



## THE EFFECT OF SELECTED AGROECOLOGICAL FACTORS ON HEALTH OF MAIZE CULTIVARS

Hanna Gołębiewska<sup>1</sup>, Ryszard Weber<sup>2</sup>, Elżbieta Płaskowska<sup>3</sup>

<sup>1</sup> Institute of Soil Science and Plant Cultivation, National Research Institute in Pulawy, Department of Weed Science and Tillage Systems, Poland

<sup>2</sup> Institute of Soil Science and Plant Cultivation, Department of Ecology and Soil Tillage, National Research Institute, Pulawy, Poland

<sup>3</sup> Department of Plant Protection, Wrocław University of Environmental and Life Sciences, Wrocław, Poland

### ABSTRACT

The problem of infestation of maize (*Zea mays*) grain with mycotoxins, in the view of particular agroecological conditions, i.e. simplified tillage, chemical protection against weeds, require continuous and profound research. The aim of the research carried out in 2008–2010 was to determine the effect of weed infestation on the increased occurrence of fungus diseases in two maize cultivars depending on the used simplified tillage systems and determination of the level of mycotoxins in tested grain cultivars. Poor efficiency of the rimsulfuron herbicide, applied in combination with an adjuvant, as well as decreased tolerance of SALGADO cultivar to that chemical compound were the cause of the following disadvantageous phenomena: increased weed infestation with *Echinochloa crus-galli* (L.) P. Beauv., *Chenopodium album* L. and *Artemisia vulgaris* L., more considerable grain infestation with fungi of *F. culmorum* and *F. avenaceum* species, significant decrease in grain yield size and elevated level of deoxynivalenol (2.648 mg·kg<sup>-1</sup>) and zearaleon (0.273 mg·kg<sup>-1</sup>) mycotoxins in grain as compared to the not treated object and to BLASK cultivar, especially in simplified tillage.

**Key words:** simplified tillage, weed infestation, *Fusarium oxysporum*, *F. culmorum*, *F. avenaceum*, deoxynivalenol, nivalenol, zearalenone.

### INTRODUCTION

Due to the significantly lower production costs and continuously increasing degradation of soil environment, simplified systems of tillage have been introduced. Because of the fact that approximately 30% of after – harvest residue remains on the soil surface, these systems do significantly affect alterations in physical and chemical, as well as microbiological properties of soil, as well as on extent of weed infestation [22]. The successive reduction in soil penetration depth by agricultural machines and increase in the content of organic matter and macroelements in upper soil layers, provides for increased biodiversity of agrobiocenoses [8, 21]. Such a dramatic reorganization of soil and the influence the response of maize (*Zea mays* L.) cultivars to the occurrence of the fungi of *Fusarium* species [14]. The threat connected with those pathogens results from the fact that they develop and produce spores on diverse plant material, both on after – harvest residues and thick – stem weeds [3]. On maize plantations, three diseases usually occur, caused by fungi species like – *Fusarium avenaceum*, *F. culmorum*, *F. moniliforme*, *F. graminearum*, involved in root rot of corn seedlings, root – rot of corn cob and stem-base rot of corn [18]. The most considerable harm in maize cultivation, destined for grain crop, is caused by stem-base rot. Affected plants mature too early and often collapse before being harvested, which makes mechanical harvest of cobs impossible. A significant factor in infestation by that pathogen is the choice of cultivar. Early maturing cultivars (FAO 190–240 class) are more disease prone than the late maturing ones (FAO 250–290). The most considerable cob infestation with disease takes place during tassel production, when the temperature ranges from 15 to 20°C and it lasts till the end of April, while prolonged flowering leads to more severe infestation with the fungi causing fusariosis [12].

The fungi of *Fusarium* species produce mycotoxins – secondary metabolites, harmful to humans and animals [1, 2, 19]. The most important products of those fungi decay involve *deoxynivalenol* (DON), zearalenone (ZEA), as well as fumonisins B1 and B2, toxins trichothecenes. They can cause the decrease in daily gain of animals, damage to internal organs, as well as disorders regarding animal fertility [7, 11].

Simplified tillage system lasted many years in corn can bring about considerable danger, namely, diminished yield size and worsening of grain quality, especially when cultivars do not suit habitat and cultivation regime conditions. Thorough analysis of maize hybrid cultivars, at different types of tillage and weeds infestation control in the region of Lower Silesia can contribute to obtaining higher yield size of the examined maize cultivars, as well as higher quality of consumption material. The aim of research was:

1. Determination of resistance of maize hybrid cultivars, cultivated in monoculture, to fungi of *Fusarium* species, according to the tillage system and the degree of weeds infestation.
2. Identification of mycotoxins species and determination of the degree of grain infestation of the examined maize cultivars in relation to the type of tillage and the degree of weeds infestation.

## MATERIALS AND METHODS

Research conducted in the years 2008–2010 involved field and lab experiments. The field experiment was established in four replications, on grey-brown podsolc soil, in five – year monoculture. The experiments were established using the split-split-plot method.

The first – order factor were two tillage variants – ploughing and simplified tillage. The ploughing variant consisted in after – harvest tillage (disc harrow or grubber to the depth of 15 cm + string shaft), basic tillage (ploughing with a plough to the depth of 15 cm + harrow) and pre-sowing tillage (cultivation unit: cultivator + string shaft). The simplified tillage variant consisted of after – harvest tillage (disc harrow or grubber to the depth of 15 cm + string shaft) and pre-sowing tillage (cultivation unit: cultivator + string shaft).

The second – order factor were two medium – early maize hybrid cultivars SALGADO and BLASK (FAO 240–260) destined for grain, medium – susceptible to fungal diseases, recommended for cultivation in the region of south-western Poland.

The third – order factor were different levels of weeds infestation, obtained under the influence of the following herbicides:

1. rimsulfuron applied in the form of Titus 25 WG herbicide used in combination with the adjuvant Trend 90 EC (rimsulfuron = 15 g·dm<sup>3</sup> + ethoxylated isodecyl alcohol (90%) in the dose 60g + 0.1%;
2. the mixtures of mesotrione and nicosulfuron in the form of herbicides Calisto 100 SC + Milagro 040 SC (mesotrione = 80 g·dm<sup>3</sup> + nicosulfuron = 40 g·dm<sup>3</sup>) in the dose 1.0 l + 0.8 l applied once, in three – leaf stage of maize – BBCH 13 (the developmental stages of maize according to BBCH scale);
3. nicosulfuron used as Accent 75 WG herbicide with Trend 90 EC adjuvant (nicosulfuron = 75% + ethoxylated isodecyl alcohol = 90%) in the dose 80g + 0.1% according to divided dose system, i.e. half of the dose in three – leaf stage of BBCH 13 and the second half in five – leaf stage of BBCH 16 maize cultivar.

On experimental plots, the subject of assessment was herbicide phytotoxicity in relation to the examined maize cultivars, covering the description of damages due to the mentioned herbicide, as well as its efficiency, following Reference Standards EPPO No: PP 1/152, PP 1/135, PP 1/181, PP 1/50 (2) [4]. Grain harvest was done in full maturity stage and determination of yield size was counted over 14% moisture.

The grain obtained from herbicide objects underwent fungi isolation using the method by Tempe (1970). From each experimental variant 200 not disinfected caryopses and the ones disinfected with 1% sodium hypochlorite for 10 min. were analyzed. After the incubation period growing fungal colonies were cleaved for the slants with standard medium PDA and their species was determined according to the available monographs [13, 20].

Numerous biological phenomena are of a quantitative character. In order to compare these research results a typical analysis of variance for quantitative variables cannot be applied. The mentioned results can be encumbered with an error originating from transformation of original value (numerical amount of different fungi species) to numbers which are quantitative variables. In biological sciences, the method most often used for testing statistical significance of the effect of different factors on variability of the examined qualitative variable is log – linear analysis. The analysis was presented after Goodman [6]. Any significant deviations, regarding the observed numerical amounts in relation to the expected ones, indicate some dependence (interactions) between the examined variables. After logarithmic transformation of the expected values, the model takes a linear form and its simplest version can be expressed by the formula:

$$\ln(E_{ij}) = M. + \lambda_i^X + \lambda_j^Y + \lambda_{ij}^{XY}$$

where:

$E_{ij}$  – expected values,

M. – overall average based on equal numerical amount in each cell,

$\lambda_i^X$  – effect of  $i$ th value of X variable;

$\lambda_j^Y$  – effect of jth value of Y variable,

$\lambda_{ij}^{XY}$  – effect of interaction of ith value of X variable and jth value of Y variable.

The assessment of changes in numerical amount of fungi isolates (*F. avenaceum*, *F. culmorum* and *F. oxysporum*) according to other factors of the experiment was based on log – linear analysis.

In maize cultivars grain, the contents of deoxynivalenol, nivalenol and zearalenone were determined. Permissible content of mycotoxins in maize grain intended for food, according to the recommendations by the EU Commission No 576/2006 for deoxynivalenol and nivalenol equals 1.25 mg·kg<sup>-1</sup> and for zearalenone 0.2 mg·kg<sup>-1</sup>. The samples underwent extraction with the use of acetonitrile-water mixture. After centrifugation, the extract the samples were purified by SPE technique, on C18 bed. Nivalenol, deoxynivalenol and zearalenone remains were washed out from the bed with the mixture of ethyl acetate and methanol. The all of the mycotoxins were assayed by HPLC method, with the use of spectrophotometric detector in UV [9].

## RESULTS AND DISCUSSION

### Efficiency of herbicides in two systems of maize cultivation

In growing periods of 2008–2010, in the community of weeds occurring in experimental plots, the dominant species were: barnyard grass (*Echinochloa crus-galli* (L.) P. Beauv.) and white goose – foot (*Chenopodium album* L.), as well as, less numerous occurring, field violet (*Viola arvensis* Murray.), speedwells (*Veronica* ssp.), shepherd's purse (*Capsela bursa pastoris* (L.)), field mayweed (*Anthemis arvensis* L.) and blubottle (*Centaurea cyanus* L.). In tillage system based on ploughing, considerably higher diversity regarding weed species was recorded in comparison to simplified tillage system. In simplified tillage system, apart from dominant *Echinochloa crus-galli* and *Chenopodium album*, perennial weed species occurred in considerable numbers, like common wormwood (*Artemisia vulgaris* L.). On that soil stand chemical weed control, which involved rimsulfuron and nicosulfuron applied once, in divided doses occurred to be not efficient. Complete resistance to herbicides featured common wormwood, while application of mesotrione and nicosulfuron mixture turned out to be the most advantageous in eliminating barnyard grass and dicotyledon weeds in each system of tillage

The effects of selected herbicide variants in the experiments conducted in different tillage systems proved the possibility of efficient reduction in weeds infestation (Fig. 1, 2). There were not reported any differences in weeds infestation between maize cultivars in particular systems of tillage. The analysis of variance proved significant influence of simplified tillage methods on the efficiency of weed control and diversified effect of herbicides in the years of the research.

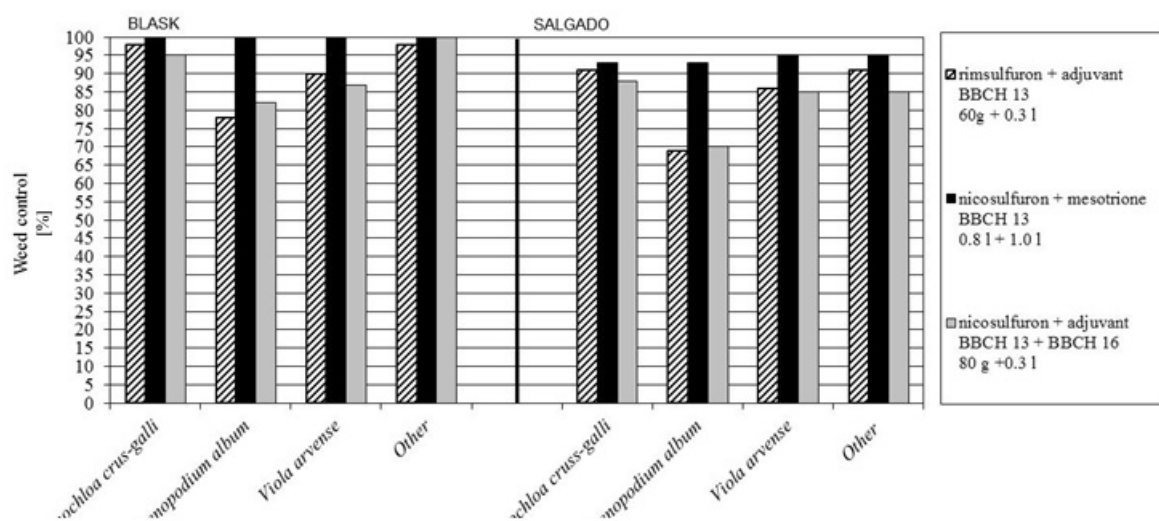


Fig. 1. Influence of herbicides on weed infestation state of maize cultivars in ploughing tillage conditions

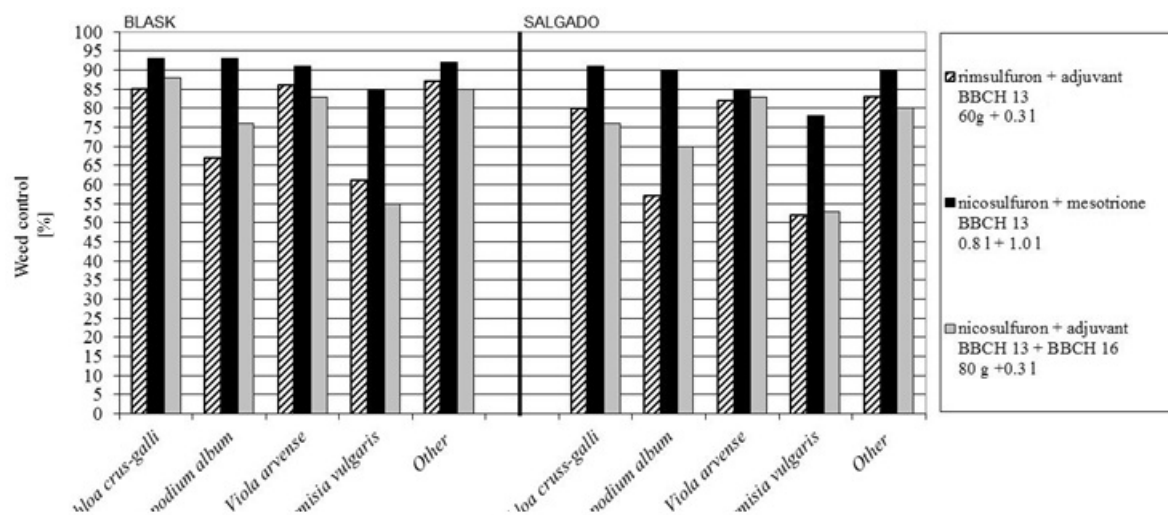


Fig. 2. Influence of herbicides on weed infestation state of maize cultivars in simplified tillage conditions

Among the cultivars selected for the experiments only SALGADO responded with lower tolerance to rimsulfuron introduced together with Trend 90 EC adjuvant, which was expressed by transient leaf blight of maize and slight deformations of plants. The latter ones showed the tendency to deepen in simplified tillage system.

### Effect of tillage variants and herbicides on grain yield of maize cultivars in 2008–2010 years

The weather conditions in the years 2008–2010 were beneficial for maize cultivation. The sums of effective temperatures, as well as even soil moisture in each growing period allowed to obtain full maturity of grain featuring average moisture 23% in the turn of September and October (Tab. 1).

Table 1. Weather conditions in vegetation seasons of maize in 2008–2010 based on means effective temperature (ET\*) and precipitations

Years	Sum temperatures and rainfall from V–X		Month							
	ET* [°C]	Precipitation [mm]		IV	V	VI	VII	VIII	IX	X
2008	2074.9	411.7	[°C]	225	238.5	399.5	391.2	422.5	264.0	134.2
			[mm]	62.2	48.5	35.3	39.3	147.6	34.5	44.3
2009	1980.8	320.6	[°C]	285.3	377.5	269.5	322.0	310.5	218.0	188.0
			[mm]	23.2	28.8	134.4	29.2	50.8	15.4	38.8
2010	2219.2	364.3	[°C]	278.6	269.5	415.0	443.5	467.5	204.0	141.1
			[mm]	35.0	153.7	52.3	4.8	106.2	8.3	4.0

\* ET =  $0.5 \times (\text{temp. max.} + \text{temp. min.}) - 6^{\circ}\text{C}$

In growing period 2010, characterizing the most beneficial conditions for maize development, the highest grain yield for the examined cultivars was obtained, both in the simplified tillage system and in the ploughing one. In the remaining years the yield of investigated maize cultivars was lower in both tillage systems.

The analysis of variance showed high diversity of cultivars yields according to the years of the research, tillage systems and herbicides applied. Considering the values of root mean squares for years, tillage, cultivars and herbicides, it is possible to state that weather conditions and tillage systems contributed, to the highest degree, to yield diversity in the examined maize cultivars (Tab. 1). Significant interaction between tillage systems and cultivars proves different reaction of cultivars to simplifications in tillage systems. Yet interaction between tillage systems and diversified variants of weed control confirms different effect of active substances on the examined herbicides according to the soil and climate environment. The interactions between the years of research and herbicides require a special attention. These values indicate a significant influence of climatic conditions on yield diversity in the analyzed tillage systems. On the other hand, the significance of interaction between the years and herbicides proves diversified effect of active substances according to weather conditions.

Maize hybrid cultivars featuring similar qualities, selected for the experiment, did considerably differ in the level of yielding, regardless the type of applied tillage system or herbicides. In each case BLASK cultivar proved to yield significantly higher than SALGADO cultivar (Tab. 2). Herbicides used in the experiment efficiently reduces weeds infestation in each tillage system as compared to the object not treated. The highest weed control efficiency was obtained after application of mesotrione and nicosulfuron mixture in ploughing system, which resulted in the highest grain yield size for BLASK cultivar ( $10.97 \text{ t}\cdot\text{ha}^{-1}$ ). The lowest grain yield figures ( $8.04 \text{ t}\cdot\text{ha}^{-1}$ ) were obtained when rimsulfuron with the adjuvant was introduced in simplified tillage system, for SALGADO cultivar (Tab. 3).

Table 2. Influence of herbicides on grain yield of maize varieties

	Grain of yield [ $\text{t}\cdot\text{ha}^{-1}$ ]	
--	--	--

Varieties/Herbicides	Untreated	rimsulfuron + adjuvant BBCH 13 60 g + 0.3 l	mesotrione + nicosulfuron BBCH 13 1 l + 0.8 l	nicosulfuron + adjuvant BBCH 13 + BBCH 16 80 g + 0.3 l	Average for varieties
BLASK	6.56	10.04	10.97	10.11	9.40
SALGADO	5.90	8.04	8.96	8.21	7.80
Average for herbicides	6.20	9.00	10.00	9.20	8.60
LSD (0.05) herbicides = 0.804					
LSD (0.05) varieties = 1.112					
LSD (0.05) herbicides x varieties = 0.931					

**Table 3. Influence of tillage variants of grain yield of maize varieties**

Tillage variants /Varieties	Grain of yield [t·ha <sup>-1</sup> ]		Average for tillage variants
	BLASK	SALGADO	
Ploughing tillage	11.75	8.60	10.21
Simplified tillage	7.12	7.00	7.06
Average for varieties	9.40	7.80	8.60
LSD (0.05) varieties = 1.112			
LSD (0.05) tillage variants = 1.332			
LSD (0.05) varieties x tillage variants = 1.465			

Regardless the herbicide or maize cultivar applied, the highest yields had always been obtained for the ploughing system (Tab. 4, 5).

**Table 4. Influence of tillage variants of grain yield of maize varieties treated herbicides**

Tillage/Herbicides	Grain of yield [t·ha <sup>-1</sup> ]				Average for tillage variants
	Untreated	rimsulfuron + adjuvant BBCH 13 60 g + 0.3 l	mesotrione + nicosulfuron BBCH 13 1 l + 0.8 l	nicosulfuron + adjuvant BBCH 13 + BBCH 16 80 g + 0.3 l	
Ploughing tillage	6.61	10.86	12.25	11.25	10.21
Simplified tillage	5.84	7.12	7.80	7.06	7.06
Average for herbicides	6.20	9.00	10.00	9.20	8.60
LSD (0.05) herbicides = 0.804					
LSD (0.05) tillage variants = 1.332					
LSD (0.05) herbicides x tillage variants = 2.047					

**Table 5. Analysis of variance variability of yielding maize cultivars depending on the tillage and herbicide**

Source of variation	Number of degrees of freedom	The mean square	Level of significance
Years	2	28.75	< 0.0001
Tillages	1	25.186	< 0.0001
Years × Tillages	2	0.075	0.0108
Error	6	0.009	—
Cultivars	1	9.675	< 0.0001
Years × cultivars	2	0.136	0.1084
Tillages × cultivars	1	3.085	< 0.0001
Years × tillages × cultivars	2	0.591	0.0025
Error	12	0.050	—
Herbicides	3	19.174	< 0.0001
Years × herbicides	6	0.582	< 0.0001
tillages × herbicides	3	2.345	< 0.0001
Years × tillages × herbicides	6	0.093	0.3772
cultivars × herbicides	3	0.317	0.0152
Years × cultivars × herbicides	6	0.290	0.0053

Tillages × cultivars × herbicides	3	0.439	0.0034
Error	72	0.085	–

Analyses of optimal statistic model, determining the effect of cultivars, tillage systems, herbicides and grain fumigation on numerical amount of three fungi species from *Fusarium* genus was performed by calculating test  $\chi^2$  value for the main effects and particular interactions between the examined factors. Calculated statistics for the model with interactions of the second, third and the fourth order featured considerable values and, therefore, the hypothesis on the lack of relation between the number of isolates of *Fusarium* fungi and maize cultivar should be rejected at  $p < 0,01$  level. Incorporating the interactions of the third and the fourth order to the analyzed model improves its fitting, which can be proved by significant values of  $\chi^2$  test. The evaluation of significance of main effects and interactions between particular experimental factors is shown in Table 5. Partial correlations in the analyzed model simultaneously take into account the remaining interactions, while boundary correlations evaluate the significance of the examined factors in the case of the absence of the other two – factorial interactions. The analysis proved high diversity of numerical amount of *F. culmorum*, *F. avenaceum* and *F. oxysporum* on wheat caryopsis according to the other parameters of the experiment. Significantly higher intensity of the population of the analyzed fungi species in comparison to the method of conventional tillage was proved in the conditions of simplified tillage (Tab. 6–9). The analyzed cultivars did not statistically differ in total number of fungi isolates on wheat caryopsis. Moreover, considerably smaller numerical amounts of *Fusarium* fungi, colonizing wheat grain fumigation with sodium hypochlorite than in the samples collected directly from the field, were recorded. Significant interaction between cultivars and herbicides is also worth noticing. The size of this interaction proves significantly different numerical amounts of fungi in the conditions of particular herbicide variant on the grain of Blask and Salgado cultivars. The latter ones characterized increased fungi population on control object as compared to herbicide variants. On the objects with Blask cultivar, in zero – tillage system, it was possible to prove significantly higher numerical amounts of *Fusarium* fungi in the conditions of warunkach nicosulfuron + adjuvant treatment. The examined maize cultivars also showed different resistance to grain infestation with fungi species *F. culmorum*, *F. avenaceum* i *F. oxysporum*, which was confirmed by significant interaction between cultivars and the investigated fungi species. Świadczy o tym istotna interakcja odmian i badanych gatunkami grzybów (Tab. 6–9).

**Table 6. Influence of herbicides on helthiness of the cultivar BLASK in ploughing tillage conditions**

Herbicides	Term of application	Dose [ha]	The number of fungal isolates in the grain contaminated				The number of fungal isolates in the grain decontaminated				The content of mycotoxins [mg/kg <sup>-1</sup> ]		
			<i>F.avenaceum</i>	<i>F.culmorum</i>	<i>F.oxysporum</i>	In total	<i>F.avenaceum</i>	<i>F.culmorum</i>	<i>F.oxysporum</i>	In total	DON	NIV	ZEA
Untreated	–	–	9	22	5	36	4	22	3	29	n.w.	n.w.	n.w.
rimsulfuron + adjuvant	BBCH 13	60 g + 0.3 l	26	6	8	40	28	2	3	33	n.w.	n.w.	n.w.
nicosulfuron + mesotrione	BBCH 13	0.8 l + 1.0 l	17	20	3	40	15	14	0	29	n.w.	n.w.	n.w.
nicosulfuron + adjuvant	BBCH 13 + BBCH 16	80 g + 0.3 l	12	14	2	28	10	9	0	19	n.w.	n.w.	n.w.
Sum			64	62	18	144	57	47	6	110			

**Table 7. Influence of herbicides on helthiness of the cultivar BLASK in reduced tillage conditions**

Herbicides	Term of application	Dose [ha]	The number of fungal isolates in the grain contaminated				The number of fungal isolates in the grain decontaminated				The content of mycotoxins [mg/kg <sup>-1</sup> ]		
			<i>F.avenaceum</i>	<i>F.culmorum</i>	<i>F.oxysporum</i>	In total	<i>F.avenaceum</i>	<i>F.culmorum</i>	<i>F.oxysporum</i>	In total	DON	NIV	ZEA
Untreated	–	–	33	21	3	57	29	13	2	44	n.w.	n.w.	n.w.
rimsulfuron + adjuvant	BBCH 13	60 g + 0.3 l	26	33	10	69	11	25	4	40	n.w.	n.w.	n.w.
nicosulfuron + mesotrione	BBCH 13	0.8 l + 1.0 l	30	15	2	47	15	11	5	31	n.w.	n.w.	n.w.
nicosulfuron + adjuvant	BBCH 13 + BBCH 16	80 g + 0.3 l	35	29	6	70	32	22	2	56	n.w.	n.w.	n.w.
Sum			124	98	21	243	87	71	13	171			

**Table 8. Influence of herbicides on helthiness of the cultivar SALGADO in ploughing tillage conditions**

Herbicides	Term of application	Dose [ha]	The number of fungal isolates in the grain contaminated				The number of fungal isolates in the grain decontaminated				The content of mycotoxins [mg/kg <sup>-1</sup> ]		
			<i>F.avenaceum</i>	<i>F.culmorum</i>	<i>F.oxysporum</i>	In total	<i>F.avenaceum</i>	<i>F.culmorum</i>	<i>F.oxysporum</i>	In total	DON	NIV	ZEN
Untreated	–	–	28	19	11	58	21	9	3	33	2.812	n.w.	0.450

rimsulfuron + adjuvant	BBCH 13	60 g + 0.3 l	21	21	14	56	15	11	3	29	1.616	0.01	0.329
nicosulfuron + mesotrione	BBCH 13	0.8 l + 1.0 l	17	2	0	19	1	6	8	15	n.w.	n.w.	n.w.
nicosulfuron + adjuvant	BBCH 13 + BBCH 16	80 g + 0.3 l	24	12	10	46	8	9	2	19	0.113	n.w.	0.012
Sum			90	54	35	179	45	35	16	96			

**Table 9. Influence of herbicides on helthiness of the cultivar SALGADO in simplified tillage conditions**

Herbicides	Term of application	Dose [ha]	The number of fungal isolates in the grain contaminated				The number of fungal isolates in the grain decontaminated				The content of mycotoxins [mg/kg <sup>-1</sup> ]		
			<i>F.avenaceum</i>	<i>F.culmorum</i>	<i>F.oxysporum</i>	In total	<i>F.avenaceum</i>	<i>F.culmorum</i>	<i>F.oxysporum</i>	In total	DON	NIV	ZE
Untreated	–	–	34	27	13	74	31	25	3	59	3.052	0.020	0.180
rimsulfuron + adjuvant	BBCH 13	60 g + 0.3 l	27	25	11	63	22	22	7	51	2.648	n.w.	0.273
nicosulfuron + mesotrione	BBCH 13	0.8 l + 1.0 l	17	9	5	31	13	6	8	27	n.w.	n.w.	n.w.
nicosulfuron + adjuvant	BBCH 13 + BBCH 16	80 g + 0.3 l	26	13	10	49	21	9	2	32	0.182	0.01	0.010
Sum			104	74	39	217	87	62	20	169			

On the basis of estimated content of mycotoxins, due to HPLC method, it was possible to detect increased level of deoxyvalenol = 1.616 mg·kg<sup>-1</sup> in ploughing system and 2.648 mg·kg<sup>-1</sup> in simplified tillage system in SALGADO cultivar grain treated with rimsulfuron with adjuvant, both in comparison to control and to the remaining objects protected from weed infestation, as well as increased level of zearalenon = 0.329 mg·kg<sup>-1</sup> in ploughing system and 0.273 mg·kg<sup>-1</sup> in simplified tillage system (Tab. 8, 9).

The health of grain was highly affected by the level of agricultural technology especially plant protection treatment. Application of herbicides through elimination of weeds competition had the advantageous effect on technological value of grain destined for consumption purposes.

However, application of herbicides featuring low selectivity in relation to cultivated maize cultivar, leads to its diminished tolerance to those chemical compounds, not only conditioned genetically, but also by climatic – soil factors [17, 22]. This situation results in damage and deformation of plants and their lodging, difficulties in producing flag leaves, twisting of leaves and delayed occurrence of panicles [5]. In research conducted in the years 2008–2010 strong phytotoxic herbicide effect on cultivated plants was not observed. Transient deformations of plants and slight chlorosis were reported only after application of rimsulfuron with adjuvant mixture in the case of SALGADO cultivar, but without affecting the yield.

Nutritive value of maize is disqualified by decreased weight of a thousand grains, moisture, and infestation by fungi from *Fusarium* species, which proves its health condition [10, 15, 16]. The decrease in volumetric mass of grain in simplified tillage systems can result from the lack of effective protection against many agrophages, as well as increased weed infestation and susceptibility to fungal diseases [5]. The level of maize grain infestation by fungi of *Fusarium* species, depending on the type of tillage system, can be minimized through the choice of cultivars resistant to fungi diseases and, at the same time, it is possible to protect plants against weeds using herbicides which are fully effective in weed control. This will reduce the occurrence of weeds as intermediate host for *Fusarium* fungi and, therefore, influence on plants health, improve grain qualitative and quantitative properties, as well as reduce the occurrence of mycotoxins in maize cultivation, in order to follow the standards imposed by the European Union [23].

**Table 10. Tests of marginal, partial association and interaction of factors of experience**

Effect	Degree of freedom	Chi <sup>2</sup> Partial association	Level of significance	Chi <sup>2</sup> Marginal association	Level of significance
Cultivars	1	0.035	0.084	0.035	0.084
Tillages	1	53.68	< 0.001	53.68	< 0.001
Herbicides	3	44.21	< 0.001	43.21	< 0.001
Decontamination	1	40.99	< 0.001	40.99	< 0.001
Fungi	2	309.00	< 0.001	309.00	< 0.001
Cultivars × Tillages	1	1.39	0.238	1.71	0.190
Cultivars × Herbicides	3	24.83	< 0.001	23.45	0.001
Cultivars × Decontamination	1	0.189	0.663	0.513	0.473
Cultivars × Fungi	2	21.00	< 0.001	20.33	< 0.001
Tillages × Herbicides	3	4.29	0.231	4.35	0.225

Tillages × Decontamination	1	1.35	0.243	1.48	0.222
Tillages × Fungi	2	1.43	0.487	2.17	0.336
Herbicides × Decontamination	3	1.01	0.797	0.94	0.813
Herbicides × Fungi	6	8.51	0.203	7.45	0.280
Decontamination × Fungi	2	4.16	0.124	4.64	0.098

## CONCLUSIONS

1. Regardless the applied variant of tillage or herbicides, in each case BLASK cultivar yielded significantly higher than SALGADO cultivar.
2. Irrespectively the cultivar and weed infestation level, the highest yield size was always obtained in the ploughing system.
3. Application of mesotrione and nicosulfuron mixture proved to be the most efficient in elimination of dominant infesting weeds, especially *Echinochloa crus-galli* and dicotyledon species in each tillage system and for each maize cultivar.
4. In simplified tillage variant, low efficiency of rimsulfuron was the cause of increased weed infestation by *Echinochloa crus-galli*, *Chenopodium album* and *Artemisia vulgaris*, especially in the case of SALGADO cultivar.
5. Simplified tillage system and low weed – control efficiency of rimsulfuron resulted in the occurrence of ears infestation by fungi from *Fusarium* species (*F. avenaceum*, *F. culmorum*, *F. oxysporum*), the lowest yielding, as well as increased level of mycotoxins - deoxynivalenol and zearaleone in grain of SALGADO cultivar.
6. BLASK cultivar characterized higher stability of yielding and more considerable resistance to infestation by fungi from *Fusarium* species on the objects treated with herbicides, in comparison to SALGADO cultivar. In BLASK cultivar, increased level of mycotoxins was not detected.

## ACKNOWLEDGMENT

Research work financed from the of the task 2.6 in the multiannual program IUNG-PIB

## REFERENCES

1. Amadi J.E., Adeniyi D.O., 2009. Mycotoxin production by fungi isolated from stored grain. African Journal of Biotechnology, 8, 7, 1219–1221.
2. Chelkowski J., Mańka M., Kwaśna H., Visconti A., Goliński P., 1989. *Fusarium sporotrichioides* Sherb., *F. tricinctum* (Corda) Sacc. and *F. poae* (Peck) Wollenw. – cultural characteristics, toxigenicity and pathogenicity toward cereals. J. Phytopathology, 124, 155–161.
3. Clifford Laura J., Qunshan J., Pestka J., 2003. An improved method for the purification of the Trichothecene deoxynivalenol (Vomitoxin) from *Fusarium graminearum* culture, J. Agric. Food Chem., 51, 521–523.
4. EPPO – European and Mediterranean Plant Protection Organization. Biuletyn 1995, No. 135, 152, 181, 214, 50.
5. Gołębiowska H., Rola H., 2008. Wpływ herbicydów sulfonilomocznikowych na zdrowotność i wybrane parametry jakościowe ziarna odmian kukurydzy uprawianych w monokulturze [Influence of sulfonyleurea herbicides on health and quality parameters of maize grain varieties in monoculture]. Fragm. Agron., 1/97, 145–157 [in Polish].
6. Goodman L.A., 1978. Analysing qualitative/categorical Data: log-linear models and latent structure analysis (Jay Magidson) ed. Cambridge, 471ss.
7. Haub G., Berthiller F., Hametner C., Rechthaler J., Jaunecker G., Freudenschuss M., Krska R., Schuhmacher R., 2007. Characterization of (13C24) T-2 toxin and its use as an internal standard for quantification of T-2 toxin in cereals with HPLC–MS/MS, Anal Bioanal Chem., 389, 931–940.
8. Kordas L., 2004. Wpływ wieloletniego stosowania uprawy zerowej w zmianowaniu na zachwaszczenie [The effect of the multiannual application of zero tillage in crop rotation on weed infestation]. Progress in Plant Protection, 44 (2), 841–844 [in Polish].
9. Kozioł A., 2009. Praca dyplomowa pt. Metoda oznaczania wybranych mikotoksyn w ziarnie zbóż i kukurydzy [Method for the determination of selected mycotoxins in cereal grains and corn]. Politechnika Wrocławska Wydział Chemiczny [in Polish].
10. Michalski T., 1997. Kukurydza jako surowiec dla przemysłu. Problemy badawcze i produkcyjne uprawy i wykorzystania kukurydzy w Polsce [Corn as feedstock for industry. Research and production problems of using corn in Poland]. Zesz. Probl. Post. Nauk Rol., 450, 201–217 [in Polish].
11. Miedaner T., Reinbrecht C., Lauber U., 2001. Effects of genotype-environment interaction on deoxynivalenol accumulation and resistance to *Fusarium* head blight in rye, triticale and wheat. Plant Breeding, 120, 97–105.
12. Nitzsche O., Schmidt W., Gebhart C., 2002. *Fusarium* pfluglos bekämpfen. Landwirtschaft ohne Pflug., 5, 1–4.
13. Pitt J.I., Hocking A.D., 2009. Fungi and food spoilage. New York, Springer, USA.
14. Płaskowska E., Matkowski K., Moszczyńska E., Kordas L., 2002a. Wpływ sposobu uprawy na zdrowotność pszenicy jarej [Effect of cultivation on the health of spring wheat]. Zesz. Nauk. AR we Wrocławiu, Sek. Rolnictwo, 445, 207–214 [in Polish].
15. Podkówa W., Podkówa Z., 2002. Kukurydza w żywieniu zwierząt. Materiały z seminarium „Forum producentów roślin zbożowych, kukurydzy i rzepaku” [Corn in animal nutrition. Proceedings of the seminar „Forum manufacturers of cereal, maize and rape”]. Poznań, 69–78 [in Polish].
16. Praca zbiorowa, 1993. Normy Żywienia Świń. Wartość pokarmowa pasz. Nutrition Standards Pigs [The nutritional value of feed: Instytut Fizjologii i Żywienia Zwierząt PAN], Jabłonna, 1–127 [in Polish].
17. Praczyk T., Skrzypczak G., 2004. Herbicydy [Herbicides]. Państwowe Wydawnictwo Rolnicze i Leśne. Poznań [in Polish].
18. Próńczuk M., Bojanowski J., Warzecha R., Ludański Z., 2007. Badania nad odpornością kukurydzy na zgorzel podstawy łodyg. Cz. I Ocena podatności odmian mieszańcowych w warunkach infekcji naturalnej [Studies on resistance of maize to fusarium stalk rot Part I. Evaluation of susceptibility of hybrid cultivars under natural infection]. Biul. IHAR, 245, 155–170 [in Polish].
19. Smijders C.H.A., Perkowski J., 1990. Effects of head blight caused by *Fusarium culmorum* on toxin content and weight of wheat kernels. Phytopathology, 80, 556–570.
20. Watanabe T., 2010. Pictorial Atlas of Soil and Seed Fungi: morphologies of cultured fungi and key to species. Boca Raton: CRC Press.
21. Weber R., 2002. Wpływ uprawy zachowawczej na ochronę środowiska [Effect of conservation tillage on the environment]. Post. Nauk Rol. t. 1, 57–67 [in Polish].
22. Wrzeńska E., Dzienia S., Wereszczaka J., 2004. Wpływ systemów uprawy roli na ilość i rozmieszczenie nasion chwastów w glebie [Effect of different cultivation systems on the number and composition of weed seedbank]. Fragm. Agronom., 2 (82), 52–60 [in Polish].
23. Zalecenie Komisji (WE) nr 576/2006 z dnia 17 sierpnia 2006 r. w sprawie obecności deoksynivalenolu, zearalenonu, ochratozyn A, T-2 i HT-2 oraz fumonizyn w produktach przeznaczonych do żywienia zwierząt. 2006. Dziennik Urzędowy Unii Europejskiej. 23.8.2006: L 229/7–9.



Hanna Gołębiowska

Institute of Soil Science and Plant Cultivation, National Research Institute in Pulawy, Department of Weed Science and Tillage Systems, Poland

phone: +48 71 363 8707

Orzechowa 61

50-540 Wrocław

Poland

email: h.golebiowska@iung.wroclaw.pl

Ryszard Weber

Institute of Soil Science and Plant Cultivation, Department of Ecology and Soil Tillage, National Research Institute, Pulawy, Poland

Orzechowa 61

50-540 Wrocław, Poland

Phone: +48 71 363 8707

email: rweber@iung.pulawy.pl

Elżbieta Płaskowska

Department of Plant Protection, Wrocław University of Environmental and Life Sciences, Wrocław, Poland

pl. Grunwaldzki 24a

Wrocław, Poland

---

Responses to this article, comments are invited and should be submitted within three months of the publication of the article. If accepted for publication, they will be published in the chapter headed 'Discussions' and hyperlinked to the article.

---