impacts weed species composition, soil health, and overall crop productivity. Nichols et al. [34] take a similar view that crop rotation is the most effective way to control weed occurrences. Every crop applies a unique set of biotic and abiotic constraints on the weed community; this will promote the growth of some weeds while inhibiting that of others. In turn, Bàrberi et al. [37] believe that cultivating diverse species of plants with different sowing times is crucial in reducing the size of the weed seed bank, presumably because it changes the timing of agronomic practices. The cultivation of each crop plant is associated with a distinct set of agronomic practices that create both spatial and temporal variability in nutrient, water, and light availability. Variability of these resources will affect where and when the soil is favorable for seed germination. For example, in a water-limited environment, a spring-irrigated crop will promote spring weed seed germination, while a fall-irrigated crop will promote fall weed germination [34]. Gunton et al. [38], based on research conducted in different agriculture fields, found that the crop date was an effective predictor of the weed community. According to Simić et.al. [33], in crop rotation they conclude that cereal and legume crops and especially maize–soybean–winter wheat rotation where wheat is the preceding crop for maize are most effective according to weed suppression and achieved yield. A diverse crop rotation is a key component in an integrated weed management program, but herbicide application and fertilization should be also appropriately applied for successful weed control [1]. Continuous cropping favors a very few weeds that are well adapted to that crop [39]. Diverse rotation will tend to favor any given species only in certain years, while relative abundance of species will tend to be more equal [40]. Monocultures often lead to weed simplification with only a few dominant weeds [41], potentially simplifying the choice of herbicide but potentially increasing selection pressure for herbicide resistant weeds [34].

Crop rotation is the most effective way to reduce the number of weeds [42], and growing a variety of crops also allows weeds in previous crops to be controlled using herbicides with different modes of action [43]. Ultimately, this strategy significantly diminishes the likelihood of the emergence of resistant weed species [44], such as barnyardgrass. During our trials, the crops previous to maize included not only various cereal species, but also winter oilseed rape. The management of weeds in grains relied on the application of various active ingredients, which was especially true for the oilseed rape. No weed species that could be considered likely to be resistant to any of the herbicides used was found during the entire test cycle, which also makes it possible to rule out the occurrence of barnyardgrass and the influence of this factor on it.

Further research into integrated weed management strategies tailored to specific agroecological contexts is warranted to address the challenges posed by barnyardgrass and other weed species in maize production systems.

5. Conclusions

The occurrence of weeds in maize cultivation is significantly influenced by the level of moisture (amount of precipitation), the type of meteorological conditions, and the preceding crop. The highest probability of barnyardgrass occurrence among all weed species occurs when maize is sown after winter wheat in a dry and warm year. Conversely, the lowest probability occurs when maize is cultivated in crop rotation after winter wheat in a cold year with average precipitation levels. Significant correlation was found between the proportion of weed mass in the total weed biomass and the temperature and precipitation in June, as well as the preceding crop. It was significantly lower when maize was sown in rotation after winter wheat compared to its cultivation after winter rye and winter oilseed rape. The previous crop influences the composition of weed communities in maize, and the results show that a higher share of barnyardgrass in the total weed count was observed in maize sowing after winter triticale than after winter rye and spring barley.

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