

Original Research

The Role of Agrotechnical Factors in Shaping the Health of Maize Plants (*Zea mays* L.)

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Abstract

The article presents the results of 3-year field studies, whose purpose was to assess the impact of maize sowing method, type of cultivar and NP fertiliser sowing method on the health of maize plants. Changing weather conditions during the study years significantly differentiated the percentage of maize plants damaged by pests and affected by diseases. The positive effect of the row method of NP fertiliser application in maize cultivation not only reduced plant infestation by *Fusarium* diseases, but also reduced Frit fly (*Oscinella frit* L.) pressure. The “stay-green” hybrid was characterized by a significantly lower susceptibility to feeding of the European corn borer (*Ostrinia nubilalis* Hbn.) compared to the traditional cultivar. Sowing maize of the traditional cultivar using the direct sowing system increased damage to plants caused by Frit fry larvae (*Oscinella frit* L.) compared to sowing into soil cultivated in a traditional way. For the “stay-green” type, the method of soil preparation for sowing did not significantly affect the pressure of this pest. A simplified method of soil preparation for sowing maize should give preference to cultivating “stay-green” varieties.

Keywords: *Zea mays* L., agrophage, agricultural practices

Introduction

Repetitive water shortages occurring almost every year in the maize growing season incline to search

for agrotechnical solutions aimed at counteracting this unfavorable situation [1, 2]. Agrotechnical treatments can result in a permanent aggregate structure formation, which promotes optimal physical conditions in the soil, preventing its excessive compaction. This ensures a favorable content of capillary pores, enabling water access to plant roots [3, 4]. In addition, stable and waterproof aggregate structure prevents soil crusting, increasing its capacity to rainwater absorption [5].

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Soil density is a property that depends on mineral and granulometric composition of soil material, organic matter content, soil structure and agrotechnical treatments [6]. It is considered to be an indirect indicator of soil structure, compactness, porosity, aeration and soil capacity to store and transport soil water [7]. Proper fertilization of plants is also very important in integrated maize protection against diseases and pests [8-10]. It not only determines the size of the yield, but also increases plant tolerance to disease infestation and pest feeding. This has been confirmed by Krauss [11], according to whom the degree of pest pressure on a crop is the resultant of its nutritional status. Therefore, the search for alternative methods to reduce the impact of pests on arable crops is such an important element of agronomic works [12]. For this reason, creating hybrids with traits that give them an advantage in an environment with limited water resources is one of the main challenges facing the breeding of new varieties [13]. Breeding in the direction of better plant health later in the growing season or "stay-green" varieties may be the solution [14]. This feature is an indicator of higher plant health in the later vegetation period, reduced progressive aging and drought tolerance after flowering [15, 16]. In integrated plant protection programs, it is extremely important to select varieties for cultivation that, on the one hand, are adapted to local soil and climate conditions, and on the other hand, are less susceptible to pests [17]. Therefore, the cultivation of maize "stay-green" varieties can be considered as one of the elements of integrated plant protection, which has been obligatory in the European Union since January 1, 2014. This issue is very important from the point of view of integrated plant protection, which particularly prefers the use of non-chemical methods, including the selection of less susceptible to damage or infestation varieties for cultivation. These studies are also important in the context of the observed climate changes that affect both the crop and the organisms damaging it [1, 18, 19]. Hence, the purpose of the field tests was to assess the occurrence of diseases and pests in maize cultivation in the conditions of using different maize sowing methods, selection of varieties and techniques of NP fertiliser application.

Materials and Methods

Experimental Field

The field experiment was carried out at the Department of Agronomy of Poznań University of Life Sciences in the years 2012-2014. It was carried out for three years in the same scheme in a split-split-plot design with three factors in 4 field replicates. The study involved the following factors: A - 1st order factor - two methods of maize sowing: A1 - sowing to the soil (traditional cultivation), A2 - direct sowing to the stubble after winter wheat (straw harvested); B - 2nd

order factor - two types of varieties: B1 - traditional cultivar SY Cooky, B2 - stay-green cultivar Drim; C - 3rd order factor - 2 methods of supplying NP fertiliser: C1 - broadcast on the entire surface before seed sowing, C2 - in rows simultaneously with seed sowing. The same level of mineral fertilization (100 kg N·ha⁻¹, 30.8 kg P·ha⁻¹ and 107.9 kg K·ha⁻¹) was applied on all experimental objects. Fertilization was balanced against phosphorus, which was applied at the whole required dose in the form of ammonium phosphate under the trade name of polidap NP. N and K fertilization was performed before maize sowing using urea and potassium salt (60%). The N dose was reduced by the amount of nitrogen present in the polidap. Soil abundance in basic macronutrients before establishing the experiment is presented in Table 1. The magnesium content in the soil was determined by the Schachtschabel method, potassium by the Egner-Riehm method, phosphorus by the Olsen method and N_{min} Kjeldahl method. Winter wheat was the forecrop for maize in each year of research. Individual cultivating treatments were carried out in accordance with the adopted schedule within the dates given in Table 2.

Weather Conditions

Thermal conditions during maize growing in the experimental years were similar to each other and were on average 15.4°C in 2012, 15.6°C in 2013 and 16.1°C in the warmest year of 2014. Significantly greater differences between years occurred in the amount of precipitation. The largest sum of rainfall, 473.6 mm, was recorded in 2012, which was 76.2 mm higher than the precipitation in 2013, and 121.8 mm higher from the amount of rainfall in 2014. The calculated hydrothermal coefficients of water preservation according to Sielianinow allowed to conclude that weather conditions for the growth and development of maize were moderately beneficial with simultaneous periodic moisture deficits. In 2012, the least amount of rainfall was recorded for April, August and September. A low amount of rainfall combined with a high average air temperature caused a period of insufficient moisture for most plants in these months. In 2001, the months with lowest precipitation were April, July, August and October. This caused the occurrence of acute drought

Table 1. The content of nutrients (mg/kg DM) and soil pH (w 1 mol·dm⁻³ KCl).

Specification		Years		
		2012	2013	2014
N _{min}	0-60 cm	18.4	15.9	19.9
P	0-25 cm	112.0	38.0	127.0
K		95.0	111.0	261.0
Mg		28.0	23.0	36.0
pH		4.90	4.80	4.70

Table 2. Dates of agrotechnical operations.

Type of treatment	Years		
	2012	2013	2014
1. Deep plowing (30 cm) The treatment was performed in the autumn of the previous year	8 th November	26 th October	18 th November
2. Trawling	26 th March	15 th April	21 st March
3. Fertiliser sowing according to the diagram of experience	19 th April	29 th April	8 th April
4. Spring tillage (tilling set)	19 th April	29 th April	9 th April
5. Seeding - precision seeder with built-in mineral fertiliser applicator	20 th April	30 th April	28 th April
6. Herbicide use ¹ - Guardian CompleteMix 664 SE (3.5 l/ha), ² - Guardian CompleteMix 664 SE (3.5 l/ha), ³ - Lumax 537,5 SE (3 l/ha), ⁴ - Nikosh 040 SC (1 l/ha)	23 rd April ¹	30 th April ²	14 th April ³ 2 th May ⁴
7. Harvesting with a field harvester	19 th October	23 rd October	20 th October

period in April, May and October and drought in July and August. Definitely the worst year in terms of moisture conditions was the last year of research, i.e. 2014. A low amount of rainfall, and simultaneous high air temperature caused a period of drought from June to October.

Statistical Analysis

Infestation of maize plants with diseases and damage by pests was determined during the period of the field experiment. Both for diseases and pests, only the number of plants that were attacked or infected by a given pathogen was recorded. The degree of disease

and pest infestation was not included. Damage to maize plants by the European corn borer was determined in the wax ripe phase of the kernels (BBCH 85), by the Frit fly in the stage BBCH 15/16, while the occurrence of *Fusarium* diseases and the common smut were determined before harvesting. The Bliss transformation was used ($\text{Arc sin } \sqrt{x}$) because the data had a binomial distribution expressed as a percentage (0-20%). Four-way analysis of variance (ANOVA) was performed on the transformed data according to the experimental design. For the primary and interactive effects, significant at $\alpha = 0.01$ or $\alpha = 0.05$, the HSD Tukey procedure was applied (STATISTICA ver. 13).

Table 3. The average monthly air temperature and the monthly sum of atmospheric precipitation in Swadzim for the growing season.

Years	Temperature (°C)															Mean/ Sum	M
	IV	M	V	M	VI	M	VII	M	VIII	M	IX	M	X	M			
2012	9.3	8.2	16.3	13.5	17.0	16.8	20.0	18.6	19.8	17.9	15.0	13.7	8.6	8.8	15.4	13.9	
2013	8.9	8.2	15.6	13.5	18.4	16.8	22.0	18.6	20.2	18.0	13.2	13.7	10.8	8.8	15.6	13.9	
2014	11.4	8.3	14.6	13.6	17.9	16.8	23.2	18.7	18.8	18.0	16.0	13.7	11.2	8.8	16.1	14.0	
Years	Precipitation (mm)															Mean/ Sum	M
2012	17.4	32.1	84.4	52.8	118.1	56.9	136.2	75.3	52.7	58.4	28.4	43.5	36.4	37.7	473.6		
2013	10.5	31.8	95.5	53.4	114.9	58.0	52.9	76.5	32.4	58.3	75.9	43.2	15.3	37.7	397.4	358.9	
2014	50.3	31.4	80.7	54.1	44.6	59.0	51.5	76.0	56.5	57.8	39.2	43.8	29.0	37.3	351.8	359.4	
Years	Value of hydrothermal coefficient of water preservation ¹															Mean/ Sum	M
2012	0.62	1.26	1.67	2.07	2.31	2.31	2.19	2.96	0.85	2.29	0.63	1.76	1.36	1.48	1.37		
2013	0.39	1.25	1.97	1.27	2.01	1.15	0.77	1.32	0.51	1.04	1.91	1.05	0.45	1.38	1.14	1.21	
2014	1.48	1.22	1.78	1.28	0.83	1.17	0.71	1.31	0.96	1.03	0.81	1.06	0.83	1.36	1.06	1.20	

¹ – according Sielianinow [20]; M – Multiplicity (since 1958)

Table 4. Infection of plants by diseases and damage of plants caused by pests and ANOVA results.

Source of variation	Df	Mean squares			
		Diseases		Pests	
		<i>Fusarium</i> diseases	Corn smut	European corn borer	Frit fly
Blocks	3	0.004977	0.005735	0.002829	0.003948
Y - Years	2	1.301463**	0.027226**	0.974462**	0.641037**
Error 1	6	0.007943	0.001382	0.007016	0.004930
A	1	0.005595	0.003468	0.003767	0.024999
Y×A	2	0.009829	0.006747	0.000352	0.009151
Error 2	9	0.004181	0.054731	0.004131	0.005082
B	1	0.004328	0.002655	0.047363**	0.010164
Y×B	2	0.006975	0.001289	0.007145	0.001044
A×B	1	0.001019	0.003197	0.010077	0.032844*
Y×A×B	2	0.001986	0.000587	0.002406	0.003442
Error 3	18	0.002117	0.036139	0.004440	0.004377
C	1	0.001997	0.051060**	0.001128	0.018613*
Y×C	2	0.002205	0.004406	0.002887	0.001573
A×C	1	0.001946	0.000779	0.000421	0.000078
B×C	1	0.002697	0.000333	0.000048	0.000457
Y×A×C	2	0.004393	0.000723	0.021568*	0.001623
Y×B×C	2	0.001460	0.002091	0.017989*	0.001844
A×B×C	1	0.006004	0.004584	0.000788	0.004875
Y×A×B×C	2	0.005348	0.007782	0.002226	0.004956
Error 4	36	0.003129	0.002475	0.005112	0.004099

** – significant at p-value<0.01, * – significant at p-value<0.05

Results and Discussion

As a result of three-year (2012-2014) studies, it was found (Tables 4-5) that regardless of the method of sowing maize, the cultivar used and the method of applying NP fertiliser, significantly the largest damage to plants caused by the studied diseases occurred in 2013 (*Fusarium* diseases, 16.21%) and in 2013 and 2014 (Corn smut, 0.809% and 0.807%). The results presented in the current study have confirmed earlier literature reports that the occurrence of fungi of the genus *Fusarium* ssp. is dependent on variable environmental conditions in individual growing seasons [21, 22]. It was observed that in 2012 the damage caused by both diseases was significantly the smallest. There was not found any significant impact of the experimental factors and their interactions on the degree of plant infection in 2012-2014, with one exception. It was noted (Table 5) that, regardless of the study year, the method of sowing maize and the cultivar used, Corn smut damaged plants more heavily ($\alpha = 0.01$) when NP fertiliser was applied before sowing the seeds (0.913%).

On the other hand, it was shown in another author's work [23] that the method of spreading the fertiliser did not have a significant impact on the percentage of plants infected by common smut. According to Beresia and Pruszyński [24], common smut currently is and will be in the coming years one of important maize diseases. As a result of the three-year field experiments mentioned above, it was found (Table 4, Table 6) that regardless of the experimental factors, the largest plant damage caused by both pests occurred in 2014. In turn, significantly the smallest damage was caused by the Frit fly in 2012 (0.37%), and by the European corn borer in 2012 and 2013 (1.39% and 0.98% respectively). In our own research, however, there was no significant effect of the maize sowing method (A) on plant damage caused by either pest, regardless of the year of research or in interaction with years (Table 4). Also, regardless of the study year and the method of sowing maize, the greatest damage to plants caused by the European corn borer was recorded for the fast maturing cultivar (6.55%). Szulc [25] also demonstrated that the "stay-green" hybrid had significantly lower susceptibility to feeding

Table 5. Mean values of infection of plants by diseases.

Factors	The levels	Fusarium diseases		Corn smut	
		(%)	°Bliss	(%)	°Bliss
Y	2012	0.19	0.013 ^c	0.130	0.011 ^b
	2013	16.21	0.411 ^a	0.809	0.058 ^a
	2014	7.52	0.269 ^b	0.807	0.064 ^a
C	C1	7.60	0.227 ^a	0.913	0.067 ^a
	C2	8.35	0.236 ^a	0.251	0.021 ^b

Values in columns marked with at least the same letter do not differ significantly ($\alpha = 0.01$)

Table 6. Mean values of damage of plants caused by pests.

Factors	The levels	European corn borer		Frit fly	
		(%)	°Bliss	(%)	°Bliss
Y	2012	1.39	0.094 ^b	0.37	0.021 ^c
	2013	0.98	0.072 ^b	2.50	0.143 ^b
	2014	14.54	0.384 ^a	9.37	0.303 ^a
B	B1	6.55	0.205 ^a	4.48	0.166 ^a
	B2	4.73	0.161 ^b	3.68	0.145 ^a
C	C1	5.66	0.187 ^a	4.77	0.169 ^a
	C2	5.62	0.180 ^a	3.39	0.142 ^b

Values in columns marked with at least the same letter do not differ significantly ($\alpha = 0.01$ or 0.05)

of the European corn borer compared to the traditional cultivar. Szulc [26] showed a high positive correlation coefficient between the occurrence of European corn borer and the infestation of maize plants by *Fusarium* spp. However, the cultivar used did not differentiate the percentage of damage done by the Frit fly (Table 6). At the same time (Table 4), significant interaction of varieties and methods of sowing maize was recorded for this pest (regardless of the year of research). It was found (Fig. 1) that, comparing both methods of maize sowing and both varieties, the Frit fly more heavily damaged plants of the fast maturing cultivar when direct sowing to stubble was used (6.04%). For the “stay-green” type, the method of soil preparation for sowing did not significantly affect the pressure of this pest. The obtained result confirms previous literature reports that “stay-green” cultivars are characterized by a stronger root system [27]. According to these authors, “stay-green” maize varieties are characterized by a more dynamic root system development during juvenile stages compared to the traditional hybrid. Hence, the simplified method of soil preparation for maize sowing should give preference to cultivating the “stay-green” cultivar. Mahalakshmi and Bidinger [14] also found that the “stay-green” varieties are more tolerant to stress conditions, such as soil compaction in which plants are more susceptible

to pathogens. In our own research, regardless of the year, the method of sowing maize and the cultivar, the greatest crop damage was caused by the Frit fly when the method of applying NP fertiliser before seed sowing (4.77%) was used. On the other hand, the method of NP fertiliser application did not differentiate the percentage of plants damaged by the European corn borer (Table 6). It was also observed (Table 7) that regardless of the cultivar, the greatest damage caused by this pest

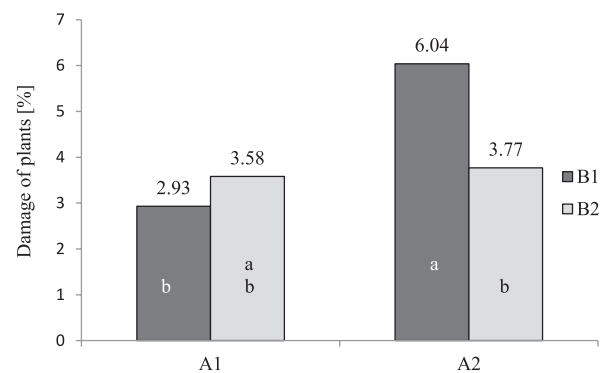


Fig. 1. Mean values of damage of plants caused by frit fly for the combination of two methods of maize sowing (A) and two types of cultivars (B). a, b – homogeneous groups ($\alpha = 0.05$)

Table 7. Mean values of damage of plants caused by European corn borer for the combination Y×A×C.

A	C	Years (Y)					
		2012		2013		2014	
		(%)	°Bliss	(%)	°Bliss	(%)	°Bliss
A1	C1	0.91	0.067 ^b	1.02	0.086 ^b	14.26	0.382 ^a
	C2	1.68	0.110 ^b	0.67	0.050 ^b	13.06	0.367 ^a
A2	C1	2.33	0.141 ^b	1.16	0.072 ^b	14.27	0.372 ^a
	C2	0.65	0.056 ^b	1.06	0.079 ^b	16.59	0.417 ^a

Values in columns marked with at least the same letter do not differ significantly ($\alpha = 0.05$)

Table 8. Mean values of damage of plants caused by European corn borer for the combination Y×B×C.

B	C	Years (Y)					
		2012		2013		2014	
		(%)	°Bliss	(%)	°Bliss	(%)	°Bliss
B1	C1	1.44	0.084 ^b	1.58	0.112 ^b	17.69	0.433 ^a
	C2	1.54	0.115 ^b	1.11	0.081 ^b	15.92	0.408 ^a
B2	C1	1.80	0.124 ^b	0.60	0.047 ^b	10.84	0.321 ^a
	C2	0.78	0.051 ^b	0.62	0.048 ^b	13.73	0.376 ^a

Values in columns marked with at least the same letter do not differ significantly ($\alpha = 0.05$)

occurred in 2014, while the combination of the method of maize sowing and the method of fertiliser application did not cause significant differences between the percentages of plant damage within that year. It was also noted (Table 8) that irrespective of the method of sowing maize, significantly the greatest damage was caused by the European corn borer in 2014, and the combination of maize varieties and NP fertiliser application methods within that year and the other years of research did not differentiate the degree of damage caused by this pest.

Conclusions

1. The percentage of plants damaged by pests or affected by diseases showed a variable response to weather conditions and experimental factors.

2. The positive effect of the row method of NP fertiliser application in maize cultivation not only reduced plant infestation by *Fusarium* diseases, but also reduced the Frit fly pressure.

3. The “stay-green” hybrid was characterized by a significantly lower susceptibility to feeding of the European corn borer compared to the traditional cultivar.

4. Sowing maize of the traditional cultivar using the direct sowing system increased damage to plants by Frit fry larvae compared to sowing into soil cultivated in a traditional way. For the “stay-green” type, the method

of soil preparation for sowing did not significantly affect the pressure of this pest.

5. Cultivation of “stay-green” hybrid such may be considered as an element of integrated maize production.

Conflict of Interest

The authors declare no conflict of interest.

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