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THE EFFECT OF PRE-HARVEST GLYPHOSATE APPLICATION ON GRAIN QUALITY AND VOLUNTEER WINTER WHEAT

Dariusz Jaskulski*, Iwona Jaskulska

Department of Plant Production and Experimenting, University of Technology and Life Sciences, Ks. Kordeckiego 20E, 85-225 Bydgoszcz, Poland

* Corresponding author. E-mail: darekjas@utp.edu.pl

ABSTRACT

Glyphosate is used in plant production as a non-selective herbicide and harvest aid. Laboratory and field experiments were performed, which aimed at determining the effect of pre-harvest desiccation on grain quality and volunteer winter wheat. We investigated an effect of glyphosate applied at the dose of 1.0 kg ha^{-1} and 2.0 kg ha^{-1} at maturity stage (BBCH 85-87) on physical characteristics of grain, germination energy, germination capacity, seedling emergence capacity from various depths and on the density and weight of volunteer wheat seedlings in cultivated field. It was found that glyphosate applied at the dose of 2.0 kg ha^{-1} decreased the thousand grain weight and already at the dose of 1.0 kg ha^{-1} decreased the grain germination energy, length and weight of primary roots. Wheat desiccation with the use of glyphosate at the lower dose also limited emergence and the weight of seedlings with deep (10 cm) placement of grain in soil, and after the application of 2.0 kg ha^{-1} the seedling weight decreased by sowing of grain already in depth 4 cm. The pre-harvest desiccation limited the density of volunteer and weight of shoot winter wheat seedlings in the field.

Key words: glyphosate, grain physical characteristics, germination, seedling emergence, volunteer winter wheat.

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the most important crop in the world. It is grown from a seeds. Results from many studies suggest that wheat grains are relatively short-live in soil. Anderson and Soper (2003) observed in field studies seedlings emergence 2 years after harvest, but the grains can keep viability much longer. Volunteer wheat and other cereals, particularly herbicide-resistant cultivars, occurred as serious weeds. Density of volunteer cereals depending on environmental conditions, cropping system, soil tillage and other agrotechnical practices (Van Acker et al., 1997; Streit et al., 2003; De Corby et al., 2007; Nielson et al., 2009).

Pre-harvest weed control and preparing the plantation for harvest are basic objectives of desiccation of crops (Baig et al., 1999; Griffin et al., 2010). Various herbicides are used, but mostly the total ones, mainly glyphosate (Bennett and Shaw, 2000a; Zagonel, 2005). Glyphosate is a non-selective, systemic herbicide that is often used as a harvest aid. It is absorbed into the foliage and translocated to the active growing parts of the plant where it interferes with the shikimic acid pathway by competitively inhibiting 5-enolpyruvyl-shikimate-3-phosphate (EPSP) synthase. The shikimic acid pathway is used by plants for synthesis of amino acids. These amino acids are important in protein biosynthesis (Hollander and Amrheim, 1980). Glyphosate applied prior to plant harvest, especially at earlier maturity stage, can have an unfavourable effect on the yield and the seed size. It also inhibits the seed germination, emergence and growth of offspring plants. This effect, however, depends mostly on the development stage at which desiccation is performed and dose of glyphosate. It was found both for crops (Bennett and Shaw, 2000b) and for weeds (Walker and Oliver, 2008). Decrease the viability of seeds is used in the strategies of limiting weed infestation of arable fields (Clay and Griffin, 2000).

The aim of the present research was to determine the effect of glyphosate used for pre-harvest desiccation of winter wheat on characteristics of grain and the possible role in control of volunteer.

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MATERIAL AND METHODS

Grain collection

The grain of winter wheat cv. Kris was obtained from the Experiment Station of the Faculty of Agriculture and Biotechnology at Mochelek (53° 12' N, 17° 51' E), Poland. Over 2008-2010 on the winter wheat plantation there were defined three treatments, on four plots 25 m^2 each. The treatments, in the maturity stage (BBCH 85-87), plant desiccation with glyphosate was performed. Glyphosate product (Roundup® Energy 450 SL, 450 g a.i. L^{-1}, SL, Monsanto Europe S.A, Belgium) was applied at the doses of glyphosate: 0.0 kg ha^{-1} – the control object, 1.0 kg ha^{-1} and 2.0 kg ha^{-1}. Moisture content was about 30%. It has not been determined exactly in each year of the study. The grain, harvested in the full maturity stage in the first half of August, constituted material for further laboratory and field tests.

Grain characteristics and germination test

The physical characteristics of grain were analysed in laboratory of Department of Plant Production and Experimenting, the University of Technology and Life Sciences in Bydgoszcz. The following were determined: thousand grain weight, grain bulk density using the SH type densimeter (Sadkiewicz Instruments, Poland), uniformity as the share of grain from the screen 2.5 x 25 mm. Germination energy of grain, germination capacity and percentage of abnormal germs were determined according international rules for seed testing (ISTA, 2006). After germination on the 8^{th} day there were evaluated the average length and weight of coleoptile with the first leaf as well as the length of the longest primary root and the germinating grain all roots weight.

Emergence test

There was made a test of plant emergence from the grain investigated. Two laboratory pot experiments were made. The pots 14x14x10 cm each, filled with sand, were each provided with 100 grains of wheat treated and untreated with glyphosate in the maturity stage. In the first experiment grains were sown 4 cm deep and in the second one – 10 cm deep. The pots, six replications for each treatment, were randomly placed and kept at 20-22^{o}C. Seedlings were counted, emergence capacity and shoot weight evaluated 14 days after sowing.

Field experiment

A field experiment with four replications of treatments in randomized block design was made at the Agricultural Production Farm at Kowroz (53° 07′ N, 18° 34′ E), the Kujawy and Pomorze Province, Poland. Grain harvested from plants of winter wheat, treated and untreated with glyphosate was sown on the soil surface at the large rate of 500 kg ha^{-1}. The sowing was performed on the mid-September. The grain was covered with ploughing – skimming. Tillage was made at the depth of about 10 cm. The density of volunteer winter wheat and the seedling weight were determined after 4 weeks.

Statistical analysis

For data collection and statistical analysis ware used software Office Excel (Microsoft Corporation) and Statistica 7.0 StatSoft Inc. The evaluation of the variation with *F* test in grain and seedling parameters was made. The differences between mean values of those characters were verified with the Tukey test ($P<0.05$). For the percentage results there homogenous groups were determined after transformation of data with formula:

$$y = \arcsin \sqrt{x}.$$

RESULTS

The weather conditions in the spring and summer period of winter wheat growth were varied in the years of study (Table 1). In July, when glyphosate was applied, the amount of rainfall ranged from 58.7 to 118 mm and the mean monthly temperature was 19.2-21.6^{o}C. This differentiated the course of growing and maturing winter wheat. However, glyphosate was applied each year in the same stage of plant development.

Table 1. Meteorological conditions in the spring and summer during the growing period of winter wheat

Year	Precipitation (mm)			Temperature (°C)		
	April-July	July	August	April-July	July	August
2008	124.4	58.7	95.5	14.4	19.2	17.8
2009	261.1	118.0	17.6	13.8	18.6	18.2
2010	251.9	107.4	150.7	14.4	21.6	18.4
Many-year	225.5	82.3	63.9	13.8	18.0	17.8

Variable weather conditions in years had an impact on the parameters of grain, its germination, emergence and growth of winter wheat seedlings. The effect of the use of glyphosate, on many of the characteristics of grain and young plants was strong and independent from years of research (Table 2).

Table 2. The significance of variation of winter wheat grain and seedlings

Parameter	Significance		
	Year (Y)	Factor (F)	Y x F
Thousand grain weight	**	**	ns
Grain bulk density	**	ns	ns
Grain uniformity	**	ns	ns
Germination energy	**	**	ns
Germination capacity	ns	ns	ns
Abnormal germs	ns	**	ns
Lenght of coleoptyle and first leaf	**	**	ns
Lenght of root	*	**	ns
Weight of shoot	**	ns	ns
Weight of roots	**	**	ns
Emergence from a depth of 4 cm	**	ns	ns
Emergence from a depth of 10 cm	**	**	ns
Weight of shoot seedling (depth of 4 cm)	ns	**	ns
Weight of shoot seedling (depth of 10 cm)	ns	**	ns
Density of volunteer	*	**	ns
Weight of shoot volunteer	**	**	ns

* - effect significant at P<0.05; ** - effect significant at P<0.01; ns - not significant effect.

The winter wheat desiccation made in the stage BBCH 85-87 using glyphosate at the dose 2.0 kg ha^{-1} resulted in a decrease in the thousand grain weight by 1.1 g (Table 3). Glyphosate, irrespective of the dose, applied in the maturity stage, however, affected neither the grain bulk density nor the grain uniformity.

Table 3. Effect of the pre-harvest glyphosate application on the parameters of winter wheat grain

Dose of glyphosate (kg ha^{-1})	Thousand grain weight (g)	Grain bulk density (kg hl^{-1})	Grain uniformity (%)
0.0	40.3	75.6	88.4^{a}
1.0	40.2	75.1	87.8^{a}
2.0	39.2	75.4	87.5^{a}
$LSD_{0,05}$	0.5	ns	-

$LSD_{0.05}$ – least significant difference; ns – non significant differences; $^{a, b, c}$ – homogenous groups, means followed by the same letter in a column do not differ significantly at P<0.05.

The winter wheat grain collected from plants desiccated with 1.0 kg ha^{-1} of glyphosate demonstrated smaller germination energy and greater (not significantly) share of abnormal germs than from control plants (Table 4). Following the application of 2.0 kg ha^{-1} of glyphosate, grain germination energy significantly decreased and the share of abnormal germs increased more than twice. Pre-harvest winter wheat desiccation, however, did not affect germination capacity. Yet there was a tendency to decrease grain seed germinability with an increase in the dose of the glyphosate applied.

Table 4. Effect of the pre-harvest glyphosate application on the winter wheat grain germination

Dose of glyphosate (kg ha^{-1})	Germination energy (%)	Germination capacity (%)	Abnormal germs (%)
0.0	68.9^{a}	93.1^{a}	2.0^{b}
1.0	62.7^{b}	92.0^{a}	2.8^{b}
2.0	55.4^{c}	90.4^{a}	4.3^{a}

$^{a, b, c}$ – homogenous groups, means followed by the same letter in a column; do not differ significantly at P<0.05.

The effect of glyphosate on roots was much stronger than on the shoot of the germ (Table 5). The first wheat leaf was shorter only when glyphosate was applied at the dose of 2.0 kg ha^{-1}. However, its inhibiting effect on the initial growth of primary roots occurred already after the application of 1.0 kg ha^{-1}; they were then 10.5 mm shorter and 4.7 mg lighter than the roots of germinating grains from non-desiccated plants. After the application of 2.0 kg ha^{-1} of glyphosate, the differences were much greater. The average length of the primary root was 25.7 mm shorter, and their weight – 9.4 mg lower.

Table 5. Effect of the pre-harvest glyphosate application on the winter wheat seedlings during germination

Dose of glyphosate (kg ha^{-1})	Lenght of coleoptyle and first leaf (mm)	Lenght of root (mm)	Weight of	
			shoot (mg)	roots (mg)
0.0	77.1	86.9	59.1	63.0
1.0	74.8	76.4	58.7	58.3
2.0	70.2	61.2	57.0	53.6
$LSD_{0,05}$	3.7	5.2	ns	2.2

$LSD_{0.05}$ – least significant difference at the P=0.05; ns – non significant differences.

In the laboratory test, winter wheat emergence from the grain harvested from desiccated and not treated with glyphosate plants did not differ significantly when the sowing depth was 4 cm. However, the weight of the seedling shoot from the grain of the plants desiccated with glyphosate at dose 2.0 kg ha^{-1} was lower than the weight of the control seedling (Table 6). The inhibiting effect of glyphosate on emergence and the initial growth of seedlings was greater when the grains were placed deeper – 10 cm. In such conditions emergence and the weight of shoot seedling from the grain of the plants desiccated with 1.0 kg ha^{-1} of glyphosate were significantly lower than the control plants. The inhibiting effect of glyphosate increased with the dose of 2.0 kg ha^{-1}.

The impact of the pre-harvest winter wheat desiccation on the emergence and early growth of volunteer in the field depended on the dose of the glyphosate (Table 7). The density of volunteer and weight of shoot seedling decreased with an increasing dose of glyphosate.

Table 6. Effect of the pre-harvest glyphosate application on the winter wheat emergence depending on the depth of grain place (DGP)

Dose of glyphosate (kg ha^{-1})	Emergence (%)		Weight of shoot seedling (mg)	
	DGP (4 cm)	DGP (10 cm)	DGP (4 cm)	DGP (10 cm)
0.0	86.2^{a}	61.4^{a}	110.8	96.0
1.0	85.5^{a}	56.6^{b}	108.7	87.8
2.0	83.3^{a}	47.7^{c}	99.0	78.7
$LSD_{0.05}$	-	-	5.1	6.3

Table 7. Effect of the pre-harvest glyphosate application on the volunteer winter wheat

Character	Dose of glyphosate (kg ha^{-1})			
	0.0	1.0	2.0	$LSD_{0.05}$
Density of volunteer (no. m^{-2})	253	231	161	17
Weight of shoot seedling (mg)	164	134	99	12

DISCUSSION

Glyphosate is a biologically active substance rapidly mineralized in soil (Alexa et al., 2009). The inhibitory effect of glyphosate on germination of crop and weed seeds, roots length, seedlings weight, and changes in the anatomy of the root was reported by other authors (Pline et al., 2002; Carlson and Donald, 2006; Çavuşoğlu et al., 2011). In a laboratory study done by (Piotrowicz-Cieślak et al., 2010) seedlings of many plant species growing for six days in soil supplemented with 2,000 μM glyphosate were strongly reduced roots. Baig et al. (2003) showed while that pre-harvest applications of glyphosate reduced also seedling shoot weight of pea.

Glyphosate used in various stages of plant growth can significantly affect the quality of the seeds. In the research simulating drift of herbicide on wheat plants, e.g. during plant protection treatments on the neighbouring plantations, already at very low amounts glyphosate caused strong damage. When applied at the doses of 70-140 g ha^{-1} in the first node stage and flowering it damaged leaves, inhibited the plant height, decreased the spike density, reduced the grain weight and decreased the yield even by more than 70% (Roider et al., 2007). Grain collected from plants which survived, however, kept their viability (Deeds et al., 2006). Glyphosate applied in the late development stages for pre-harvest plant desiccation affects the yield less considerably; however, it can limit the grain quality (Craven et al., 2007). The results of the research made so far, however, are not clear-cut (Blackburn and Boutin, 2003).

The effect of the pre-harvest desiccation on the wheat grain quality depends mostly on the development stage in which the treatment is made, the a.i. used and its dose. In the reports by Manthey et al. (2004) the application of glyphosate in the soft dough stage resulted in changes in the properties of grain of durum wheat. As a result of glyphosate, the grain bulk density was 1.3 kg hl^{-1} lower and the thousand grain weight – 3.5 g lower. The changes were greater than those reported in the present research. Moshatati and Gharineh (2012) showed that thousand grain weight of wheat had not direct effect on germination capacity and germination time, but changes seedling growth. Yenish and Young (2000) applied of glyphosate in three maturity stages of wheat: milk stage, soft dough and hard dough stage at the doses of 0.62 and 0.84 kg ha^{-1}. Despite much lower doses than those in the present research glyphosate applied in the earlier stage (milk

stage) reduced the weight of grain by 19-73% and by 2-46% their germination, as compared with grain of non-desiccated wheat. Glyphosate also affected the growth of plants of the successive generation. The density of seedlings and the plant height were, respectively, 28-99% and 19-39% lower. In the present investigation where glyphosate was applied in the later development stage yet at higher doses, its effect on the initial seedling growth was also significant in each year of the study.

CONCLUSIONS

In this study, we found that the glyphosate applied in the maturity stage of winter wheat already at the dose of 1.0 kg ha^{-1} decreased the grain germination energy, lenght and weight of primary roots, inhibited the emergence and the initial growth of seedlings when the grains were placed deep (10 cm) in soil. The pre-harvest desiccation using of 2.0 kg ha^{-1} of glyphosate decreased the thousand grain weight, increased percentage of abnormal germs and reduced weight of seedlings when the sowing depth was even 4 cm. Effect of plant desiccation on the characteristics of grain and winter wheat seedlings was independent of the year. Glyphosate used in the BBCH 85-87 stage also limited significantly density of volunteer wheat and their weight of shoot seedling.

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