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THE EFFECT OF WEATHER CONDITIONS ON CORN SMUT INFECTION AND EUROPEAN CORN BORER INFESTATION IN SEVERAL CULTIVARS OF SWEET CORN

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ABSTRACT

The aim of this study was to assess the effect of temperature and precipitation on the occurrence of corn smut and European corn borer on several cultivars of sweet corn. The field experiment was conducted in the years 2010-2012 at the Gorzyn Experimental and Teaching Station, branch in Swadzim, belonging to the Poznan University of Life Sciences. Eight cultivars of sweet corn were analysed in this study. Prior to harvest the number of plants infested with corn smut was determined, while after ear harvest the number of plants damaged by the European corn borer was established. The analysis of variance (α=0.05) and calculations of the correlation coefficient and regression were performed using the Statistica 10 programme. Analyses showed a significant effect of temperature ($p<0.001$) and precipitation ($p<0.05$) on the incidence of corn smut and damage by the European corn borer. In both cases temperature played a considerable role ($r=0.6411$, $r=0.4362$). Weather conditions influenced the occurrence of corn smut to a greater extent than they influenced the damage by the European corn borer. The study showed a significant effect ($p<0.05$) of insect feeding on *Ustilago maydis* Corda. infestation. Synthesis of the three years of experiments indicated significant differences between sweet corn cultivars in the number of plants damaged by European corn borers and infested by corn smut.

Key words: ***Ustilago maydis*, *Ostrinia nubilalis*, *Zea mays*,** infestation, weather conditions.

INTRODUCTION

At present world production of sweet corn (*Zea mays* ssp. *saccharata* Koern.) grain amounts 600,000 ton (Bartczak, 2012). In Europe primary producers of this crop include Hungary and France, while the USA hold the world record, with sweet corn being a national favourite and its annual per capita consumption amounting to approx. 12 kg (Waligóra et al., 2011). The area cropped to sweet corn in Poland has been increasing for the past several years. Both the high interest in this crop and the frequent maize monoculture has posed a threat of spreading diseases and pests (Bereś et al., 2007).

Corn smut (*Ustilago maydis* Corda.) is a common fungal disease, found in all areas where maize is grown (Sprague and Dudley, 1988). Fungal cells, upon penetration to the plant cell at all stages of development are surrounded by the cell membrane of the host plant. Thus they establish strict interaction zones with the plant cells, which provide optimal access to nutrients (Wahl et al., 2010). Corn smut is found on plants as galls on all young aboveground parts of maize plants, first of all ears and panicles. The fungus winters on crop residues and in soil, where it may survive for many years. Moreover, due to the spread of fungal spores by wind and dispersal by rain drops falling on the ground crop, rotation does not bring any major results in the control of this disease (Sprague and Dudley, 1988). Greater intensity of corn smut is observed in hot and humid years (Christensen, 1963), since then this fungal finds excellent conditions promoting its growth and in the vegetation season it may produce several generations of spores (Shurtleff, 1980). The strongest infestation is observed at slight precipitation in the early development phases and at temperatures between 26 and 34°C. Dry weather or cooler, wet days slow down the growth of young plants and thus promote infections (Carr, 1977). The infection rate increases on fields with excessive nitrogen fertilization, at hail damage, winds carrying

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soil or sand particles, at all types of mechanical cultivation measures, spraying, damage by plant bugs or at topping on seed plantations. Many new fodder maize hybrids exhibit certain resistance to corn smut, but none shows complete resistance (Specker, 1993). Few data may be found in literature indicating an increased resistance of sweet corn cultivars to corn smut. On sweet corn plantations losses caused by this disease are greater than on plantations of fodder maize (Christensen, 1963). Corn smut found on fodder maize plantations is not particularly dangerous, as it does not causes poisoning in animals, while in sweet corn ear infestation always leads to yield losses.

The European corn borer (*Ostrinia nubilalis* Hbn.) is a pest causing high economic losses in maize growing (Razze and Mason, 2012). These insect chew tunnels in stalks, which has a negative effect on plant growth and reduces yields. The second generation larvae additionally cause yield losses due to stalk breaking and feeding on ears (Cullen and Wedberg, 2005). The presence of this pest in sweet corn kernels results in condemnation of the entire batch of raw material from processing, while infested ears may not be sold on the fresh vegetable market or used for direct consumption (Waligóra et al., 2008a). At present the European corn borer is found commonly throughout the country, although in greater numbers in warmer regions. On many plantations of grain maize in regions of intensive culture, caterpillars of this moth damage from 50 to 80% and locally even up to 100% plants, causing yield losses amounting to 20-30% and occasionally up to 40% (Lisowicz et al., 2005).

The development of this insect begins in spring, when the temperature exceeds 10°C. Larvae pupate in May and moths appear in June. Warm and dry weather is particularly adverse for larvae. Imagines fly between plants and lay clusters of eggs on them. In that period at lower temperatures they fly at lower height and thus the number of laid eggs is reduced. In contrast, high temperature and low humidity may increase moth mortality (Cullen and Wedberg, 2005).

The aim of the study was to assess the effect of temperature and precipitation on corn smut infection and infestation by the European corn borer on several sweet corn cultivars.

MATERIAL AND METHODS

Field experiment

The field experiment was conducted in the years 2010-2012 at the Department of Agronomy, the Poznan University of Life Sciences, the Gorzyn Experimental and Teaching Station, branch in Swadzim (52°26' N; 16°45' E). The experiments were planned in the random block design in four replications. The field experiment was established on lessive soil, of light loamy sands, deposited in a shallow layer on light loam belonging to the good rye complex. According to the FAO international soil classification (FAO, 1977) the analysed soils are classified to *Phaeozems* or *Mollisols* according to the US soil taxonomy (Soil Survey Staff, 1951). In each year of the study winter wheat was the forecrop. On each experimental plot of $12m^2$ one hundred plants were sown in two rows. Eight sweet corn cultivars: Golda, GSS7158, Overland, Passion, Signet, Sweet Tasty, Sweet Trophy and Tessa, were tested. In each year maize was sown in the 1st decade of May, while ears were harvested in the 1^{st} and 2^{nd} decades of September.

Weather conditions

During plant vegetation, from May to September, weather data were collected daily, including maximum and minimum air temperature using a mercurial thermometer and precipitation using a pluviometer. Based on precipitation and air temperature the Sielianinow index (Bac et al., 1993), also called the water supply index was calculated using the following formula:

$$K = \frac{10 \times P}{t \times l}$$

where: P – total monthly rainfall, t – average temperature of the period, l – number of days of the period.

Table 1. Mean monthly air temperature (°C), total precipitation (mm) and the hydrothermal coefficient according to Sielianinow at the Swadzim Station in the years 2010-2012

Year	Month					The growing season
	May	June	July	August	September	
	Mean monthly air temperature (°C)					
2010	12.2	18.4	22.6	19.2	13.0	17.1
2011	15.5	19.9	18.5	19.5	15.9	17.9
2012	16.3	17.0	20.0	19.8	15.0	17.6
	Total precipitation (mm)					
2010	110.5	43.4	97.5	143.5	69.9	464.8
2011	22.5	66.5	218.7	50.5	28.5	386.7
2012	84.4	118.1	136.2	52.7	28.4	419.8
	Hydrothermal coefficient					
2010	2.9	0.8	1.4	2.4	1.8	1.9
2011	0.5	1.1	3.8	0.8	0.6	1.4
2012	1.7	2.3	2.2	0.9	0.6	1.5

Interpretation of the hydrothermal coefficient: K<0.50 – drought, K=0.51-1.00 – semidrought, K=1.01-2.00 – good moisture content, K>2.01 – excessive moisture content.

Table 1 presents weather data from the years 2010-2012 in Swadzim Station.

Assessment of occurrence of European corn borer and corn smut

Shortly before ear harvest (BBCH 70) plants infected with corn smut were counted in each experimental plot and next the percentage of infested plants was calculated. After ear harvest (BBCH 75) the number of plants damaged by the European corn borer was determined and the results were expressed as the percentage of damaged plants. The only criterion was for plants to be affected by the pest and the disease, while the degree of damage was not evaluated.

Statistical analysis

Statistical analysis was conducted using the *STATISTICA 10* programme. The assumption of a normal distribution for the recorded values was verified with the Shapiro-Wilk test (Shapiro and Wilk, 1965). Homogeneity of variance was tested using the method proposed by Brown and Forsythe (Brown and Forsythe, 1974). Analysis of variance (α=0.05) for the principal effects from the three years of the study was performed for plants damaged by the European corn borer. The two-way analysis of variance (α=0.05) was performed based on the synthesis from the three years of the study for the Bliss angular degrees for plants infested by corn smut. Next the correlation coefficient was calculated and the regression equation was used to determine the dependence between the occurrence of corn smut and damage caused by the European corn borer. Based on data concerning temperature and precipitation the correlation coefficient and regression equations were calculated for the number of plants damaged by the European corn borer and infested with corn smut.

RESULTS AND DISCUSSION

The highest percentage of plants infested by *Ustilago maydis* Corda. was recorded in 2011 (Table 2). That year, during the period of plant vegetation, was characterised by a high mean temperature (17.86°C) (Table 1). Precipitation total from May to September (386.7 mm) was lower than in 2010 and 2012. However, in July 2011 considerable amounts of precipitation were recorded (218.7 mm) and the hydrothermal index according to

Sielianinow in that month indicated excessive moisture content. Zeberca and Borcean (2011) observed that *Ustilago maydis* Corda. is detected in larger amounts in the years with temperatures in July and August exceeding the average. They stated that temperature plays a more important role than precipitation in the development of the fungus.

Table 2. Percentages of plants infested by corn smut for eight sweet corn cultivars in the years 2010-2012

Cultivar	Percentages of plants infested			
	2010	2011	2012	Average
Golda	1.38	11.33	2.88	5.19 (a, b)
GSS 7158	2.88	5.90	5.50	4.76 (b)
Overland	0.33	1.88	4.95	2.38 (d)
Passion	0.88	3.20	4.50	2.86 (c)
Signet	8.40	6.60	3.15	6.05 (a,b)
Sweet Tasty	9.15	6.48	3.50	6.38 (a)
Sweet Trophy	7.08	11.95	2.70	7.24 (a)
Tessa	0.50	8.95	3.33	4.26 (c)
Average	3.82	7.03	3.81	4.89

a, b, c, d – averages followed by the same letter are not significantly different at $p<0.05$

A high percentage of plants damaged by *Ostrinia nubilalis* Hbn. were recorded in 2010 and 2012 (Table 3). In those years mean temperature during the vegetation period was not high, although precipitation was considerable (464.8 and 419.8 mm). May in the successive years turned out to be an extremely wet month, as precipitation totals were 110.5 and 84.4 mm. According to Lisowicz (2004), the European corn borer is found in regions with a warm climate. Mortality rate of *Ostrinia nubilalis* Hbn. at the egg stage is higher at humidity of 35-55%, while it is lower at 75% humidity. Droughts may lead to high mortality rates at the stage of both eggs and larvae (Dennis, 1988).

Table 3. Percentages of plants damaged by the European corn borer and for eight sweet corn cultivars in the years 2010-2012

Cultivar	Percentages of plants infested			
	2010	2011	2012	Average
Golda	7.15	5.13	2.68	4.98 (b, c)
GSS 7158	5.30	1.80	8.23	5.11 (b)
Overland	1.93	4.25	3.60	3.26 (c)
Passion	2.28	3.38	5.48	3.71 (c)
Signet	8.65	3.88	6.93	6.48 (a)
Sweet Tasty	8.40	4.20	7.83	6.81 (a)
Sweet Trophy	9.83	2.95	3.78	5.52 (b)
Tessa	1.50	0.50	1.53	1.18 (d)
Average	5.63	3.26	5.00	4.63

a, b, c, d – averages followed by the same letter are not significantly different at $P<0.05$.

Results of observations concerning plant infestation by corn smut and damage by the European corn borer as related to weather conditions are presented in Figures 1, 2, 3 and 4. After the calculation of the correlation coefficient and regression equation it was found that, both in the case of corn smut and the European corn borer, the dependence on weather conditions was significant ($P<0.001$, $P<0.05$).

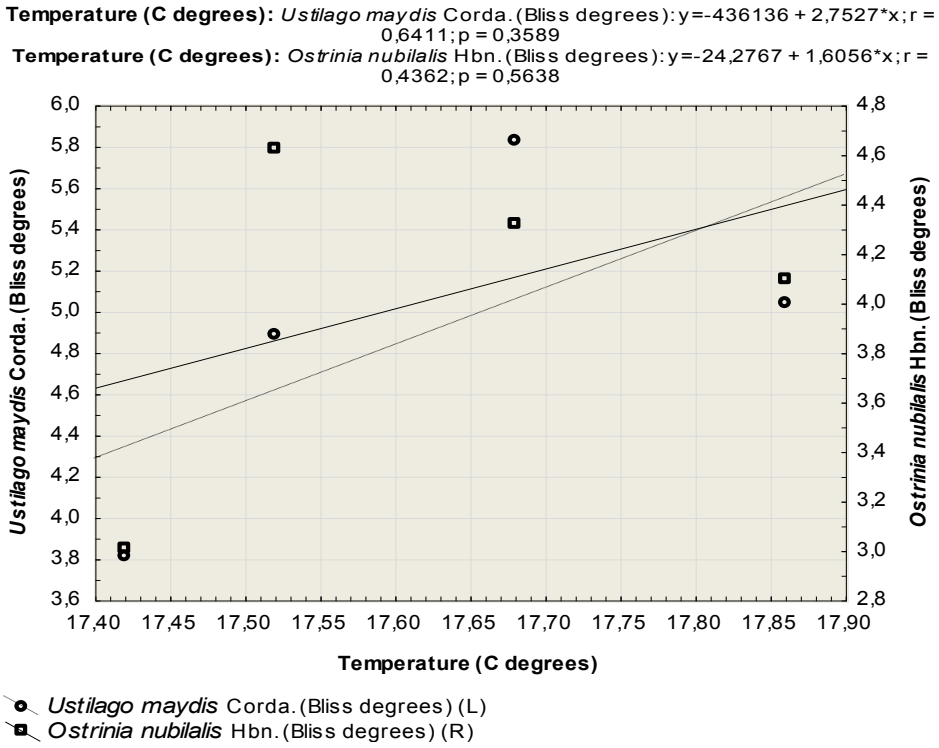


Figure 1. The effect of temperature (°C) on the occurrence of corn smut and the European corn borer on sweet corn

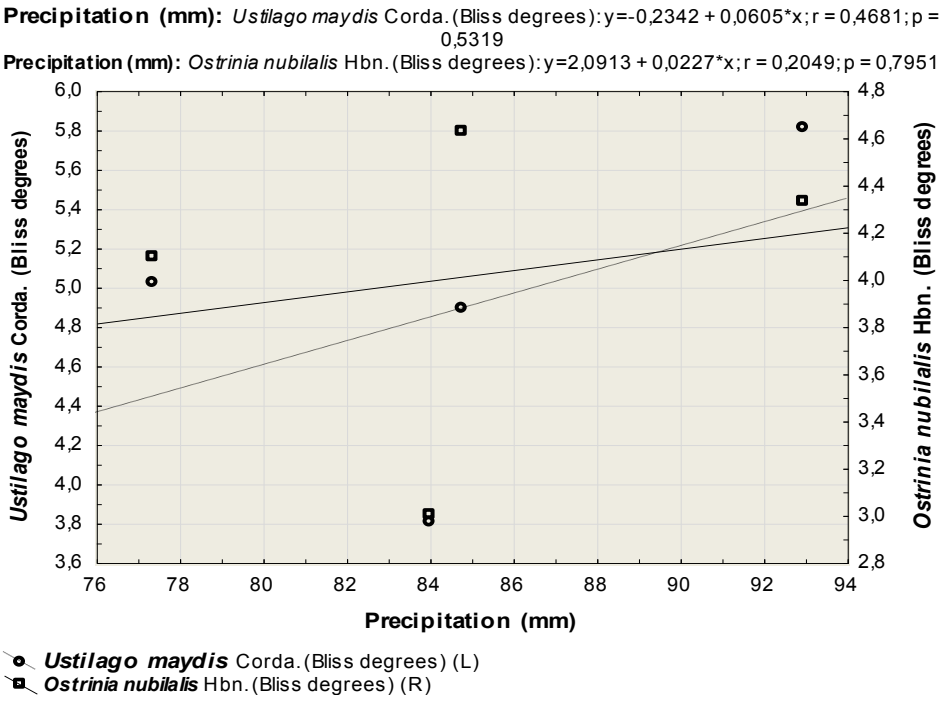


Figure 2. The effect of precipitation (mm) on the occurrence of corn smut and the European corn borer on sweet corn

Incidence of the disease and infestation by the pest were directly proportional to air temperature (r=0.6411, r=0.4362) and precipitation (r=0.4681, r=0.2049).

It results from the calculated correlation coefficient and regression equation describing the dependence between weather factors and the incidence of disease that this

relationship was higher than in the case of feeding by the European corn borer. In another experiment on sweet corn Waligóra et al. (2008a) stated that the extent of infestation by corn smut was closely correlated with the weather conditions. A higher number of infested plants were recorded in the warmest and wet year. Zeberca and Borcean (2011) confirmed the significant effect of weather conditions on the incidence of this disease. Infestation of maize plants was higher in the year in which precipitation total was lower. However, in summer months alone, particularly July, precipitation levels exceeded the average.

This type of weather conditions was more conducive of *Ustilago maydis* Corda infestation. Onstad (1988), in an attempt to create a model determining the population size of *Ostrinia nubilalis* Hbn. stated that, apart from natural enemies and the photoperiod, air temperature is the most important environmental factor.

Results presented by that author confirm those recorded in this study. In the case of temperature the correlation coefficient was r = 0.4362, while for precipitation it was lower, amounting to r = 0.2049 (Figures 1 and 2). Similar conclusions were drawn by Stanley (1983), who observed that temperature during the development of the pest is the most important factor determining growth of larvae as well as their size and viability.

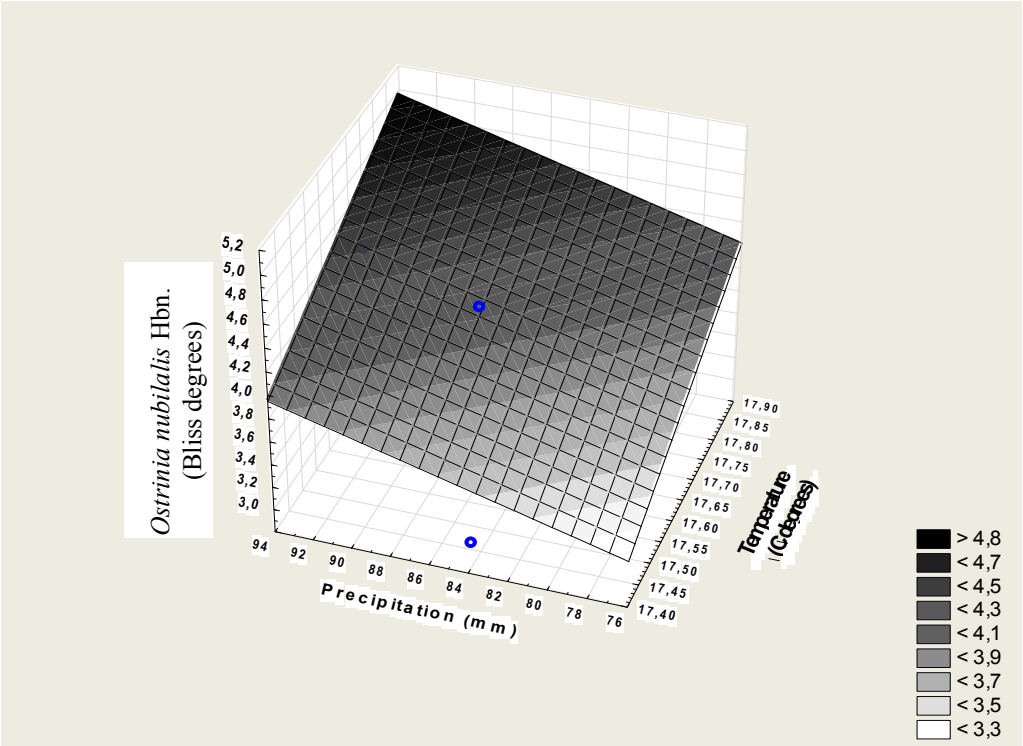


Figure 3. The effect of temperature (°C) and precipitation (mm) on the occurrence of European corn borer on sweet corn

Young larvae of *Ostrinia nubilalis* Hbn. initially feed on pollen, next they begin feeding on panicles, ear inceptions and stigmas. Upon reaching the third developmental stage caterpillars bite into stalks and ears, where they feed on the pith and soft kernels. In September caterpillars leave their feeding site and bite into the base of stalks, where they overwinter (Bereś, 2007). European corn borers, by causing mechanical damage in plant tissues, contribute to easier penetration of fungal pathogens and lead to secondary infections (Bohn et al., 1999).

The greatest number of plants damaged by the European corn borer in the three years of the study was recorded for cv. Sweet Tasty (6.81%) and Signet (6.48%) (Table 3). Also in the case of those cultivars a significantly high infestation rate by corn smut was observed (14.29 and 13.81%) (Table 2).

The lowest number of damaged plants was found in cv. Tessa (4.73%). One of the lowest infestation rates with corn smut (9.86%) was also recorded in that cultivar. Upon calculation of the correlation coefficients and regression equations a significant effect of plant damage by the European corn borer on the incidence of corn smut was determined ($P<0.05$). The correlation coefficient in that case was 0.3567 and it indicated a directly proportional dependence of infestation on damage by the European corn borer (Figure 5).

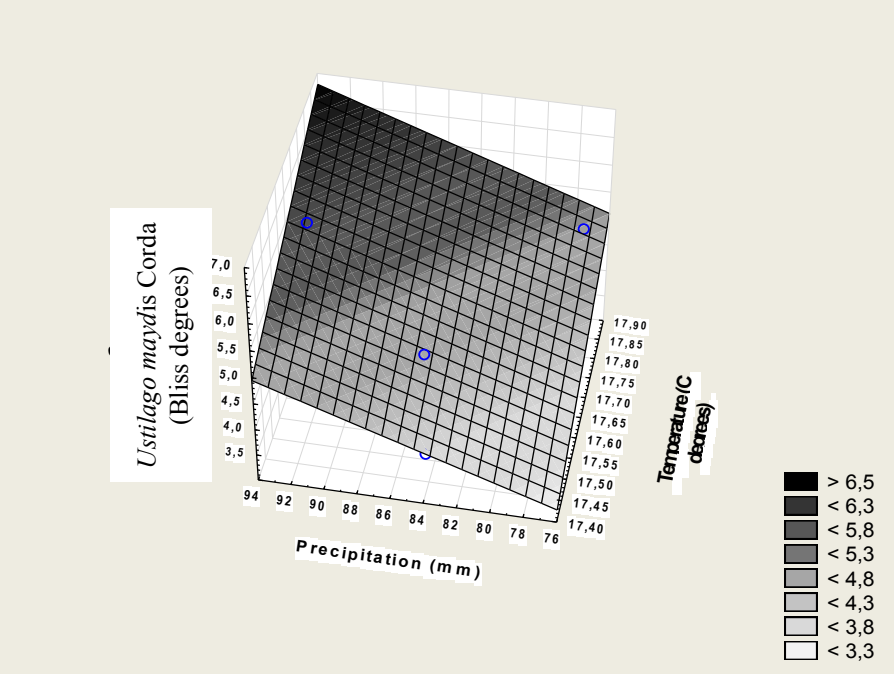


Figure 4. The effect of temperature (°C) and precipitation (mm) on the occurrence of corn smut on sweet corn

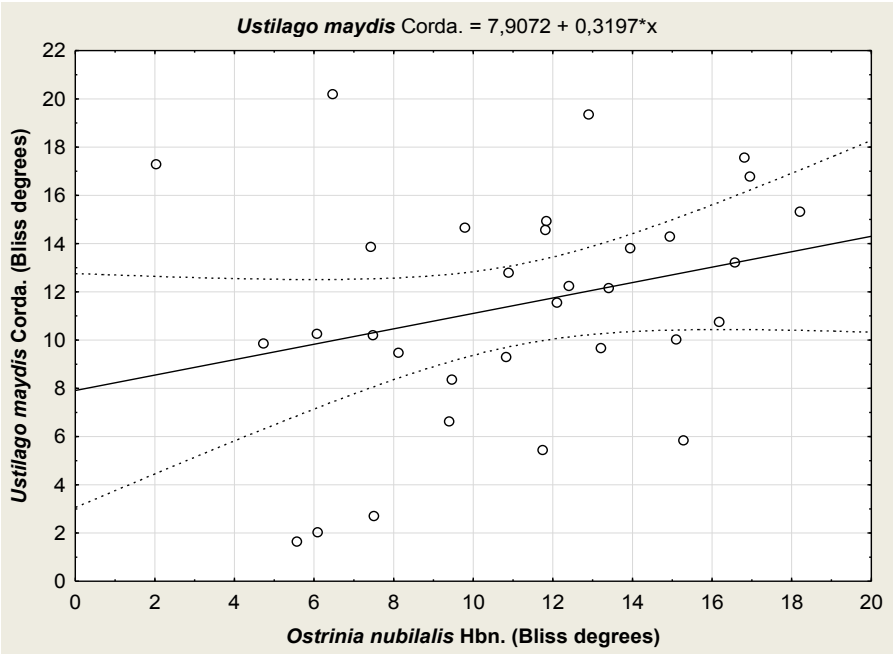
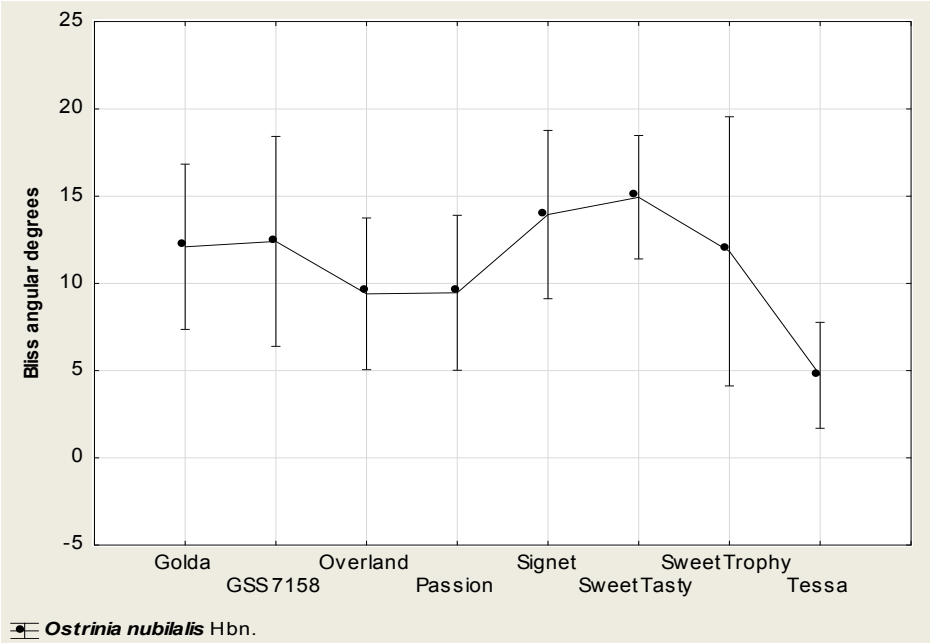
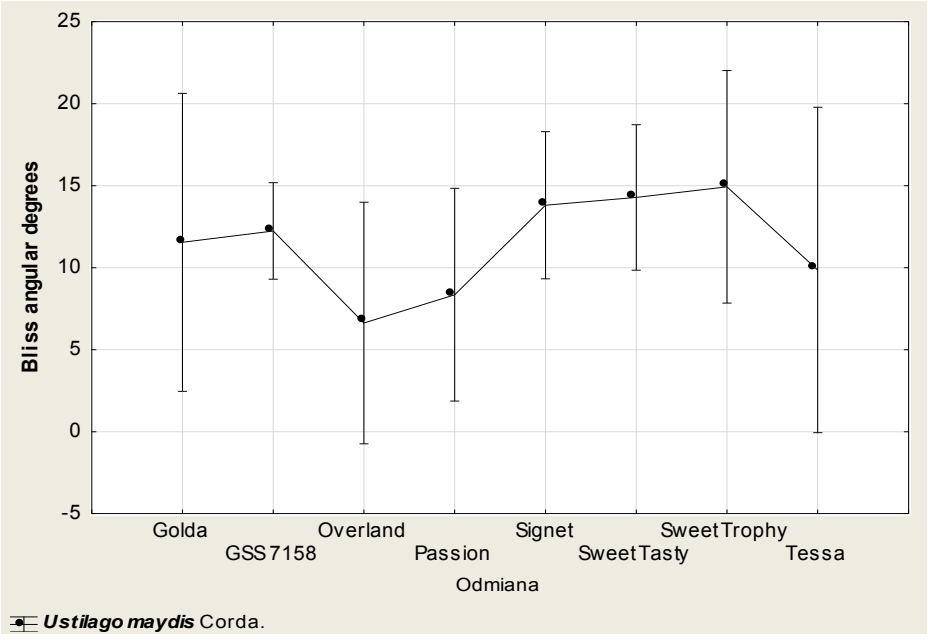


Figure 5. The effect of damage caused by the European corn borer on the incidence of corn smut, synthesis of three years of analyses (2010-2012)

According to Szoke et al. (2002) and Sobek and Munkvold (1999), secondary damage is a major danger posed by the European corn borer infestation. Fungal pathogens penetrate the plant tissue through holes bit by the pest and they infect maize plants. The occurrence of fungal infection may be limited e.g. by growing of cultivars resistant to *Ostrinia nubilalis* Hbn. (Sobiech et al., 2011). Tables 2 and 3, as well as Figures 6-7, present results of a synthesis from the three years of analyses, concerning plant damage and infestation rates depending on the cultivar. Results of the analysis of variance indicate significant differences between cultivars ($P<0.05$).





Figures 6-7. Plants damaged by *Ostrinia nubilalis* Hbn. and infested by *Ustilago maydis* Corda. in sweet corn cultivars, synthesis from the three years of the study 2010-2012

In the three years of the study the highest number of plants damaged by larvae of the European corn borer was recorded for cv. Sweet Tasty and Signet (over 6.48%), while high numbers were found in cv. GSS 7158, Golda and Sweet Trophy (over 4.98%).

In this study cv. Tessa was least susceptible to damage caused by this pest (1.18%). Results of previous analyses conducted e.g. by Lisowicz (2004) indicated that the percentage of damaged plants of grain maize was correlated with earliness of a given cultivar. That author reported than the earlier a cultivar; the less damage by the European corn borer was recorded. This is related with rapid plant maturation and tissue hardening, which hinders caterpillar feeding on plants and reduces its duration, as a consequence of which a portion of the pest population does not reach full development. In this study the highest number of plants infested by corn smut was found in cv. Sweet Trophy, Sweet Tasty, Signet and Golda (over 5.19%). Cultivar Overland turned out to be least susceptible (2.38%). Cultivars of medium sensitivity include Golda, Tessa and Passion. Results of the previously presented studies, conducted e.g. by Waligóra and Sulewska (1997), indicated that the percentage of infested sweet corn plants was influenced by the cultivar, i.e. its resistance and earliness. This is related with rapid plant maturation and tissue hardening, which hinders tissue infestation (Waligóra et al., 2008b).

CONCLUSIONS

Changes in temperature in the vegetation period of sweet corn had a significant effect on the number of plants damaged by the European corn borer and infestation by corn smut. Temperature determined to a greater extent infestation by corn smut than pest feeding. Precipitation over the entire vegetation period of plants had a proportional effect on feeding by the European corn borer and on the incidence of corn smut, although this effect was weaker than in the case of temperature. The number of plants damaged by the European corn borer was to a lesser degree determined by precipitation than the number of plants infested by corn smut.

Plant damage caused by the European corn borer had a significant effect on the incidence of corn smut and the calculated correlation coefficient indicated a proportional dependence.

There were significant differences between cultivars in the numbers of plants damaged by the European corn borer. The highest number of damaged plants was recorded for cv. Sweet Tasty and Signet, while it was lowest in cv. Tessa.

Cultivars differed significantly in terms of the numbers of plants infested by corn smut. The highest number of infested plants was found in cv. Sweet Trophy, Sweet Tasty, Signet and GSS 7158. In contrast, the lowest number of diseased plants was recorded in cv. Overland.

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