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CEREAL MIXTURES IN POLISH SCIENTIFIC LITERATURE IN THE PERIOD 2003-2007

REVIEW ARTICLE

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Abstract. The paper comprises a review of the results of studies on cereal mixtures published in 2003-2007 in the Polish scientific literature. There are presented herein the most important issues concerning yield ability, weed, pest and diseases infestation. Cereal mixtures occupy the highest area among spring cereals in Poland and grain harvested from mixtures plays an important role in production of feedstock in the country. The highest concentration of mixtures is noted in the eastern region and the lowest in the south-western part of Poland. The higher yield ability of mixtures compared to pure cereal stands is connected with complementary utilization of environmental resources in different time, space (under- or aboveground) or form (water, light, nutrients) by mixtures' components as well as with competition, responsible for changes in proportion of components in the mixture yield. The better stability of yield is attributed to a better competition ability against weeds and lower susceptibility of mixtures to diseases compared to pure stands. Mixed stands show a better response to some agronomical factors, such as irrigation, mineral fertilization and chemical protection against pests, weeds and diseases. A higher proportion of naked forms of barley and oat in mixtures has been recommended recently. Therefore, the mixture yields are lower than those of mixtures with hulled forms but their feeding value is higher, because of a lower content of fibre and a higher content of protein and fat.

Key words: cultivar mixtures, fertilization of mixtures, naked barley, naked oat, protection against pathogens, weed infestation control

INTRODUCTION

In Polish literature it is stressed that cereal growing in mixtures is characteristic of Polish agriculture [Noworolnik 2007, Sulewska and Michalski 2007]. From statistical data it follows that their acreage in 2004-2008 ranged from 1 437 to 1 544 thousand ha (16.8-18.4% in the cereal cropping area), and grain yield from 3.38 to 4.32 mln t [Rocznik Statystyczny... 2009]. Leszczyńska [2003] and Noworolnik [2007] indicate

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that in Europe cereal mixtures are of marginal importance in cereal cropping. In the European Union, in 1980 they occupied an area of only 482 thousand ha, and in 2000 their acreage was half as big [Leszczyńska 2003]. After the extension of the European Union, the cropping area of cereal mixture increased considerably, but mainly because of Poland. In 2007 their stands in the EU occupied an area of 1 713 thousand ha, and in 2008, 1 626 thousand ha, and grain production was 4.90 and 4.28 m. t, respectively [FAOSTAT 2010].

A review of Polish agrotechnological research over cereal mixtures comprises the years 2003-2007. The study presents the major issues concerning a selection of components for mixtures, their yields, weed infestation as well as infestation by pathogens and pests.

REVIEW OF LITERATURE

The issues concerning agrotechnological research over cereal mixtures are widely presented by numerous authors in Polish scientific journals. Sulewska and Michalski [2007] report that in Poland in 2005 cereal mixtures took the second place after wheat in respect of cereal crop area. They were grown on every eight hectare occupied by cereals. Based on data of GUS from 1995-2005, the authors indicated that the proportion of cereal mixtures in cereal crops is rather varied in particular regions of the country. They occupy the largest cropping area in the eastern region (Podlaskie, Lubelskie, Świętokrzyskie and Podkarpackie Voivodeships), and the smallest in the south-west region (Opolskie and Dolnośląskie Voivodeships). From the acreage of mixtures in Poland, as much as 29% fall in the east region, where spring mixtures predominate (29.6% of the area of their cropping in Poland). The most winter mixtures (29.4% of their total area) are grown in the central region. The authors indicate that in respect of the proportion of mixtures in the cropping pattern the central region is in first place (22.9%). The information above corresponds to the study by Jastrzębska et al. [2006a], who made an analysis of this form of cereal cropping in the Podlaskie Voivodeship on the basis of the last agricultural census from 2002. It shows that the Podlaskie Voivodeship is characterized by the largest average percentage of cereal mixtures in the cropping area in the country. Their proportion in field crops is much varied depending on the region and it ranges from 3.6 to 51.9% in particular communes. Their greatest participation in crops occurs in communes situated in the north and south--west parts of the Voivodeship. Among mixtures, forms of spring cereals prevail, and winter ones occur sporadically (on average only 0.1%). It was proved that under the environmental conditions of Podlasie, that is generally not very favourable for plant production, rather better soils are intended for mixtures. Their proportion in cropping area increases along with the soil valorization index, the improvement of water conditions and a reduction in the coefficients of agroclimate and the lie of the land.

Leszczyńska [2003] and Sulewska and Michalski [2007] stress that cereal mixture grain is not a commercial product, but mainly a fodder raw material used in the own farm for extensive animal breeding, since feed rations are difficult to balance, due to the proportion of components in grain yield, changing in years. These remarks correspond to observations of Jastrzębska et al. [2006a], who claim that a large proportion of cereal mixtures in crops in Podlasie is positively connected with development of cattle and swine breeding. Leszczyńska [2003] thinks that in a longer time perspective, with an increase in production of ready-made industrial fodders and a lack of market for

mixture grain for fodder in the intervention purchase of EU, a reduction will occur in the cropping area of this form of cereals.

Sulewska and Michalski [2007] claim that mixtures of winter cereals, irrespective of the year, give higher yield than spring ones. The yield potential of mixtures is higher than that of oat, but lower in relation to spring barley. On the basis of variation coefficients calculated for the long term period 1995-2005, they indicated that mixtures gave more variable yields in years than spring barley, but more stable than oat (Table 1).

Table 1. Characteristics of yield ability and total volume of grain production of cereal mixtures on the background of oat and barley and variation coefficients in 1995-2005 [Sulewska and Michalski 2007]

Tabela 1. Charakterystyki plonów i zbiorów mieszanek na tle owsa i jęczmienia jarego w latach 1995-2005 oraz współczynniki zmienności [Sulewska i Michalski 2007]

Specification Wyszczególnienie	Value – Wartość			
	mean średnia	min. – min	max – maks.	variation coefficient współczynnik zmienności %
Grain yield – Plon ziarna, t·ha^{-1}				
Cereals mixtures – Mieszanki zbożowe	2.95	2.61	3.57	9.09
Oats – Owies	2.46	1.89	2.75	9.21
Spring barley – Jęczmień jary	3.02	2.44	3.44	8.29
Harvests, thousand t – Zbiory, tys. t				
Cereals mixtures – Mieszanki zbożowe	3 854	3 084	4 319	9.24
Oats – Owies	1 400	1 070	1 630	12.00
Spring barley – Jęczmień jary	2 852	2 342	3 510	11.33

A considerable part of research on cereal mixtures is devoted to the question of using in their stands cultivars of naked cereals. This results from new forms of oat and spring barley introduced in recent years, characterizing by grain without glumelles and, consequently, by a lower content of fibre in grain, and a higher content of protein and fat [Piech et al. 2003, Szempliński 2003a, Kijora and Wróbel 2004, Dubis and Szempliński 2007]. Although the fertility of naked forms of oat and spring barley clearly is worse in pure stands than that of hulled cultivars [Piech et al. 2003, Szempliński 2003b, Kijora and Wróbel 2004, Dubis and Szempliński 2007, Szumiło and Rachoń 2007b], more and more studies concern their use as components of mixtures with hulled forms. Leszczyńska [2003] points out that the introduction of growing hulled forms of oat and spring barley increases a possibility of a wider application of grain of their mixtures as a fodder. The usefulness of naked forms for growing in mixtures finds both supporters (better grain quality), and opponents (lower grain yields).

The analysis of spring cereal mixtures grown in two-component inter-cultivar stands (with 50% proportion of each cultivar in the stand) indicates that the yield of mixtures of naked and hulled oat forms was from 5,9 to 7,9% higher than average yields of the components grown in pure stand [Szempliński 2003a, Wróbel et al. 2003, Kijora and Wróbel 2004]. In the case of cultivar mixtures of naked and hulled forms of spring barley, an increase in grain yield was also positive, but a difference in yield in relation to average yields of the components was lower and amounted to only 1.0-2.1% [Szempliński 2003a, Dubis and Szempliński 2007] (Table 2).

Table 2. Yield of intra-cultivar mixtures of spring cereals (according to various authors)
Tabela 2. Plonowanie mieszanek odmianowych zbóż jarych (według różnych autorów)

Author(s) Autor(zy)	Grain yield – Plon ziarna, t·ha^{-1}			
	naked cultivar odmiana nagoziarnista	hulled cultivar odmiana oplewiona	mixture mieszanka	increase of yield in relation to pure stands wzrost plonowania w stosunku do siewów czystych %
Oats – Owies				
Szempliński [2003a]	4.26	6.35	5.67	7.9
Wróbel i in. [2003]	3.42	4.98	4.52	7.6
Kijora i Wróbel [2004]	2.83	3.42	3.31	5.9
Spring barley – Jęczmień jary				
Szempliński [2003b]	4.45	5.79	5.23	2.1
Dubis i Szempliński [2007]	5.07	6.71	5.95	1.0

In the literature – apart from analyses of two-component cultivar mixtures, reports concerning the yield of three-component mixtures are also presented. Jastrzębska [2009], in strict statistic field experiments with different proportions of cereals in crop rotation, studied the effect of three-component mixed stands of cultivars of winter wheat and spring barley on yield and shaping the soil environment, on the background of pure stands of those species. The author indicated that in light soil (without chemical protection) the cultivar mixture of winter wheat (with the composition Elena + Symfonia + Almari), grown after winter rape in a specialist cereal crop rotation (75% cereals), ensured a higher yieldlevel than the Elena cultivar in pure stand and both types of stands in the crop rotation with 50% proportion of cereals. The cultivar mixture of spring barley (with the composition Rabel + Boss + Bryl) responded to an increase in cereal proportion in crop rotation up to 75% and a worse previous crop with a similar decrease in grain productivity as the Rabel cultivar in pure stand. The tested cultivar mixtures did not improved yieldstability in the years. It is notable that cultivar mixtures left considerable weight of post-harvest residues, similar to pure stands, and of a similar quality. Cereal stands in mixtures and stands of single cultivars shaped the soil environment in a similar way in respect of humidity and temperature, pH and the content of macroelements. Soil biological activity under one- and many-cultivar stands, as well as at a different position of cereals in crop rotations, turned out to be difficult for clear assessment based on the results obtained, due to a large dynamics of the analysed parameters in time.

In the study by Szempliński [2003b], a three-component mixture of spring barley cultivars (Boss + Rambo + Rodos), differentiated in respect of the type of resistance to powdery mildew breeds, did not differ in the yieldlevel from the Rodos cultivar grown in pure stand. This can result from a small degree of plant infestation by fungal pathogens in all the years of the study.

Research on inter-species mixtures of cereals involved their various species and forms (hulled, naked). In two-species mixtures, hulled forms of spring barley and oat were most often used, whose proportion in the stand was 50% each (Table 3). They guaranteed very high and stable yields, and an increase in yield in relation to pure stands of the components ranged from 1.5 to 15.2% [Klima and Szarek 2003, 2004,

Piech et al. 2003, Sobkowicz 2003b, Szempliński 2003a, Kijora and Wróbel 2004, Idziak et al. 2007, Jakubiak and Gałęzewski 2007].

Table 3. Yield of inter-species mixtures of spring cereals of different species composition (according to various authors)

Tabela 3. Plonowanie mieszanek międzygatunkowych zbóż jarych o różnym składzie gatunkowym (według różnych autorów)

Author(s) Autor(zy)	Grain yield – Plon ziarna, $t \cdot ha^{-1}$			
	hulled oats owies oplewiony	hulled spring barley jęczmień jary oplewiony	mixture mieszanka	increase of yield in relation to pure stands wzrost plonowania w stosunku do siewów czystych %
1	2	3	4	5
Klima i Szarek [2003]	3.68	3.93	3.94	3.5
Piech i in. [2003]	6.43	5.58	6.24	3.9
Sobkowicz [2003a]	4.52	5.80	5.64	9.3
Szempliński [2003b]	6.35	5.79	6.35	4.6
Kijora i Wróbel [2004]	3.42	2.91	3.47	9.6
Klima i Szarek [2004]	4.44	4.29	4.43	1.5
Idziak i in. [2007]	4.50	4.20	4.70	8.0
Jakubiak i Gałęzewski [2007]	3.53	3.78	4.21	15.2
Michalski i Szołkowska [2007]	5.43	5.82	5.79	2.8
Michalski i Szołkowska [2007]	5.43	5.22	5.53	3.8
	naked oats owies nagoziarnisty	hulled spring barley jęczmień jary oplewiony	mixture mieszanka	
Szempliński [2003a]	4.26	5.79	5.36	6.7
Piech i in. [2003]	4.88	5.58	5.26	0.6
Klima i Szarek [2003]	2.70	3.93	3.56	7.4
Kijora i Wróbel [2004]	2.83	2.91	2.94	2.4
	hulled oats owies oplewiony	naked spring barley jęczmień jary nagoziarnisty	mixture mieszanka	
Szempliński [2003a]	6.35	4.45	5.47	1.3
Piech i in. [2003]	6.43	5.58	6.24	3.9
Klima i Szarek [2003]	3.68	3.93	3.94	3.5
Klima i Szarek [2006]	2.98	4.33	3.97	8.6
	naked oats owies nagoziarnisty	naked spring barley jęczmień jary nagoziarnisty	mixture mieszanka	
Szempliński [2003a]	4.26	4.45	4.49	3.2
	hulled oats owies oplewiony	spring triticale pszenżyto jare	mixture mieszanka	
Sobkowicz [2003b]	4.52	6.28	5.77	6.8
Klima i Szarek [2004]	4.44	4.43	4.53	2.1

Table 3 continued – cd. tabeli 3

1	2	3	4	5
	hulled spring barley jęczmień jary oplewiony	spring triticale pszenżyto jare	mixture mieszanka	
Sobkowicz [2003b]	5.80	6.28	6.33	4.8
Klima i Szarek [2004]	4.29	4.43	4.74	8.7
Klima i Szarek [2006]	4.33	3.92	4.22	2.3
	hulled spring barley jęczmień jary oplewiony	spring wheat pszenica jara	mixture mieszanka	
Jakubiak i Gałęzewski [2007]	3.53	3.52	3.30	-6.4
	spring wheat pszenica jara	hulled oats owies oplewiony	mixture mieszanka	
Jakubiak i Gałęzewski [2007]	3.52	3.78	4.05	10.9
	naked oats owies nagoziarnisty	spring triticale pszenżyto jare	mixture mieszanka	
Klima i Szarek [2003]	2.70	3.73	3.33	3.6

Mixtures of naked oat with hulled barley under better environmental conditions ensured a yield of 5,3-5,4 t·ha^{-1}, in weaker soils 3,0-3,6 t·ha^{-1}, and an increase in their yield in relation to weighted average grain yields of the components ranged from 0.6 to 7.4% [Klima and Szarek 2003, Piech et al. 2003, Szempliński 2003a, Kijora and Wróbel 2004]. Mixtures of hulled oat with naked barley gave yields at a level of 3.9-6.2 t·ha^{-1}, and an increase in their grain yield in relation to weighted average yields of the components from pure stands ranged from 1.3 to 8.6% [Klima and Szarek 2003, 2006, Piech et al. 2003, Szempliński 2003a].

The least research in the analysed literature referred to two-component mixtures with a proportion of naked forms of oat with spring barley, hulled barley with spring wheat, spring wheat with hulled oat, naked oat with spring triticale, hulled oat with spring triticale and hulled barley with spring triticale [Klima and Szarek 2003, 2004, 2006, Sobkowicz 2003a, Szempliński 2003a, Jakubiak and Gałęzewski 2007]. In most hose mixtures the yields were higher by 2.1 to 10.9% as compared with weighted average yields of the components. In experiments by Jakubiak and Gałęzewski [2007], the mixture of hulled spring barley with spring wheat gave a lower yield than it results from weighted average grain yields of the components (Table 3).

In practice, growing cereal mixtures is recommended in light soils, in which mixture components better utilize the site elements than their species in pure stands. Dudek et al. [2006] studied the effect of sprinkling and nitrogen fertilization on the yield of spring cereal mixtures (barley with oat, barley with wheat), cultivated in a very light soil of low water capacity. They indicated that sprinkling, irrespective of climatic conditions, always significantly increased the grain yield of cereal mixtures and resulted in favourable changes in yield structure. Average grain increase obtained under the influence of sprinkling exceeded 100% and in the case of oat with barley they amounted to 2.31 t·ha^{-1}, and for oat with wheat – 2.66 t·ha^{-1}. The result of sprinkling, expressed with an increase in grain weight, for oat with barley was on average 31.6 kg·mm^{-1}, and for oat with wheat, on

average 36.4 kg·mm^{-1} of water. Sprinkling in the first place resulted in an increase in 1000 grain weight – in the oat-barley mixture by 11.1%, and in the oat-wheat mixture by 14.8%. The proportion of wheat in the mixture increased by 14.4%, and of barley by 3.5%. Fertilization of mixtures with nitrogen did not differentiated significantly their yield and to a small extent affected useful features. Under conditions without sprinkling, higher grain yield was usually obtained when fertilization was lower, whereas after the application of irrigation, mixtures fertilized with a double rate of nitrogen yielded slightly better. The authors point our that the mixture of oat with spring wheat gave higher yields and responded better to sprinkling than that of oat with spring barley.

In the study by Oleksy and Szmigiel [2005], where the grain yield heigth of winter triticale (Bogo, Fidelio) mixtures with a growing proportion in the stand (25, 50, 75%), with winter wheat (Almari) was estimated, they did not observed a higher yield of triticale-wheat mixtures in relation to triticale cultivated in pure stand. Higher yields of the mixtures were favoured by a growing proportion of triticale. Triticale cultivars grown in mixtures with wheat formed the less grains in ears than in pure stand, the higher was the proportion of wheat in the mixture.

Tobiasz-Salach et al. [2007] compared the yield level of two oat cultivars (hulled and naked forms) in pure stand and in mixtures with barley (hulled and naked) and with wheat and triticale. Grain yields of mixtures with hulled oat of the Bajka cultivar were by 1.4 to 14.2% lower than those of oat in pure stand. The mixture of naked oat of the Polar cultivar with triticale yielded by 16.3%, and with naked barley by 5.4% higher than the Polar cultivar in pure stand. The other mixtures (with wheat and hulled barley yielded by 5.4 and 20.0% lower than oat of the Polar cultivar in pure stand. Hulled oat in mixture with triticale reduced the number and weight of grains per panicle in comparison with pure stand, and naked oat obtained a smaller number of grains per panicle in mixture with hulled barley, and their lower weight in mixture with naked barley.

Boligłowa and Znój [2003], determining the yieldlevel of oat in pure stand and in mixtures with barley and triticale under mountainous conditions, indicated that mixtures ensured by 2.1 to 5.9% higher yield level than oat in pure stand, and the highest, significant increase in yield was ensured by the oat-spring barley mixture. In the study by Buczek et al. [2007], mixtures with a predominance of oat and wheat turned out to be more fertile than other variants of mixtures, and than pure stands of cereals. The results obtained by Idziak et al. [2007], however, indicate better yieldof mixtures with a higher proportion of barley, and relatively lower – of mixtures with a predominance of oats in sowing, although oat in pure stand gave a slightly higher yield than barley.

Noworolnik and Terelak [2006], on the basis of the study concerning soil chemical conditions (pH, abundance in P, K, Mg), found that abundance of soil in magnesium had the largest effect on variability of yields of spring barley and oat in pure stands and mixtures, and soil abundance in phosphorus – the smallest. A stronger negative response of spring barley to soil acidity was observed in relation to the mixture, and much less in comparison with oat, which showed the highest toleration to low pH. Cereals responded to soil abundance in phosphorus in a similar way. High grain and protein yields of spring barley and oat and their mixture were obtained in conditions of soil pH above 5.5, the content of phosphorus above 48 mg P, potassium above 130 mg K and magnesium above 60 mg Mg·kg^{-1} soil. Barley showed a higher sensitivity to unfavourable agrochemical soil properties as compared with oat and the mixture. A larger proportion of spring barley in the grain yield of the mixture in relation to oat was observed in soils of pH above 5.5 and low abundance in potassium.

In another study, Noworolnik and Terelak [2005] compared the yield of spring barley, oat and their mixture in soil of very good rye complex, good rye complex and weak rye complex, formed from formations of different granulation. It was found that soil conditions had a significant effect on yield. The highest grain yield was obtained in soils of the very good rye complex. Barley and its mixture with oat in soils of the good rye complex yielded significantly higher than in the weak rye complex soils, and differences in oat yield were insignificant. Higher yields of barley, oat and their mixtures were obtained in more tight soils (heavy loamy sands, full and bedded down with light loamy sand). Cereals cultivated in soils of more loose granulometric composition decreased grain yield. This applied to a larger extent to barley and to a smaller extent to oat, whereas the mixture were in between this respect. Under worse soil conditions, grain of all cereals contained more protein, whereas under better conditions a higher proportion of barley grain than oat was obtained in mixture yield.

Idziak and Michalski [2007], comparing a response of spring barley and oat to cultivation in mixtures of various proportion of components, taking into account nitrogen fertilization, found that the preplant application of nitrogen affected a growth in cereal grain yield, irrespective of the sowing method. Lack of differences in mixture grain yield between treatments fertilized with rates 65, 80 and 95 kg $N \cdot ha^{-1}$ indicates a possibility of their high yield at reducing the amount of applied nitrogen. The authors characterized the behaviour of species in mixtures, in comparison with their pure stands, using the species response index (R). Spring barley gave the most favourable yields in mixtures with oat, where the proportion of barley in the seed material was 75 and 25% (R = 1.06 and 1.09). The best variant for oat was definitely cultivation in mixture with equal proportions of both components in the stand (R = 1.27), where at the same time the highest grain yield was obtained. A growth in grain yield in this mixture was the highest, by 8% higher in relation to weighted average yields of both components.

Szumiło and Rachoń [2007a], in the study over the effect of diversified chemical plant protection on yield of naked and hulled cultivars of spring barley and oat cultivated in purer stands and in mixtures indicated that the application of intensive protection, irrespective of cultivars and mixtures, resulted in a significant growth in yield – by 9.8% in relation to the treatment with the minimal level of plant protection. According to the authors, a higher productivity of mixtures can be obtained under conditions of intensive cultivation. A higher level of protection increased the mean productivity of a mixture by 8.7%. From the analysis of actual and expected yields it follows that mixed stands of naked forms of barley with oat responded with a decrease in grain yield by 7.8%, whereas mixtures of barley cultivars Antek + Rastik –with an increase in the actual yield by 7.3%.

It is stressed in the studies that the higher yield of mixtures is attributed to the phenomenon of complementary utilization of environmental resources by components of mixtures in different time, space (above- or underground) or form (water, light, nutrients) and inter-species competition responsible for changes in proportions of components in the final yield of the mixture. In experiments of Sobkowicz [2003a] grain yield of all the mixtures was significantly higher than the yield of one of its components cultivated in pure stand. Of the tested mixtures, the spring barley-triticale mixture gave the highest yield (63.3 $dt \cdot ha^{-1}$), and the other mixtures yielded significantly worse (from 4.9% to 10.9%). Yield stability of particular cereals was varied. The barley-triticale mixture was the least stable in yield, whereas the barley-oat mixture – the most. The author stresses that the most yield-forming character of the barley-triticale mixture and the three-element (barley + oat + triticale) mixture was

a result of complementary utilization of limited environmental factors and smaller lodging of barley. Plants of oat and triticale functioned as a support for barley, thus allowing for a higher relative productivity than in pure stand.

Sobkowicz [2003a] undertook to estimate the rate of accumulation of macroelements (nitrogen, phosphorus, potassium) by spring cereal mixtures at different growth stages. The study indicated that accumulating the mentioned macroelements by plants of mixtures by the major part of the growing period was similar to taking up of those elements by a more efficient component of mixtures cultivated in pure stand. As compared with pure stands, mixtures accumulated in the biomass a larger amount of nitrogen and phosphorus in the final yield. A comparison of potassium accumulation, however, was difficult due to its large losses in the last period of plant growth. Barley showed the highest effectiveness of utilization of accumulated elements to form grain yield, whereas oat showed the lowest. Of mixtures, the barley-triticale mixture best utilized the accumulated elements. In the ontogenetic development of plants a negative correlation was shown between the percentage content of macroelements and the biomass yield of cereals.

In the study by Leszczyńska [2006], conducted under laboratory and pot conditions over the allelopathic effect of spring cereals (barley, oat, wheat, triticale) in mixed stands, it was indicated that germination energy and germination capacity of cereal grain in mixtures and in pure stands did not differ significantly. The species composition of mixtures had an effect on the length and weight of germs and roots formed by kernels during germination. The chromatographic analysis of root exudates showed the presence of phenolic compounds, of which benzoic acid was dominant.

Szagała et al. [2004] estimated the sowing value of spring barley and oat obtained from pure and mixed stands. They indicated that barley found more favourable conditions for growth in mixture, reaching higher parameters of 1000 grain weight, uniformity, germination energy and capability of grain, as well as grain vitality and health, than in pure stand. Oat was characterized by slightly more favourable parameters of grain in pure stand (germination energy and capacity, vitality, as well as purity and humidity) than in mixture, and in the mixture it showed more favourable parameters only in respect of 1000 grain weight, a degree of their uniformity and the content of offal.

In studies over mixtures much attention is devoted to the state of their weed infestation in comparison with pure stands of the components. In the experiments by Jastrzębska [2009] the main external, biotic factor limiting cereal productivity was weed infestation. Inter-cultivar stands of winter wheat and spring barley in all crop rotations did not differ in respect of the degree of weed infestation in comparison with one--cultivar stands. Cereal cultivation in mixtures favoured potential weed infestation to a smaller degree than one-cultivar stands.

Also the results of 11-year study by Jastrzębska et al. [2006b], concerning comparison of biodiversity of the phytocenosis of a cereal mixture stand in relation to pure stands, are interesting. Biodiversity of cereal phytocenoses, besides the cultivated species (one in purer stand and two in mixed stands) was largely formed by weeds. The authors stress that the diversity of all the cereal stands strongly depended on the count of weeds, as an increase in their number in the stand weakened domination of the field crop, and the number of their species had a slightly less importance. Sowing two species of cereals instead of one clearly changed the value of the Shannon-Wiener diversity index calculated for the whole agrophytocenosis and it applies to both the spring analysis and that made before cereal harvesting. In spring, the diversity of mixture stand measured by this index was 1.58, and in summer – 0.99 and in both cases it was significantly higher than that calculated parallel for oat and barley in pure stands. The mixture was also

characterized by a significantly higher species diversity. Diversity indexes of weed communities for the mixture were usually higher than for all the association, since no field taxon reached the count equalling the cultivated species. On average for the years of the study, weed communities in stands did not differ in the values of the specific indexes of diversity and uniformity. The authors conclude that the highest grain yields were obtained in the mixture, with the lowest variability in years. A relation between yield and the count and diversity of weeds in cereal stands was not confirmed. Their productivity showed a negative correlation with the weed biomass.

Buczek et al. [2007], when assessing the herbicidal effect of spring cereal mixtures with varied proportions of oat, wheat and barley grown after different previous crops, indicated that the applied previous crops and variants of cereal mixtures significantly decreased the number of weeds and their dry weight in relation to pure stands. A method of sowing did not affect the number of weed species occurring, and short-lived weeds were dominant taxons.

Idziak et al. [2007], determining the weed infestation of stands of spring barley and oat and their mixtures at varied level of chemical protection, indicate that barley in pure stand was characterized by the strongest weed infestation, and the weed infestation of mixtures decreased along with increasing proportion of oat in the stand. The number of weeds in oat was similar to the weed infestation level of the treatment sown with the mixture with equal proportions of both components. However, chemical control of field plants did not cause changes in grain yield as compared with the treatment with only mechanical weed control. Only the application of full protection (including that against diseases and pest) resulted in an increase in grain yield by almost 3.5 $dt \cdot ha^{-1}$. Jakubiak and Gałęzewski [2007], assessing the effect of spring cereal cultivation in pure stand and in mixtures on weed infestation, indicated that spring wheat-oat and spring barley--oat mixtures were characterized by a smaller weed infestation, expressed by fresh and dry weight of weeds, as compared with pure stands of both components.

There are many works in the literature presenting the health of cereals cultivated in mixtures in relation to their pure stands. In the study by Wanic et al. [2005] the health of spring barley and oat cultivated in two-species mixtures after various previous crops was estimated. It was found that the incidence of all diseases of barley and oat in the mixture was considerably lower than in pure stand. The effect of the previous crop on development of barley diseases turned out to be small, whereas oat as a previous crop deteriorated the health of oat sown after it.

Jastrzębska [2009] found that inter-cultivar stands of winter wheat and spring barley in all crop rotations did not differ in respect of health from the compared one-cultivar stands. In the study by Boligłowa and Znój [2003], carried out under mountainous conditions depending on location on the slope, oat cultivated in two- or three-component mixtures showed almost ten times smaller infestation of leaves by *Puccinia coronata* than in pure stands, and it to a smaller extent reduced the growth of *Helminthosporium avenae*. Smaller infestation of oat leaves was observed in the three-component mixture than in that composed of two components. However, selection of a species to a mixture (barley, triticale) and location on a slope did not have an effect on changes in infestation of leaves by pathogens. Oat growing in the upper part of the slope, where worse soil conditions prevail, resulted in a significant increase in Fusarium foot rot.

Kurowski et al. [2007] in their studies estimated the health of spring barley and oat cultivated in a two-species mixture and pure stands after various previous crops. Growing cereals in a mixture had a positive effect on the health of plant assimilation apparatus. An increase in the incidence of all diseases in mixed stands was considerably

lower than that in pure stands. Mixed stand reduced foot rot on oat stronger than on barley. The fungus *Pseudocercosporella herpotrichoides* responded to the smallest extent both on the previous crop and on the stand in inter-species mixtures. From the tested previous crops, pea had the most favourable effect on the health of spring barley and oat.

Szumiło and Rachoń [2007a, b] indicated that inter-species mixtures with oat were more resistant to crown rust of oats (3.0-7.7%) than naked oat in pure stand. A mixture of spring barley cultivars decreased infestation by leaf rust of barley on average by 7.2% as compared with pure stand. Inter-species stands reduced the sensitivity of barley cultivars on net blotch of barley by 7.3-10.4%, and in naked barley they also decreased a degree of infestation by powdery mildew of cereals on average by 5.8%.

Tratwal [2006] examined the effect of mixed stands (two- and three-component) on reduction of diseases in winter barley. She found that growing of intra-cultivar mixtures can be an alternative form of its cultivation especially in small-outlay and ecological agriculture. The largest reduction in diseases occurred in the most diversified genetically three-component mixture. Plant infestation by *Blumeria graminis* f. sp. *hordei* was observed in a higher intensity. In the mixture, a reduction in the disease intensity in comparison with pure stands ranged from 2 to 41%.

Also the results of studies concerning the count of selected pests occurring in mixtures are presented in the literature. Such experiments were carried out among others by Jakubiak and Gałęzewski [2007], who indicated that spring wheat was the least infested by larvae of cereal leaf beetles, and their count on oat in pure stand was over two times larger than on barley. In mixtures of spring wheat with oat, a reduction in the count of cereal leaf beetle larvae amounted to almost 37%, and in mixtures of spring wheat with spring barley – 7%. In the mixture of spring barley with oat no reduction in the count of cereal leaf beetle larvae was recorded in relation to pure stands. In the case of thripses, no reduction was observed in any of the tested mixtures.

Szumiło and Rachoń [2007a, b] indicated a stronger feeding of cereal leaf beetles on plants of spring barley, especially of the naked form, than on plants of oat. Inter-species mixtures of cereals were to a smaller extent damaged by this pest than pure stands. The most damage of leaves was observed in inter-cultivar mixtures of spring barley. A higher level of protection, including the application of an insecticide, reduced the incidence of cereal leaf beetles both in pure stands and in all the variants of mixtures.

The presented review of literature is incomplete and it does not include many publications which appeared in the analysed period. Therefore, we apologize to the Authors whose works were not cited due to the limited scope of this study.

SUMMARY

In recent years, cereal mixtures occupy the largest area of spring cereals in Poland, and their grain plays an important role in the national fodder balance. The highest concentration of mixtures is noted in the east region, and the lowest in the south-west region. Higher yields of cereal mixtures results from complementary use of environmental resources by the mixture components in various time, space (above- or underground) or form (water, light, nutrients) and competition responsible for changes in components proportion in the final yield of the mixture. A better stability of yield is attributed to a higher competitiveness towards weeds and lower sensitiveness to diseases and pests than in pure stands of the components. Mixed stands of cereals show a favourable response in grain yield to intensification of their cultivation, especially to sprinkling, mineral fertilization

and chemical protection against agrophages. In recent years, a growing proportion of barley and oat with hulled grain in mixtures has been recorded. Although their yields are lower than those of mixtures of hulled forms, the grain is characterized by a better fodder quality – a lower content of fibre, and a higher content of protein and fat.

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MIESZANKI ZBOŻOWE W POLSKIM PIŚMIENNICTWIE NAUKOWYM Z LAT 2003-2007

ARTYKUŁ PRZEGLĄDOWY

Streszczenie. Opracowanie obejmuje przegląd wyników badań nad mieszankami zbożowymi opublikowanych w latach 2003-2007 w krajowych czasopismach naukowych. Przedstawiono w nim ważniejsze zagadnienia dotyczące plonowania, zachwaszczenia, porażenia przez patogeny i szkodniki. Mieszanki zbożowe zajmują w Polsce w ostatnich latach największą powierzchnię zasiewów spośród zbóż jarych, a ich ziarno pełni ważną rolę w krajowym bilansie paszowym. Najwięcej mieszanek uprawia się w regionie wschodnim, a najmniej w południowo-zachodnim. Wyższe plonowanie mieszanek zbożowych w porównaniu z siewami jednogatunkowymi wynika z komplementarnego wykorzystania zasobów siedliskowych przez komponenty mieszanki w różnym czasie, przestrzeni (nadziemnej lub podziemnej) czy formie (woda, światło, składniki pokarmowe) oraz konkurencji odpowiedzialnej za zmiany udziału komponentów w plonie końcowym mieszanki. Lepszą stabilność plonowania mieszanek zbożowych przypisuje się większej konkurencyjności wobec chwastów i mniejszej wrażliwości na choroby i szkodniki niż w siewach czystych komponentów. Uprawy mieszane zbóż wykazują korzystną reakcję w plonie ziarna na intensyfikację ich uprawy, zwłaszcza na deszczowanie, nawożenie mineralne oraz ochronę chemiczną przed agrofagami. Ze względu na coraz większy w ostatnich latach udział w mieszankach jęczmienia i owsa o nieoplewionym ziarnie, ich plony są wprawdzie niższe niż mieszanek form oplewionych, ale ziarno odznacza się lepszą jakością paszową – mniejszą zawartością włókna, a większą białka i tłuszczu.

Słowa kluczowe: mieszanki odmianowe, nagoziarnisty jęczmień, nagoziarnisty owies, nawożenie mieszanek, ochrona przed patogenami, regulacja zachwaszczenia

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