https://doi.org/10.17221/22/2017-PPS

Assessment of the Influence of Fertilisation and Environmental Conditions on Maize Health

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Abstract

Szulc P., Bocianowski J., Nowosad K., Michalski T., Waligóra H., Olejarski P. (2018): Assessment of the influence of fertilisation and environmental conditions on maize health. Plant Protect. Sci., 54: 174–182.

Field experiments showed the occurrence of such agrophages as the frit fly (*Oscinella frit* L.) and the European maize borer (*Pyrausta nubilalis* Hbn.). Identified diseases included fusariosis (*Fusarium* ssp.) and maize smut (*Ustilago maydis* Corda). The incidence of the frit fly was influenced by weather conditions, mainly temperature, in the period from sowing to the BBCH 15–16 phase. Moderate temperature conditions contributed to the occurrence of the pest. The significantly highest percentage of plants damaged by larvae of this pest was recorded on maize fertilised only with potassium (K) and phosphorus with potassium (PK). In turn, the lowest percentage of plants damaged by frit fly larvae was recorded for maize fertilised with nitrogen and potassium (NK). The percentage of plants damaged by the European maize borer was influenced by temperature and humidity conditions in individual years of the study. The highest percentage of plants damaged by larvae of the pest was found in the vegetation season characterised by the highest amount of rainfall with the lowest mean daily air temperature. The presence of potassium in a given fertiliser combination, the application of manure or combined application of manure and mineral fertilisation resulted in an enhanced resistance of maize plants to *Fusarium* ssp. fungi. The significantly greatest infestation of maize plants by the fungus *Ustilago maydis* Corda was recorded in the treatment in which only nitrogen was applied. In turn, the lowest percentage of plants with symptoms of this disease was recorded in the treatment with the application of potassium alone and in the application of potassium together with phosphorus.

Keywords: *Zea mays* L.; mineral fertilisation; manure; diseases; pests

A considerable percentage of light soils in farmland areas and the changing cropping structure result in the need to apply organic fertilisers (Szulc *et al.* 2012). Organic fertilisers, particularly manure, apart from supplying plants with nutrients have a beneficial effect on physico-chemical and biological properties in the soil environment provided that the principles and dates of their applications are observed (Boateng *et al.* 2006). In balanced fertilisation of crops the recommended practice is to apply mineral and organic fertilisers at proportions adjusted to match the soil properties. On light soils it is recommended to apply organic fertilisers, while for more compact soils it is advisable to use mineral fertilisation balanced with minerals supplied by organic fertilisers. The consequences of imbalanced mineral fertilisation, particularly on light soils, may be alleviated by organic fertilisation. When growing maize, the most frequent

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practice is to use mineral fertilisation, providing readily available nutrients. In turn, organic fertilisation is used on a limited scale despite the positive response of maize to such fertilisation (Boateng *et al.* 2006). Adequate plant nutrition throughout the entire period of growth and development not only affects the yield level, but also it enhances resistance to infestation related with diseases and pest feeding. According to Grzebisz *et al.* (2007), sensitivity of a plant species to the attack of pathogens and pests results not only from its genetic properties, but also from growth conditions for both these groups of organisms. In turn, Marschner (1986) reported that the degree of parasite pressure on crops depends on the external and internal susceptibility of the attacked organism, which results from its nutrient status.

The aim of the conducted field experiments was to determine the health condition of maize grown for grain during three years and at varied levels of mineral and organic fertilisation.

MATERIAL AND METHODS

Experimental field. The field experiment was performed in 2009–2011 in the fields of the Experimental and Demonstration Station in Swadzim (52°26'N; 16°45'E), at the Department of Agronomy, Poznań University of Life Sciences. According to the international classification of WRB (World Reference Base for Soil Resources 2014), the examined soils should be classified as Phaeozems (Haplic Phaeozems), while according to the US Soil Taxonomy (Soil Survey Staff 1999) they are classified as Mollisols (Typic Endoaquolls). Each year a unifactorial experiment with 12 levels of varied mineral and organic fertilisation (Table 1) was conducted in four field replications. Nitrogen was applied as urea and phosphorus in the form of pelleted triple superphosphate, while potassium was applied in the form of potash salt. Cattle manure used each year of the study in the field experiment contained 0.47% nitrogen, 0.49% phosphorus, and 0.78% potassium. The utilisation of nutrients from manure in the first year after its application is 30% for N, 20% for P, and 30% for K. Thus, the application of 30 t/ha of cattle manure each time supplied to soil 42.3 kg N/ha, for phosphorus it was 29.4 kg P_2O_5/ha, and for potassium it was 70.2 kg K_2O/ha. In this experiment the hybrid Clarica FAO 280 by Pioneer was sown. Macronutrient contents and pH in soil were determined each year prior to the establishment of the experiment (Table 2) following the research procedure/standard (Regional Chemical and Agricultural Station in Poznań).

Thermal and humidity conditions. Total precipitation amount and mean diurnal air temperature in individual years of the study are given in Figure 1. It was shown that the years in which field experiments were conducted were highly varied in terms of their temperature and humidity conditions. The lowest total precipitation amount was recorded in 2011 (424.2 mm), while the highest in 2010 (500.7 mm). In turn, mean diurnal air temperature measured at a height of 2 m ranged from 14.5°C (2010) to 15.9°C (2011).

Table 1. Amount of nutrients delivered in individual fertiliser combinations (kg/ha)

Fertiliser combinations	Mineral fertilisation [M]			Organic fertilisers – manure [O]						Total sum of nutrients [M+O]		
				30 t/ha			15 t/ha					
	N	P	K	N	P	K	N	P	K	N	P	K
Control	0	0	0	0	0	0	0	0	0	0	0	0
NPK	150	90	160	0	0	0	0	0	0	150	90	160
N	150	0	0	0	0	0	0	0	0	150	0	0
P	0	90	0	0	0	0	0	0	0	0	90	0
K	0	0	160	0	0	0	0	0	0	0	0	160
NP	150	90	0	0	0	0	0	0	0	150	90	0
NK	150	0	160	0	0	0	0	0	0	150	0	160
PK	0	90	160	0	0	0	0	0	0	0	90	150
M	0	0	0	42.3	29.4	70.2	0	0	0	42.3	29.4	70.2
M+NPK	107.7	60.6	89.8	42.3	29.4	70.2	0	0	0	150	90	160
½ M	0	0	0	0	0	0	21.1	14.7	35.1	21.1	14.7	35.1
½ M+NPK	128.9	75.3	124.9	0	0	0	21.1	14.7	35.1	150	90	160

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Table 2. Soil conditions at Swadzim

Specification	2009	2010	2011
P (mg/kg soil)	82.7	38.7	41.8
K (mg/kg soil)	146.9	129.4	79.6
Mg (mg/kg soil)	29.0	33.0	70.0
pH in 1 mol/dm^3 KCl	4.6	4.8	4.9

Determination of health condition of maize plants. The analyses conducted during field experiments showed the occurrence of such pests as the frit fly (*Oscinella frit* L.) and the European maize borer (*Pyrausta nubilalis* Hbn.). Damage to maize plants by the frit fly was determined at the phase of 5–6 leaves (BBCH 15–16) while damage caused by the European maize borer occurred at the dough stage of kernels (BBCH 85). Diseases observed on maize plants included fusariosis *(Fusarium* ssp.) and maize smut (*Ustilago maydis* Corda). Infestation of maize plants by diseases was assessed at the dough stage of kernels (BBCH 85). In the case of pests and diseases only the number of plants with symptoms of insect feeding or disease damage was recorded and the results were expressed in percentages. Plant damage caused by pests and diseases was assessed visually without any indication of the degree of infection or damage caused by the pathogen.

Statistical analysis. Values of all the four observed characteristics expressed in percent were transformed into degrees according to Bliss following the formula: $y = \arcsin\sqrt{x/100}$; where: y – value of a characteristic after transformation; x – observed value of the trait before transformation.

The Bliss transformation is typically applied to data having the binomial distribution expressed in percent most frequently assuming values in the range of 0–20% or 80–100%. All the statistical analyses given below were conducted on transformed data.

Statistical analysis was conducted using Bartlett's tests for comparison of variances. One-way or two-way analyses of variance (ANOVA) were applied when there were no significant differences between the variances of the different fertiliser combinations ($P > 0.05$ according to Bartlett's test). Analyses of variance (ANOVA) were carried out for the occurrence of the frit fly (one-way ANOVA) and for maize infestation by fungi from the genus *Fusarium* ssp., maize damage by *P. nubilalis*, and infestation of maize by *Ustilago maydis* Corda (two-way ANOVA). Least significant differences (LSD) for each trait were calculated. Homogeneous groups for the analysed traits were determined on the basis of least significant differences. Data analysis was performed using the GenStat v10.1 statistical package (2007).

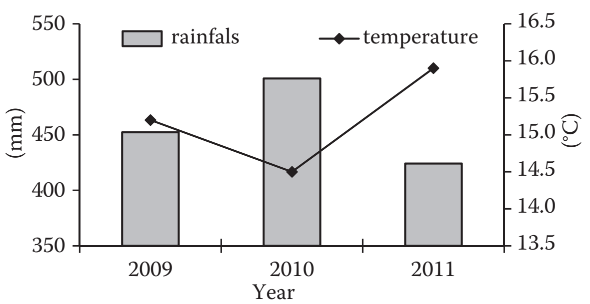

Figure 1. Total precipitation amount and mean air temperature in growing seasons

RESULTS

Bartlett's tests of differences in the variances between the 12 fertiliser combinations were not significant at the 0.05 level for any studied trait. Damage to maize plants caused by the frit fly *O. frit* was observed only in one year of the study – 2009 (Figure 2). Original values of means and values obtained after transformation to the degrees according to Bliss are presented in Table 3. It was shown that fertiliser combinations had a significant effect ($F_{11,33} = 2.30$, $P = 0.032$) on the mean percentage of maize plant

Table 3. Mean values and standard deviations (SD) for the infestation of maize by the frit fly *O. frit* in 2009

Combinations	Mean (%)	°Bliss	
		mean	SD
Control	1.049	0.09^{ab}	0.07
NPK	1.563	0.12^{ab}	0.03
N	1.555	0.11^{ab}	0.07
P	1.023	0.10^{ab}	0.02
K	1.659	0.13^{a}	0.03
NP	1.630	0.12^{ab}	0.05
NK	0.704	0.07^{b}	0.05
PK	1.674	0.13^{a}	0.00
M	0.827	0.09^{ab}	0.00
M+NPK	1.371	0.12^{ab}	0.02
½ M	1.092	0.10^{ab}	0.02
½ M+NPK	0.953	0.08^{ab}	0.06
$LSD_{0.05}$		0.05	
Mean	1.258	0.1	0.04

Means in columns followed by the same letters are not significantly different; M – mineral fertilisation

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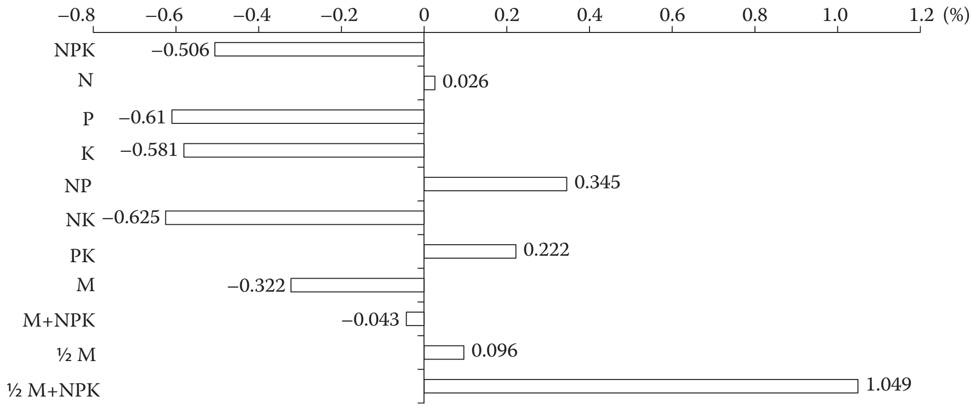

Figure 2. Effects (as a difference from the control) of applied combinations of mineral and organic fertilisation on the occurrence of the frit fly (*Oscinella frit* L.)

damage caused by the frit fly. The significantly highest percentage of plants damaged by larvae of this pest was recorded on maize fertilised only with potassium and phosphorus with potassium. In turn, the lowest percentage of plants damaged by frit fly larvae was recorded for maize fertilised with nitrogen and potassium (Table 3). Mean air temperature in the period from sowing to the BBCH phase (15–16), in which the frit fly pest damaged maize plants, amounted to 12.5°C (2009) and 13.9°C (2010), while in 2011 it was 14.8°C. The year 2009, in which the occurrence of the frit fly was recorded, was characterised by a cool spring in comparison with the other two years of the study. This may also explain the occurrence of this pest on maize stand only in 2009. The results indicated a significant effect of weather conditions in the years of the analyses ($F_{2,105}$ = 126.38, P < 0.001) on the amount of damage caused by *P. nubilalis* (Table 4 and Figure 3). On average for the years of the study the amount of damage caused by caterpillars of this insect, irrespective of the individual fertilisation variants, amounted to 1.22% (2009), 7.41% (2010), and 2.45% (2011) (Table 4). The greatest damage to maize plants by the European maize borer in 2010 was promoted by the considerable amount of precipitation (in the vegetation season 500.7 mm, at mean air temperature 14.5°C) (Figure 1). In contrast, on average for the years of the study no significant effect was shown for any of the tested combinations of mineral and organic fertilisation ($F_{11,105}$ = 1.37, P = 0.199) on the percentage of damage caused by caterpillars of *P. nubilalis* (Table 4). Moreover, the year × fertiliser combinations interaction did not determine the value of the observed trait ($F_{22,105}$ = 1.23, P = 0.236). This study showed a significant effect of weather conditions ($F_{2,105}$ = 42.40, P < 0.001), varying between the years of the study, on the rate of maize plant infestation by *Fusarium* ssp. fungi

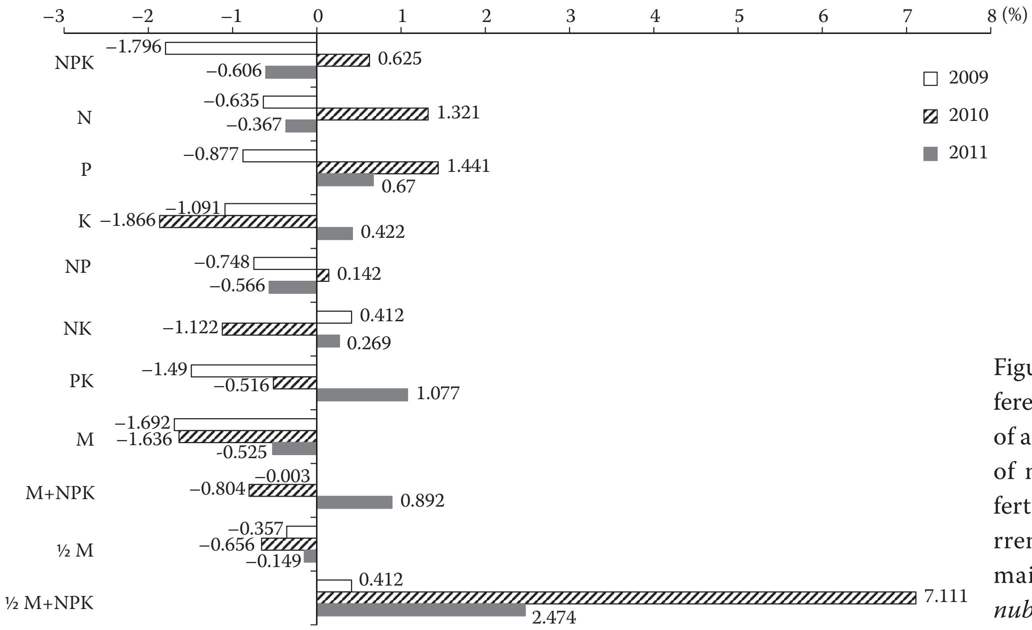

Figure 3. Effects (as a difference from the control) of applied combinations of mineral and organic fertilisation on the occurrence of the European maize borer (*Pyrausta nubilalis* Hbn.)

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Table 4. Mean values and standard deviations (SD) for the infestation of maize by *P. nubilalis*

Combinations	2009			2010			2011			Mean for years		
	mean (%)	°Bliss		mean (%)	°Bliss		mean (%)	°Bliss		mean (%)	°Bliss	
		mean	SD		mean	SD		mean	SD		mean	SD
Control	0.41	0.05^{cd}	0.05	7.11	0.26^{a}	0.07	2.47	0.15^{ab}	0.04	3.33	0.15^{a}	0.10
NPK	1.80	0.12^{abc}	0.08	7.64	0.27^{a}	0.09	3.30	0.18^{a}	0.03	4.25	0.19^{a}	0.09
N	2.21	0.15^{a}	0.04	6.49	0.25^{a}	0.08	3.08	0.17^{ab}	0.02	3.93	0.19^{a}	0.06
P	1.05	0.07^{abcd}	0.08	5.79	0.23^{a}	0.06	2.84	0.17^{ab}	0.03	3.23	0.16^{a}	0.09
K	1.29	0.11^{abc}	0.02	5.67	0.23^{a}	0.06	1.80	0.11^{b}	0.08	2.92	0.15^{a}	0.08
NP	1.50	0.10^{abc}	0.07	8.98	0.30^{a}	0.06	2.05	0.14^{ab}	0.04	4.18	0.18^{a}	0.1
NK	1.16	0.11^{abc}	0.02	6.97	0.26^{a}	0.05	3.04	0.17^{ab}	0.02	3.72	0.18^{a}	0.07
PK	0.00	0.00^{d}	0,00	8.23	0.28^{a}	0.07	2.21	0.14^{ab}	0.05	3.48	0.14^{a}	0.13
M	1.90	0.12^{abc}	0.08	7.63	0.27^{a}	0.04	1.40	0.12^{ab}	0.03	3.64	0.17^{a}	0.09
M+NPK	2.10	0.14^{ab}	0.03	8.75	0.29^{a}	0.06	3.00	0.17^{ab}	0.06	4.62	0.20^{a}	0.08
½M	0.42	0.05^{cd}	0.05	7.92	0.28^{a}	0.06	1.58	0.12^{ab}	0.02	3.30	0.15^{a}	0.11
½M+NPK	0.77	0.06^{bcd}	0.07	7.77	0.27^{a}	0.1	2.62	0.16^{ab}	0.03	3.72	0.16^{a}	0.11
$LSD_{0.05}$		0.08			0.10			0.06			0.08	
Mean	1.22	0.09	0.07	7.41	0.27	0.06	2.45	0.15	0.04			

Means in columns followed by the same letters are not significantly different; M – mineral fertilisation

(Table 5 and Figure 4). On average for the years the rate of infestation was lowest in 2010 (13.5%), which was characterised by the greatest total precipitation amount (Figure 1). In turn, maize with the greatest infestation rates by *Fusarium* ssp. fungi was observed in 2011, characterised by the lowest total precipitation amount during the period of maize growth and development (424.2 mm). On average for the years of the study a significant effect of varied mineral and organic fertilisation ($F_{11,105}$ = 2.78, P = 0.003) was shown on the infestation of maize plants by *Fusarium* ssp. fungi (Table 5). It was shown that only fertilisation of maize with nitrogen as well as fertilisation with nitrogen and phosphorus increased the susceptibility of maize plants to the pressure of this fungus in comparison with the other fertiliser combinations. Results of this study did not indicate any effect of years × fertilisation combinations ($F_{22,105}$ = 0.62, P =

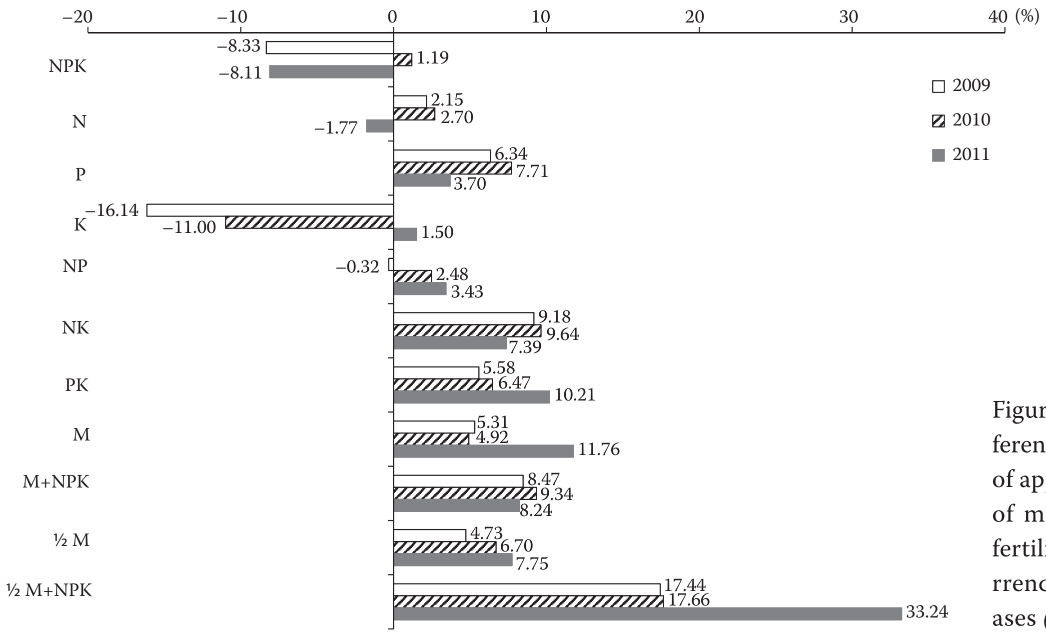

Figure 4. Effects (as a difference from the control) of applied combinations of mineral and organic fertilisation on the occurrence of fusarium diseases (*Fusarium* ssp.)

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Table 5. Mean values and standard deviations (SD) for the infestation of maize by *Fusarium* spp. fungi

Combinations	2009			2010			2011			Mean for years		
	mean (%)	°Bliss		mean (%)	°Bliss		mean (%)	°Bliss		mean (%)	°Bliss	
		mean	SD		mean	SD		mean	SD		mean	SD
Control	17.44	0.35[bc]	0.27	17.66	0.35[ab]	0.28	33.24	0.58[a]	0.04	22.78	0.43[abc]	0.23
NPK	11.37	0.26[c]	0.25	7.91	0.22[b]	0.20	32.95	0.58[a]	0.04	17.41	0.35[c]	0.24
N	25.77	0.49[ab]	0.18	16.47	0.37[ab]	0.19	41.35	0.65[a]	0.04	27.86	0.50[ab]	0.18
P	15.29	0.28[c]	0.33	14.96	0.28[b]	0.33	35.01	0.59[a]	0.08	21.75	0.38[bc]	0.29
K	11.10	0.30[c]	0.18	9.95	0.28[b]	0.16	29.54	0.55[a]	0.05	16.86	0.38[bc]	0.18
NP.	33.58	0.54[a]	0.28	28.66	0.49[a]	0.28	31.74	0.57[a]	0.05	31.33	0.53[a]	0.21
NK	17.76	0.41[abc]	0.11	15.18	0.38[ab]	0.09	29.81	0.55[a]	0.01	20.92	0.45[abc]	0.11
PK	8.26	0.25[c]	0.16	8.02	0.25[b]	0.16	25.85	0.51[a]	0.05	14.04	0.34[c]	0.17
M	11.86	0.32[bc]	0.15	11.19	0.31[b]	0.14	23.03	0.48[a]	0.06	15.36	0.37[bc]	0.14
M+NPK	12.13	0.35[bc]	0.06	12.74	0.35[ab]	0.11	21.48	0.46[a]	0.10	15.45	0.38[bc]	0.10
½M	8.97	0.29[c]	0.10	8.32	0.28[b]	0.10	25.00	0.50[a]	0.04	14.10	0.36[c]	0.13
½M+NPK	12.71	0.35[bc]	0.06	10.96	0.33[ab]	0.06	25.49	0.51[a]	0.04	16.39	0.40[abc]	0.10
$LSD_{0.05}$		0.17			0.17			0.76			0.13	
Mean	15.52	0.35	0.19	13.5	0.32	0.18	29.54	0.54	0.07			

Means in columns followed by the same letters are not significantly different; M – mineral fertilisation

0.898) on the rate of maize infestation by *Fusarium* ssp. fungi. The infestation of maize plants by *Ustilago maydis* Corda was not determined ($F_{1,69}$ = 0.02, P = 0.877) by varied weather conditions in the years of the study (Table 6). In this study this fungus was not observed on maize plants in 2009 (Table 6). That year was characterised by average total precipitation amount (452.3 mm) and average air temperature (15.2°C) in comparison with the other two years of the study. In turn, in 2010 (the highest total precipitation amount, the lowest air temperature) the mean percentage of plants with symptoms of *Ustilago maydis* Corda, irrespective of the fertiliser combination, was highest, amounting to 7.37%, while in 2011 (a dry and hot year) it was 2.39% (Table 6). On average for the years of the study a significant effect of varied mineral and organic fertilisation ($F_{11,69}$ = 4.48, P < 0.001) and the absence of the years × fertilisation combinations interaction ($F_{11,69}$ = 0.41, P = 0.945) was found on the percentage of plants infested by

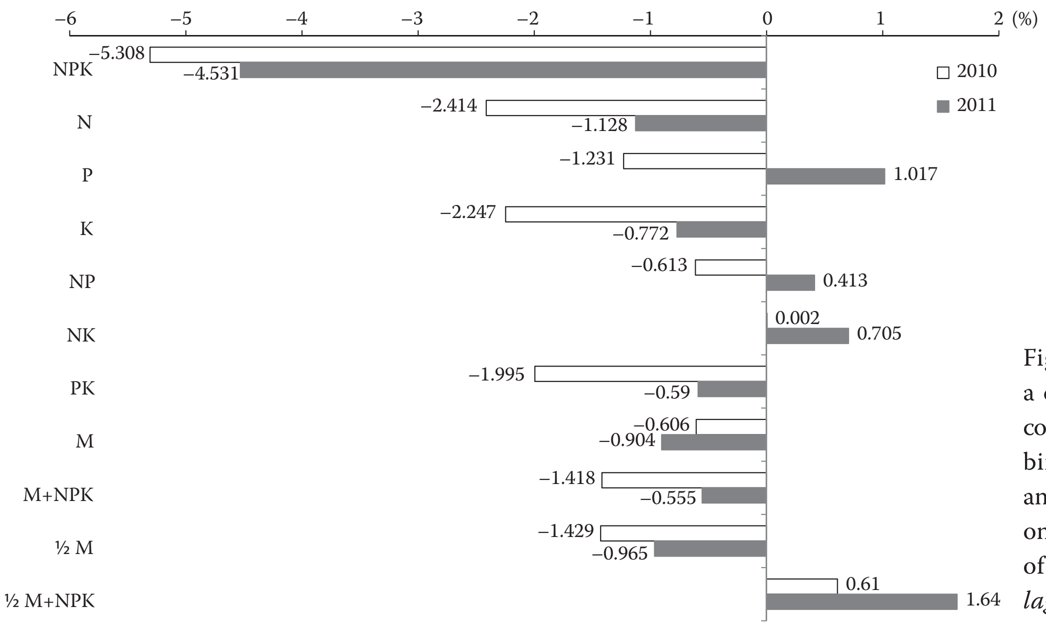

Figure 5. Effects (as a difference from the control) of applied combinations of mineral and organic fertilisation on the occurrence of maize smut (*Ustilago maydis* Corda)

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Table 6. Mean values and standard deviations (SD) for the infestation of maize by *Ustilago maydis* Corda

Combinations	2010			2011			Mean for years		
	mean (%)	°Bliss		mean (%)	°Bliss		mean (%)	°Bliss	
		mean	SD		mean	SD		mean	SD
Control	0.610	0.05^{c}	0.06	1.640	0.11^{ab}	0.08	1.125	0.08^{cd}	0.07
NPK	1.402	0.12^{bc}	0.03	3.355	0.16^{ab}	0.11	2.378	0.14^{bc}	0.08
N	5.918	0.24^{a}	0.03	6.171	0.24^{a}	0.06	6.044	0.24^{a}	0.05
P	3.024	0.17^{ab}	0.06	2.768	0.13^{ab}	0.12	2.896	0.15^{b}	0.09
K	1.841	0.12^{bc}	0.08	0.623	0.06^{b}	0.07	1.232	0.09^{bcd}	0.08
NP	2.857	0.15^{b}	0.08	2.412	0.13^{ab}	0.09	2.635	0.14^{bc}	0.08
NK	1.223	0.09^{bc}	0.07	1.227	0.10^{b}	0.06	1.225	0.09^{bcd}	0.06
PK	0.608	0.05^{c}	0.06	0.935	0.08^{b}	0.06	0.772	0.07^{d}	0.06
M	2.605	0.16^{ab}	0.04	2.230	0.12^{ab}	0.10	2.417	0.14^{bc}	0.07
M+NPK	1.216	0.11^{bc}	0.02	2.544	0.13^{ab}	0.11	1.880	0.12^{bcd}	0.07
½M	2.028	0.13^{bc}	0.05	2.195	0.12^{ab}	0.09	2.111	0.13^{bcd}	0.07
½M+NPK	2.039	0.14^{b}	0.04	2.605	0.13^{ab}	0.11	2.322	0.13^{bcd}	0.08
$LSD_{0.05}$		0.08			0.13			0.06	
Mean	2.114	0.13	0.07	2.392	0.13	0.09			

Means in columns followed by the same letters are not significantly different; M – mineral fertilisation

the fungus *Ustilago maydis* Corda (Table 6). The significantly greatest infestation of maize plants by the fungus *Ustilago maydis* Corda was recorded in the treatment in which only nitrogen was applied (6.04%). In turn, the significantly lowest percentage of plants with symptoms of this disease was observed in the combination with potassium applied alone (0.62%) and potassium applied together with phosphorus (0.93%) (Figure 5).

DISCUSSION

Along with the increasing area of maize cultivation, production intensification, use of numerous simplifications in soil and plant cultivation as well as progressive climate changes, the threat of pests and diseases to maize has increased. According to Bereś (2011) and Bocianowski *et al.* (2016), the occurrence of the frit fly depends closely on weather conditions in early spring. Kruczek (1997) also stated that the wet and cool spring in the initial phases of maize development increases the damage of the plants by *Oscinella frit*, which has also been shown in our own tests. A very good method of the pest control, apart from balanced mineral fertilisation, is the use of chemical mortars, but they are dangerous. By applying formulations that contained imidacloprid, the number of plants damaged by larvae was reduced by 69.6–98.1%, while in the case of the insecticide that contained methiocarb, by 65.1–96.2%. The pre-sowing treatment of maize grain with the studied insecticides also resulted in higher grain yield (Bereś 2011). Currently, the most dangerous pest of maize in Poland is a millet broth European corn borer which in many plantations in the southern part of the country damages 50–80% and locally up to 100% of the crop. European corn borer (*Ostrinia nubilalis* Hbn.) is one of the major pests attacking the maize. Perrenoud (1990) reported that in the control of this pest, next to the application of pesticides, it is also important to prevent losses by the use of appropriate cultivation measures, adherence to sowing dates and the application of optimal and balanced NPK fertiliser rates. Moreover, as it was reported by Ajanga and Hillocks (2000), plants damaged by the European maize borer are more intensively infested by fungal pathogens causing root rot, foot rot, and fusarium head blight. In turn, in their study Bartos and Michalski (2006) showed that an increasing level of nitrogen application resulted in an increased number of maize plants damaged by the European maize borer. In this study no such effect was found for phosphorus fertilisation. Also in the opinion of those authors (Bartos & Michalski 2006) the application of high potassium fertilisation

https://doi.org/10.17221/22/2017-PPS

rates reduced the number of plants damaged by larvae of this pest. However, it needs to be emphasised that a positive effect of potassium on the health condition of maize, manifested in the lesser feeding of the European maize borer, was observed only starting from the rate of 200 kg K_2O/ha, i.e. higher than that applied in this study.

Based on research conducted over the last few years, it is estimated that maize fungi are the cause of a decline in crop yields of up to 30% in some years, as well as deterioration of its quality. Early fungal infestation by fungi and bacteria causes seed loss, as well as significant deterioration in feed value and quality of feed obtained from maize. As the most dangerous are considered diseases caused by the Fusarium fungus, which is the main causal agent of seedling blight, root rot, and root stump gnawing and also flasks fusariosis. Weather conditions have a significant impact both on pathogen incidence and on yield quality. This study showed a significant effect of weather conditions, varying between the years of the study, on the rate of maize plant infestation by *Fusarium* ssp. fungi. The result recorded in this study confirms earlier literature reports indicating that the occurrence of *Fusarium* ssp. fungi is determined by variable environmental conditions in individual vegetation seasons (Dorn *et al.* 2009; Scauflaire *et al.* 2011; Gromadzka *et al.* 2012; Mesterházy *et al.* 2012). As it was reported by Marschner (1995), better plant nutrition with nitrogen contributes to an increase in disease intensity. Tissues of plants strongly fertilised with nitrogen as a result of rapid and intensive growth are spongy and soft and for this reason vulnerable to damage, which promotes penetration by pathogens. In turn, in this study the use of potassium in a given fertiliser combination, the application of manure or combined application of manure with mineral fertilisation caused a greater resistance of maize plants to *Fusarium* ssp. fungi. The above dependence of maize infestation by *Fusarium* ssp. fungi determined by varied mineral and organic fertilisation was recorded in 2009 and 2011. In the opinion of Grzebisz *et al.* (2007), potassium plays a significant role in crops in the development of their resistance to the attack of diseases and pests. According to those authors, an increased susceptibility of plants is recorded in the system in which excess of nitrogen occurs simultaneously with potassium deficit. For this reason resistance of crops to parasite attack does not result from the contents of these nutrients alone, but rather from their mutual relationships. Thus, it may be stated that the better the potassium nutrition of plants in relation to nitrogen, the greater the resistance of these plants to pathogen attack, which was shown in this study. The occurrence of diseases and pests decreases with an increase in plant nutrition with potassium (Bocianowski *et al*. 2016). For this reason it is recommended to apply potassium fertilisers to improve the health condition of crops (Imas & Magen 2000).

The maize smut is a common fungal disease, occurring wherever maize is grown. The disease occurs on the plant in the form of growths on all young, aboveground parts, and above all on the ear and the tassel (Sprague & Dudley 1988). The fungus wintering in the remains of maize crops and in the soil can survive for many years. In addition, the ability to carry fungus spores by the wind and splashes on the surface of the soil with rain drops causes that plant rotation is less important in reducing the disease. Maize smut is a disease commonly found throughout Poland, at its intensity being highly varied in individual years. Drought causing the weakening of plants and considerable mechanical damage, followed by heavy rainfall at high temperatures during the day and considerably lower at night, creates ideal conditions for spore germination and development of the maize smut mycelium. Kruczek (1997) showed that periodical droughts or excessive precipitation as well as a cool spring resulted in an increase in the number of plants infested with this fungus.

Numerous studies conducted on the role of potassium in the development of crop resistance to biotic stresses showed that plants well nourished with potassium are capable of reducing parasite pressure, which at the same time has a significant, positive yield-promoting effect (Marschne 1995; Amtmann *et al.* 2008; Bocianowski *et al.* 2016). The above statement concerning the effect of potassium on the health condition of maize plants was also shown in this study.

CONCLUSIONS

(1) Occurrence of the frit fly was determined mainly by temperature conditions in the initial period of development, i.e. from sowing to the BBCH 15–16 phase, while the percentage of maize plants damaged by the European maize borer depended only on temperature and humidity conditions throughout the entire vegetation period.

(2) The application of ½ manure rate or mineral fertilisation with phosphorus and potassium (PK)

https://doi.org/10.17221/22/2017-PPS

increased the resistance of maize plants to *Fusarium* ssp. fungi. In turn, fertilisation with nitrogen and phosphorus (NP) resulted in the highest percentage of plants damaged by this pathogen.

(3) The lowest percentage of plants with symptoms of infestation by *Ustilago maydis* Corda was found in maize fertilised only with potassium (K), or potassium and phosphorus applied jointly (PK).

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Received: 2017–02–07
Accepted after corrections: 2017–09–09
Published online: 2017–11–06