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Department of Herbology and Plant Cultivation Techniques, University of Life Sciences i Lublin
Akademicka 13, 20-950 Lublin
e-mail: czarkw@poczta.onet.pl

CEZARY A. KWIATKOWSKI, MARIAN WESOŁOWSKI,
MAGDA DRABOWICZ, BARBARA MISZTAL-MAJEWSKA

The effect of adjuvants and reduced rates of crop protection agents on the occurrence of agricultural pests and on winter wheat productivity

Wpływ adiuwantów oraz zredukowanych dawek środków ochrony roślin na występowanie agrofagów i produkcyjność pszenicy ozimej

Summary. A field experiment in growing winter wheat was carried out in Czesławice (the central part of the Lublin region) in 2009–2011. The experiment was set up as a split-block design with 3 replications on grey-brown podzolic soil derived from loess. Tillage was performed in accordance with the agronomic practices typical of this species. NPK mineral fertilization was adjusted to high soil nutrient availability. The research included 3 rates of herbicides, fungicides and a retardant (100, 75, 50%) as well as various types of adjuvants (surface-active, oil, mineral). Plots without adjuvant application were the control treatment. It was shown that a 50% reduction in the rates of crop protection agents caused a considerable decrease in winter wheat grain yield and in some yield components compared with the 75% rate and the maximum rate. Due to the addition of adjuvants (especially the oil adjuvant) to the spray solution, the reduction in the rates of crop protection agents by 25% did not cause any decrease of winter wheat productivity. A further reduction (by 50%) in the rates of crop protection agents, in spite of the application of adjuvants, had a negative effect on wheat yield caused by an intense accumulation of air-dry weight of weeds in the crop as well as by higher susceptibility of wheat to a complex of fungal diseases infecting the stem base.

Key words: winter wheat, adjuvants, rates of crop protection agents, productivity, agricultural pests

INTRODUCTION

The use of intensive technologies in growing winter wheat can positively affect wheat productivity, but it is not always economically justified [Kaniuczak 2000]. Apart from that, the decreased risk of environmental contamination and the reduction in permissible levels of residues of biologically active substances in cereal products speak for reduced rates of crop protection agents applied [Kuś 1998, Lipa 2004]. Efforts to reduce the consumption of crop protection agents consist in lowering their doses in a reasonable way so that intended weed or fungus-killing effects can be achieved by using these agents [Pietryga and Drzewiecki 2000, Rola and Rola 2002]. One of the methods of compensating for the decreased dose of the active substance is to add aiding agents (adjuvants) that improve the physico-chemical properties of the spray solution [Stock 1991, Kierzek 2000]. Most adjuvants are products intended for use mainly with herbicides and only few of them can be used with other agents (e.g. fungicides, retardants). One of the main objectives of a combined application of adjuvants with crop protection agents is to increase the biological activity of pesticides by improving retention of water drops by the plant and absorption of the active substance by the plant as well as to reduce the negative effect of weather conditions on the action of the active substance [Holloway *et al.* 2000, Woźnica *et al.* 2005]. In the present study, a hypothesis was made that lowering the rates of crop protection agents by 25–50%, with the simultaneous addition of adjuvants, would allow agricultural pests to be effectively eliminated and, in effect, it would enable grain yield and the parameters of yield components to be maintained at a level similar to those found under the conditions when the recommended rates are applied without any adjuvant.

The aim of the present study was to determine the effect of reduced rates of herbicides, fungicides and growth retardant as well as of three adjuvant types on weed infestation, health, lodging and yield of winter wheat and on some yield components.

MATERIALS AND METHODS

The field experiment in growing winter wheat (cv. 'Smuga') was carried out in the period 2009–2011 at the Czesławice Experimental Farm belonging to the University of Life Sciences in Lublin. It was set up as a split-block design with 3 replications, in 27 m^2 plots. The experiment was established on grey-brown podzolic soil derived from loess, classified as good wheat complex. Potato was the previous crop for winter wheat. Mineral fertilization, adjusted to high soil nutrient availability, was applied at the following rates on a per hectare basis: N – 70 kg, P_2O_5 – 60 kg, K_2O – 90 kg. The present study investigated the following types of adjuvants: A – control treatment (without any adjuvant), B – surface-active adjuvant Break Thru S 240 (0.9 l ha^{-1}), C – oil adjuvant Atpolan 80 EC (1.5 l ha^{-1}), D – mineral adjuvant – ammonium sulphate (10% solution – 1.5 l ha^{-1}), as well as 3 rates of herbicides, growth retardant, and fungicides (100%, 75%, and 50%). The following pesticides were applied: herbicides (Sekator 6,25 WG + Puma Uniwersal 069 EW – 0.3 + 1.2 l ha^{-1} (100% rate), 0.23 + 0.9 l ha^{-1} (75% rate), 0.15 + 0.6 l ha^{-1} (50% rate); growth retardant (Terpal C 460 SL) – 2.0 l ha^{-1} (100% rate), 1.5 l ha^{-1} (75% rate), 1.0 l ha^{-1} (50% rate); fungicides (Tilt Plus 400 EC and Alert 375 SC) at identical rates – 1.0 l ha^{-1} (100% rate), 0.75 l ha^{-1} (75% rate), and 0.5 l ha^{-1} (50% rate). The crop protection agents were applied using a field sprayer under a pressure of 0.25 MPa, on dates in accordance with the recommendations of the Institute of Plant Protection – State Research Institute in Poznań (at the moment of planning the experiment – 2008).

Infection of wheat plants by a complex of pathogens causing stem base diseases was determined at the milk stage (BBCH 75). 50 plants were pulled out from each plot. After washing away the soil, the plants were divided, depending on the degree of stem base infection, into groups according to a five-point scale (% of the infected stem base). Subsequently, the disease index was calculated for stem base diseases in accordance with Mc Kinney's formula given by Łacicowa [1969]. Assessment of weed infestation of the winter wheat crop was made at the dough stage (BBCH 83–85) using the dry-weight-rank method in 1 × 0.5 m sampling plots, with two replications per plot. At the same time, ear density of winter wheat was determined in the above-mentioned sampling plots. The degree of lodging of winter wheat was estimated several days before harvest, using a 9-point scale. Number of grains per ear and ear length were determined on the basis of 30 randomly sampled ears from each plot. After harvest of winter wheat (the 1st decade of August) and after the grain was dried to 14% moisture content, grain yield was determined (in kg per plot) and calculated on a per hectare basis as well as 1000 grain weight was determined.

The obtained results were statistically analysed using the analysis of variance and determining the significance of differences by Tukey's test (p = 0.05).

RESULTS AND DISCUSSION

Regardless of the adjuvants, the application of the recommended (100%) rates of crop protection agents resulted in the stem base infection index ranging on average 7.6–9.7% (tab. 1). The reduction in the rates of crop protection agents by 1/4 caused a significant increase in the wheat stem infection index up to the range of 8.8–15.1%. On the other hand, lowering the rates of crop protection agents by 50% resulted in a more than twofold increase in infection of the wheat stem base by a complex of fungal diseases. Irrespective of the type of adjuvant and the rate of crop protection agents, all adjuvants tested contributed to a significant decrease in the stem base infection index of winter wheat compared to the control treatment.

Table 1. The index of winter wheat stem-base infection by the fungal disease complex at the milk stage (%) – mean for 2009–2011
Tabela 1. Indeks porażenia podstawy źdźbła pszenicy ozimej kompleksem chorób grzybowych w fazie dojrzałości mlecznej (%) – średnio z lat 2009–2011

Treatment Zabieg	Rates of crop protection agents Dawki środków ochrony roślin			Mean Średnio
	100%	75%	50%	
A – without adjuvant (control treatment) bez adiuwanta (obiekt kontrolny)	9.7	15.1	21.3	15.4
B – Break Thru S 240 – surface-active adjuvant – adiuwant powierzchniowo czynny	8.6	9.5	18.3	12.1
C – Atpolan 80 EC – oil adjuvant – adiuwant olejowy	7.6	8.8	16.2	10.9
D – ammonium sulphate adjuvant – siarczan amonu	8.0	9.4	17.0	11.5
Mean – Średnio	8.5	10.7	18.2	–
LSD $_{(0.05)}$ – NIR $_{(0,05)}$ for – dla: rates – dawek = 2.49; adjuvants – adiuwantów = 2.56				

Table 2. Air-dry weight of weeds in the winter wheat crop per 1 m^2 (g) – mean for 2009–2011
Tabela 2. Powietrznie sucha masa chwastów w łanie pszenicy ozimej na 1 m^2 (g) – średnio z lat 2009–2011

Treatment Zabieg	Rates of crop protection agents Dawki środków ochrony roślin			Mean Średnio
	100%	75%	50%	
A – without adjuvant (control treatment) – bez adiuwanta (obiekt kontrolny)	3.7	8.8	42.7	18.4
B – Break Thru S 240 – surface-active adjuvant – adiuwant powierzchniowo czynny	2.9	5.3	25.5	11.2
C – Atpolan 80 EC – oil adjuvant – adiuwant olejowy	2.0	4.9	21.4	9.4
D – ammonium sulphate adjuvant – siarczan amonu	3.1	6.2	36.8	15.3
Mean – Średnio	2.9	6.3	31.6	–
LSD $_{(0.05)}$ – NIR $_{(0,05)}$ for – dla: rates – dawek = 2.43; adjuvants – adiuwantów = 2.95				

Table 3. Winter wheat lodging in a 1–9 scale* – mean for 2009–2011
Tabela 3. Wyleganie pszenicy ozimej w skali 1–9* – średnio z lat 2009–2011

Treatment Zabieg	Rates of crop protection agents Dawki środków ochrony roślin			Mean Średnio
	100%	75%	50%	
A – without adjuvant (control treatment) – bez adiuwanta (obiekt kontrolny)	8.2	7.4	6.4	7.3
B – Break Thru S 240 – surface-active adjuvant – adiuwant powierzchniowo czynny	8.8	8.0	6.9	7.9
C – Atpolan 80 EC – oil adjuvant – adiuwant olejowy	9.0	8.4	7.5	8.3
D – ammonium sulphate adjuvant – siarczan amonu	8.5	8.0	6.8	7.8
Mean – Średnio	8.6	7.9	6.9	–
LSD $_{(0.05)}$ – NIR $_{(0,05)}$ for – dla: rates – dawek= 0.90; adjuvants – adiuwantów = 0.88				

*1 – complete lodging of the crop – łan kompletnie leżący; 9 – no lodging – brak wylegania

Air-dry weight of weeds in the winter wheat crop was significantly dependent on both experimental factors (tab. 2). The reduction in the rates of crop protection agents by 50% resulted in a more than tenfold increase in the trait in question compared to the application of the recommended rates (100%) and a fivefold increase in weed biomass in the crop relative to the 75% rates. All the adjuvants, regardless of the rates of crop protection agents, contributed to a reduction in air-dry weight of weeds in the wheat crop on average by 17% (ammonium sulphate) – 49% (Atpolan 80 EC).

In the situation where the recommended 100% rates of crop protection agents were applied, lodging of winter wheat was insignificant (tab. 3). The lowering of the doses of crop protection agents by 25% did not also have a significant effect on cereal lodging and the average increase in lodging under these conditions was only 0.7 percentage points. It was only when the recommended rates of crop protection agents were reduced by half that this caused a statistically proven increase in lodging (on average by 1.7 percentage points) compared to the 100% rates. In the group of adjuvants under evaluation, only Atpolan 80 EC effectively caused a reduction in lodging of winter wheat crops compared to the control treatment, on average by 1.0 percentage point.

Table 4. Number of ears per 1 m^2 in winter wheat (pcs) – mean for 2009–2011
Tabela 4. Liczba kłosów pszenicy ozimej na 1 m^2 (szt.) – średnio z lat 2009–2011

Treatment Zabieg	Rates of crop protection agents Dawki środków ochrony roślin			Mean Średnio
	100%	75%	50%	
A – without adjuvant (control treatment) – bez adiuwanta (obiekt kontrolny)	481	464	416	454
B – Break Thru S 240 – surface-active adjuvant – adiuwant powierzchniowo czynny	492	487	443	474
C – Atpolan 80 EC – oil adjuvant – adiuwant olejowy	498	495	452	482
D – ammonium sulphate adjuvant – siarczan amonu	488	483	428	466
Mean – Średnio	490	482	435	–
LSD $_{(0.05)}$ – NIR $_{(0,05)}$ for – dla: rates – dawek = 19.4; adjuvants – adiuwantów = 18.8				

Table 5. Ear length of winter wheat (cm) – mean for 2009–2011
Tabela 5. Długość kłosa pszenicy ozimej (cm) – średnio z lat 2009–2011

Treatment Zabieg	Rates of crop protection agents Dawki środków ochrony roślin			Mean Średnio
	100%	75%	50%	
A – without adjuvant (control treatment) – bez adiuwanta (obiekt kontrolny)	9.5	9.3	9.0	9.3
B – Break Thru S 240 – surface-active adjuvant – adiuwant powierzchniowo czynny	9.8	9.6	9.4	9.6
C – Atpolan 80 EC – oil adjuvant – adiuwant olejowy	9.8	9.8	9.6	9.7
D – ammonium sulphate adjuvant – siarczan amonu	9.6	9.5	9.2	9.4
Mean – Średnio	9.7	9.5	9.3	–
LSD $_{(0.05)}$ – NIR $_{(0,05)}$ for – dla: rates – dawek = n.s. – r.n.; adjuvants – adiuwantów = n.s. – r.n.				

Winter wheat ear density per 1 m^2 significantly depended on the experimental factors in question (tab. 4). The reduction in the rates of crop protection agents by half resulted in a decrease in the number of ears per unit area, on average by approx. 10–11% compared to the rates reduced by 25% and the recommended rate. Such a trend occurred in spite of the addition of adjuvants to the spray solution. Regardless of the rates of crop protection agents, the adjuvants had a positive effect on the number of winter wheat ears per 1 m^2; however, the application of crop protection agents in combination with the oil adjuvant (Atpolan 80 EC) or the surface-active adjuvant (Break Thru S 240) guaranteed a significant increase in ear density.

Table 6. Number of grains per ear in winter wheat (pcs) – mean for 2009–2011
Tabela 6. Liczba ziaren w kłosie pszenicy ozimej (szt.) – średnio z lat 2009–2011

Treatment Zabieg	Rates of crop protection agents Dawki środków ochrony roślin			Mean Średnio
	100%	75%	50%	
A – without adjuvant (control treatment) – bez adiuwanta (obiekt kontrolny)	29	24	20	24
B – Break Thru S 240 – surface-active adjuvant – adiuwant powierzchniowo czynny	35	32	26	31
C – Atpolan 80 EC – oil adjuvant – adiuwant olejowy	36	36	26	33
D – ammonium sulphate adjuvant – siarczan amonu	31	30	23	28
Mean – Średnio	33	30	24	–
LSD $_{(0.05)}$ – NIR $_{(0,05)}$ for – dla: rates – dawek = 2.8; adjuvants – adiuwantów = 2.6				

Table 7. 1000 grain weight of winter wheat (g) – mean for 2009–2011
Tabela 7. Masa 1000 ziaren pszenicy ozimej (g) – średnio z lat 2009–2011

Treatment Zabieg	Rates of crop protection agents Dawki środków ochrony roślin			Mean Średnio
	100%	75%	50%	
A – without adjuvant (control treatment) – bez adiuwanta (obiekt kontrolny)	51.1	50.6	49.2	50.3
B – Break Thru S 240 – surface-active adjuvant – adiuwant powierzchniowo czynny	51.8	51.2	50.2	51.1
C – Atpolan 80 EC – oil adjuvant – adiuwant olejowy	52.1	51.6	50.4	51.4
D – ammonium sulphate adjuvant – siarczan amonu	51.4	51.0	50.0	50.8
Mean – Średnio	51.6	51.1	49.9	–
LSD $_{(0.05)}$ – NIR $_{(0,05)}$ for – dla: dawek – rates = n.s. – r.n.; adjuvants – adiuwantów = n.s. – r.n.				

Average ear length of winter wheat proved to be a trait independent of the experimental factors (tab. 5). Nevertheless, the study found a trend towards the shortening of the ear length with the increasing reduction in the rates of crop protection agents.

The reduction in the rates of crop protection agents had a significant effect on the decrease in the number of grains per ear in winter wheat (tab. 6). Already 3/4 of the rate of crop protection agents contributed to the formation of a smaller (on average by 3 pieces) number of grains per ear, whereas the next reduction resulted in a loss of 9 grains on average, thus a decrease in their number by as much as 27% compared to the recommended rates. All the adjuvants applied in the present experiment positively affected the number of grains per ear and the average increase of the above described parameter was 14–27% under the influence of the adjuvants.

Table 8. Grain yield of winter wheat (t/ha) – mean for 2009–2011
Tabela 8. Plon ziarna pszenicy ozimej (t/ha) – średnio z lat 2009–2011

Treatment Zabieg	Rates of crop protection agents Dawki środków ochrony roślin			Mean Średnio
	100%	75%	50%	
A – without adjuvant (control treatment) – bez adiuwanta (obiekt kontrolny)	6.0	5.9	5.0	5.6
B – Break Thru S 240 – surface-active adjuvant – adiuwant powierzchniowo czynny	6.4	6.1	5.7	6.1
C – Atpolan 80 EC – oil adjuvant – adiuwant olejowy	6.6	6.4	5.9	6.3
D – ammonium sulphate adjuvant – siarczan amonu	6.2	6.0	5.4	5.9
Mean – Średnio	6.3	6.1	5.5	–
LSD (0.05) – NIR (0,05) for – dla: rates – dawek = 0.36; adjuvants – adiuwantów = 0.34				

Table 9. The simple correlation coefficient (r) between grain yield of winter wheat and the occurrence of agricultural pests as well as crop lodging, irrespective of the adjuvants – mean for 2009–2011
Tabela 9. Współczynniki korelacji (r) między plonem ziarna pszenicy ozimej i występowaniem agrofagów oraz wyleganiem roślin niezależnie od adiuwantów – średnio z lat 2009–2011

Treatment Zabieg	Rates of crop protection agents Dawki środków ochrony roślin		
	100%	75%	50%
Air-dry weight of weeds Powietrznie sucha masa chwastów	–0.11	–0.30	–0.61*
Stem base infection index Indeks porażenia podstawy źdźbła	–0.07	–0.22	–0.56*
Winter wheat lodging Wyleganie roślin pszenicy ozimej	–0.01	–0.19	–0.43
*significant correlation coefficient $_{(0.05)}$ – istotny współczynnik korelacji $_{(0,05)}$			

The reduction in the rates of crop protection agents as well as application or no application of adjuvants did not differentiate significantly 1000 grain weight in winter wheat (tab. 7). We can only speak about a trend towards a smaller grain size in the grain harvested from the plots protected by crop protection agents with their rates reduced by half. It is also worth noting that the adjuvants Break Thru S 240 and Atpolan 80 EC had a positive effect on thousand grain weight (TGW) of wheat, while in the event that the rates of crop protection agents were reduced by 25% these adjuvants ensured the maintenance of the parameter in question at a level higher than in the control treatment (100% rate, with no adjuvant).

Winter wheat grain yield was significantly modified by both experimental factors (tab. 8). The reduction in the rates of crop protection agents by half resulted in a decrease in grain yield by respectively 10–13% compared to the application of the rates reduced by 25% and the recommended rates. The addition of the surface-active adjuvant to the spray solution, in particular the oil adjuvant (Atpolan 80 EC), irrespective of the rates of crop protection agents, caused an increase in wheat grain yield by more than 10% relative to the control treatment. It is worth noting that in spite of the reduction in the rates of crop protection agents by 25%, the application of all adjuvants gave higher or identical yields compared to the treatment with the full doses without the application of any adjuvant. Moreover, the addition of the oil adjuvant to the rates of crop protection agents reduced by 50% also guaranteed wheat yield at a level almost identical to that obtained in the control treatment (without any adjuvant) with the application of the recommended rate. This suggests that lowering the rates of crop protection agents within certain limits, combined with the application of substances increasing the adhesion of the spray liquid (Atpolan 80 EC), is fully justified.

Under the conditions where the rates of crop protection agents were reduced by 50%, a significant negative correlation was found between winter wheat grain yield and intensive occurrence of weeds in the crop (air-dry weight of weeds) as well as infection of the stem base by the fungal disease complex. A lower reduction in grain yield was noted under the influence of lodging of plants (tab. 9).

As a rule, reducing the rates of crop protection agents causes a decrease in crop productivity and worse yield quality as a result of the intensive occurrence of agricultural pests [Woźnica 2003, Lipa 2004]. Kwiatkowski and Wesołowski [2011b] found that the reduction in the rates of crop protection agents by 50% caused an increase in the number and air-dry weight of weeds in the winter wheat crop and the addition of adjuvants did not help to reduce this trend. Nevertheless, a reduction in the rates of crop protection agents within reasonable limits, not exceeding 25–33%, may bring satisfactory production effects [Wesołowski *et al.* 2005], in particular if adjuvants are added to the spray solution [Skrzypczak *et al.* 2003, Kwiatkowski 2010]. In the study of Piekarczyk [2005], lowering the rates of crop protection agents by 50%, combined with the addition of adjuvants (Atpolan 80 EC), did not deteriorate significantly their weed-killing properties and had no effect on spring barley grain yield. In the opinion of Pecio *et al.* [2000] as well as Rola and Rola [2002], the above described situation may arise from the fact that weed infestation was low and, on the other hand, cereals are a group of crop plants showing high competitiveness towards weeds. In the opinion of Domaradzki *et al.* [2002], weeds that are not destroyed completely can contribute to a significant decrease in yield, increased weed infestation of subsequent crops, and the development of fungal diseases. Wachowiak and Kierzek [2003] argue that the addition of an adjuvant to the rate of fungicides reduced by 50% allowed good results to be obtained in the control of potato blight. The study of Kwiatkowski *et al.* [2006] shows that the reduction of the amount of NPK fertilizers applied and of the rates of herbicides and fungicides by half led to a slight deterioration of some grain yield components of winter wheat, such as ear length, number of grains per ear, and grain plumpness. In the experiment under discussion, number of grains per ear proved to be a yield component that responded negatively to the reduction in the rates of pesticides by 50%. Kwiatkowski and Wesołowski [2011a] proved on the example of spring barley that the reduction in the rates of herbicides, fungicides and growth retardant by 25% did not result in the deterioration of yield components and of the cereal crop thanks to the application of crop protection agents together with an adjuvant. An identical conclusion can be drawn from the results of the present study on winter wheat productivity. The aspect of environmental protection associated with the reduction in the rates of crop protection agents is also of major importance. On the basis of few studies [Kucharski 2004], it can be presumed that the addition of an adjuvant to a herbicide causes a slowing of its mobility into the deeper layers of the soil profile, which extends the time of its action on weed seedlings and reduces or prevents the penetration of herbicides into groundwater [Kucharski 2004].

CONCLUSIONS

1. As a result of the addition of adjuvants to the spray solution of crop protection agents, the reduction in their rates by 25% did not cause a decrease in winter wheat productivity.

2. The reduction in the rates of crop protection agents by 50% resulted in a significant fall in winter wheat yield as manifested in a rapid decrease in ear density per unit area and in number of grains per ear, while the addition of an adjuvant had no effect on the reduction of this trend. The deterioration of winter wheat yield was closely related to increased weed infestation of the crop and infection of the stem base by a complex of fungal diseases.

3. The oil adjuvant Atpolan 80 EC proved to have the highest effectiveness in eliminating negative consequences of the reduction in the rates of herbicides, fungicides and growth retardant.

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Streszczenie. Eksperyment polowy z uprawą pszenicy ozimej prowadzono w Czesławicach (środkowa Lubelszczyzna) w latach 2009–2011. Doświadczenie założono metodą split-block w trzech powtórzeniach, na glebie płowej wytworzonej z lessu. Uprawa roli była zgodna z zasadami agrotechniki typowej dla gatunku. Nawożenie mineralne NPK dostosowano do dużej zasobności gleby w składniki pokarmowe. W badaniach uwzględniono 3 dawki herbicydów, fungicydów i retardanta (100, 75, 50%) oraz rodzaje adiuwanta (powierzchniowo czynny, olejowy, mineralny). Obiekt kontrolny stanowiły poletka bez użycia adiuwanta. Dowiedziono, że redukcja dawek środków ochrony roślin o 50% powodowała istotne zmniejszenie plonu ziarna pszenicy ozimej oraz niektórych elementów struktury plonu w porównaniu z dawką 75% i dawką maksymalną. Dodatek adiuwantów (zwłaszcza olejowego) do cieczy użytkowej sprawiał, że redukcja dawek środków ochrony roślin o 25% nie wpływała na zmniejszenie produkcyjności pszenicy ozimej. Dalsza redukcja (o 50%) dawek środków ochrony roślin, pomimo zastosowania adiuwantów, wpływała negatywnie na plonowanie pszenicy poprzez nasilone nagromadzenie powietrznie suchej masy chwastów w łanie oraz większą podatność zboża na kompleks chorób grzybowych porażających podstawę źdźbła.

Słowa kluczowe: pszenica ozima, adiuwanty, dawki środków ochrony roślin, produkcyjność, agrofagi