www.czasopisma.pan.pl PAN www.journals.pan.pl

JOURNAL OF PLANT PROTECTION RESEARCH Vol. 53, No. 1 (2013)

DOI: 10.2478/jppr-2013-0010

THE EFFECT OF WHEAT, BARLEY, AND OAT ROOT SYSTEM INTERACTIONS, IN TWO-SPECIES MIXTURES

Sylwia Kaczmarek, Kinga Matysiak, Roman Krawczyk*

Institute of Plant Protection – National Research Institute
Department of Weed Science and Plant Protection Techniques
Władysława Węgorka 20, 60-318 Poznań, Poland

Received: August 7, 2012
Accepted: January 12, 2013

Abstract: Pot experiments performed in the Institute of Plant Protection – National Research Institute were designed to determine the influence of the root systems of various spring cereal species sown in mixtures. The experiment used the Bryza variety of spring wheat, Antek variety of spring barley, and Cwał variety of oat, sown in two-species mixtures (8 + 8 plants per pot). In three of the six study objects, plastic sleeves were used at the time of sowing the seeds so as to separate the root systems of the cereal species under study. Cereals were harvested at full maturity. The height and number of stalks, the number of cereal spikes (panicles), dry root weight, dry stalk weight, the number of grains per spike (panicle), the 1,000-grain weight, and grain yield were established. The results have shown that the strongest competitor in the mixtures was barley. Barley also responded positively to the presence of both wheat and oat in the mixtures.

Key words: barley, cereal mixtures, oat, root competition, wheat

INTRODUCTION

A very high share of cereals in the crop structure has forced the search for ways to lessen the consequences of their excessive concentration in crop rotation. The solution to this problem may be the cultivation of cereals in mixtures. Biodiversity of mixed crops as a result of different morphological and physiological features, different soil, climate and cultivation requirements can greatly facilitate complementary use of habitat factors. Crop productivity can then be increased or at least yield stability can be improved. Knowledge of the biology of plants, their mutual tolerance in mixtures, and the response of mixture components to environmental factors is a prerequisite for choosing the species, the varieties, and their proportions in crop sowing and agricultural practice (Rudnicki 1994). The differences in the developmental speed of cereals in mixtures may lead to the domination of one of the species and subdomination of another (Listowski 1975; Rudnicki and Wasilewski 1993). Plant species composition can affect the intensity of the interaction between the root systems of individual species. Competition between root systems may change the availability of nutrients, either as a result of their exhaustion, or through mechanisms that limit access to them (Schenk *et al*. 1999; Kroon *et al*. 2003).

The study emphasizes the impact of root systems on biomass yield. The impact of root systems is said to be stronger compared to the competition of plants for light (Aerts *et al*. 1991). Mahmoud and Grime (1976) argue that the early type of competition takes place even before the development of the assimilation apparatus of plants.

Plants can also compete for nutrients as a result of allelopathic interactions (Callaway 2002). Cereals are the type of plants which contain numerous substances of an allelopathic nature. These substances can have an inhibitory or stimulatory effect on other neighbouring species (Barnes and Putnam 1986; Perez and Ormeno-Nunez 1991; Liu and Lovett 1993). Allelopathic compounds can be found in various parts of a plant, including the roots (Kato-Noguchi *et al*. 1994; Ashrafi *et al*. 2007; Ashrafi *et al*. 2009; Yuyan *et al*. 2009).

The aim of the study was to assess the competitive impact of the root systems of spring cereals, in mixed sowing.

The working hypothesis was that the root systems of cereal species interact, which in turn differentiates their morphological features and crop-yielding.

MATERIALS AND METHODS

In 2006, pot experiments were performed in five completely randomized replications, in a greenhouse at the Institute of Plant Protection – National Research Institute in Poznań, Poland. The study objects were the Bryza variety of wheat, the Antek variety of spring barley and the Cwał variety of oat, sown in mixtures (8 + 8 plants in a pot). All total, there were 6 objects with mixed sown seeds. In three of the objects, plastic sleeves (+S) were used during sowing. A quarter of a sleeve was filled with

*Corresponding address:
s.kaczmarek@iorpib.poznan.pl

soil and 4 kernels of a given species, thereby separating the species. The objects of the experiment were the following: 1. wheat (W) + barley (B) (-S), 2. wheat + oat (O) (-S), 3. barley + oat (-S), 4. wheat + barley (+ S), 5. wheat + oat (+S), 6. barley + oat (+S).

The ground for sowing the cereal seeds was a mixture of peat soil with a pH of 5.5–6.5 and a salinity of 1–2 g NaCl/l and quartz sand having a grain size of 0.2–0.8 mm, in a 1:1 ratio. The kernels sprouted in Petri dishes were placed in the ground. In each pot there were 20 kernels. Each pot had a diameter of 22 cm, height of 18 cm and the capacity of 4 litres. After 7 days of emergence, the number of kernels was reduced to 16 per pot. Mineral fertilizer NPKMg (4-15-15-3) at a dose of 1.52 g per pot was applied before cereal emergence. Ammonium nitrate (34%) at a dose of 0.95 g per pot was applied after cereal emergence. During the experiment, optimal moisture conditions were maintained.

Plants were harvested at full grain maturity (BBCH 89). The following parameters were determined for each cereal: the height and number of stalks, the number of spikes (panicles), dry root weight, dry stalk weight, the number of grains per spike (panicle), the 1,000-grain weight, and grain yield.

The results were statistically analyzed for one-factorial experiments using the analysis of variance at the significance level $\alpha \leq 0.05$. The least significant difference was described using Tukey's test.

RESULTS AND DISCUSSION

The aim of the pot experiment was to evaluate the impact of root systems of specific cereal species grown in mixtures, as many authors (Mahmoud *et al*. 1976; Vandermeer 1989; Sobkowicz 2001; Sobkowicz 2003) argue that the competition of root systems for nutrients precedes the competition for light. The research by Sobkowicz (2001) shows that dominance of barley over oat was the highest if these species interacted using their root systems or that dominance was the result of the combined interaction of their root systems and aerial parts. Taylor (1978), Michalski (1991) and Michalski and Idziak (1999) report that the phenomenon of competition between plants grown in mixtures, is manifested in the various characteristics of plants. The characteristics become modified due to morphological and developmental differences of individual species and other factors.

Rudnicki and Wasilewski (1994) report that the 1,000-grain weight of wheat in mixtures with barley and oat was lower than the weight of wheat in pure sowing. In contrast, Cousens *et al*. (2003) found a significant reduction in the number of kernels per spike of wheat grown in a mixture with oats.

Barley reacted positively to being in close proximity to wheat and oat root systems. This close proximity of the roots had a positive influence on almost all parameters evaluated in the experiment, except for the number of barley grains per spike (Figs. 1–7). The beneficial effects of the wheat and oat root systems on barley was confirmed in barley's grain yield. There was a significantly higher grain yield, compared to the study objects in which root systems of individual species were separated (Fig. 8).

In laboratory tests, Ashrafi *et al*. (2007 and 2009) confirmed the inhibitory effect of aqueous extracts made from leaves, stems, flowers and roots of barley. In these experiments, extracts of various parts of barley plants resulted in the reduction of the germination, seedling length, and weight of *Hordeum spontaneum* and *Agropyron repens*. An allelopathic potential of barley extracts on the germination and seedling growth of wheat was observed by Ben-Hammoud *et al*. (2001).

The dominance of barley grown in mixtures was also confirmed in the studies by Noworolnik (2007) and Sobkowicz (2003).

Michalski (1991) and Rudnicki and Wasilewski (1993) reported a similar number of barley tillers in the mixture and in pure stand.

An increase in the number of grains, of the barley grown in a mixture with oat compared with barley grown in pure stand was observed by Sobkowicz (2003). Rudnicki and Wasilewski (1994) found an increase in the number of grains of the barley grown in a mixture with wheat compared with barley grown in pure stand. On the other hand, Wanic (1994) found no significant differences in the number of grains when comparing barley grown in pure stand and in a mixture with oat.

In the presence of wheat, oat was characterized by a significantly greater number of stalks, greater plant height, a larger number of heads, greater weight of roots and stalks, and greater grain weight (Figs. 1–4, 6, 7). The presence of barley significantly affected the height of the oat plants, and increased root mass and the mass of stalks (Fig. 3, 4, 6). The root systems of both species sown with oat had a significant (stimulatory) effect. It was wheat, however, that turned out to be the more friendly species. In the presence of wheat, oat produced a significantly higher grain yield (Fig. 8).

In their experiments on the occurrence of allelopathy in oat, Kato-Noguchi *et al*. (1994) showed a significant inhibitory effect of L-tryptophan found in root exudates, on the growth of roots and coleoptile of other plants, including the species *Triticum aestivum*. In the studies by Idziak *et al*. (2007) and Sobkowicz (2003), oat grown in a mixture with barley, tillered better than in pure sowing. The growth of productive tillering of oat in mixtures with wheat compared to the mixture with barley were reported by Tobiasz-Salach *et al*. (2007).

Leszczyńska (1999), Rudnicki and Wasilewski (1994), Sobkowicz (2003), Tobiasz-Salach (2007), and Wanic (1994) found that oat produced a significantly greater number of grains in the panicle, in pure stands, than in mixtures with barley and wheat.

In her experiments, Wanic (1994) found no difference in the 1000-grain weight of barley and oat grown in pure and mixed sowing. In the studies conducted by Idziak *et al*. (2007) and Szumiło and Rachoń (2007), the cultivation methods used, to get a 1,000-grain weight of barley and oat did not significantly change the barley and oat weight.

Leszczyńska and Grabinski (2004) showed the inhibitory effect of barley and the stimulatory effect of oat on the roots of wheat. They also showed that wheat and barley had a negative effect on the kernels of oat. The same authors obtained different results with respect to barley, which in the presence of other cereal species responded with a reduction in root length.

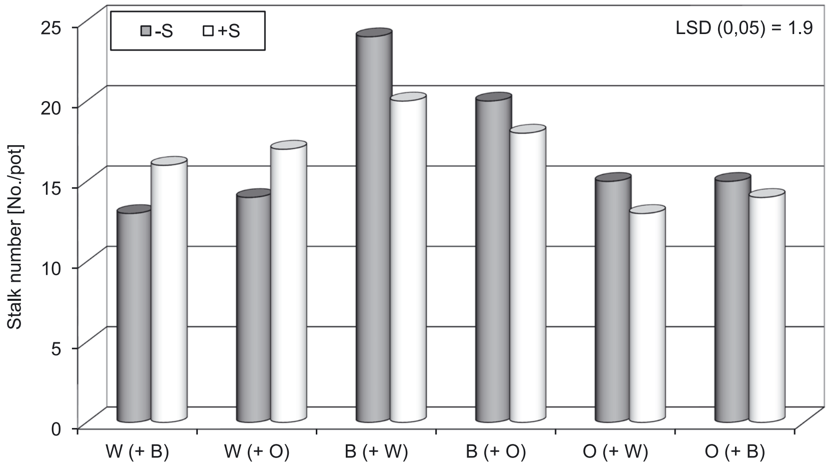

Fig. 1. Spring cereal stalk numbers [No./pot] – number
+S – objects with plastic sleeves, -S – objects without sleeves W – wheat, B – barley, O – oat

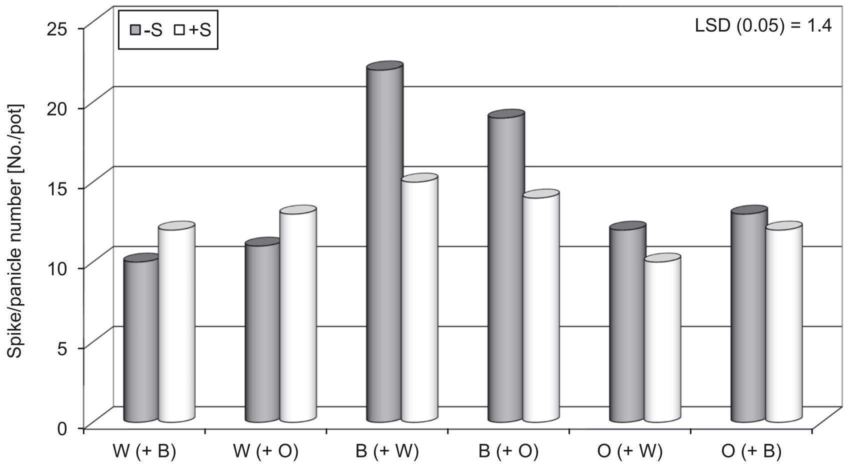

Fig. 2. Spring cereal spike/panicle numbers [No./pot] – number
+S – objects with plastic sleeves, -S – objects without sleeves W – wheat, B – barley, O – oat

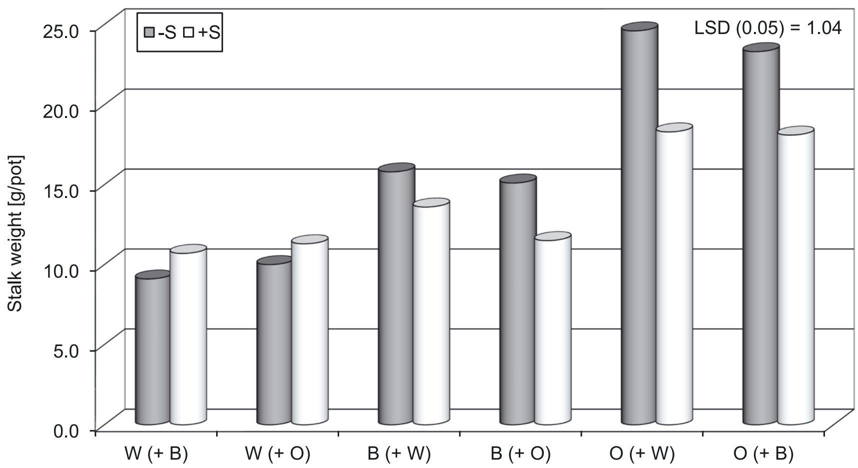

Fig. 3. Spring cereal stalk weights [g/pot] – weight
+S – objects with plastic sleeves, -S – objects without sleeves W – wheat, B – barley, O – oat

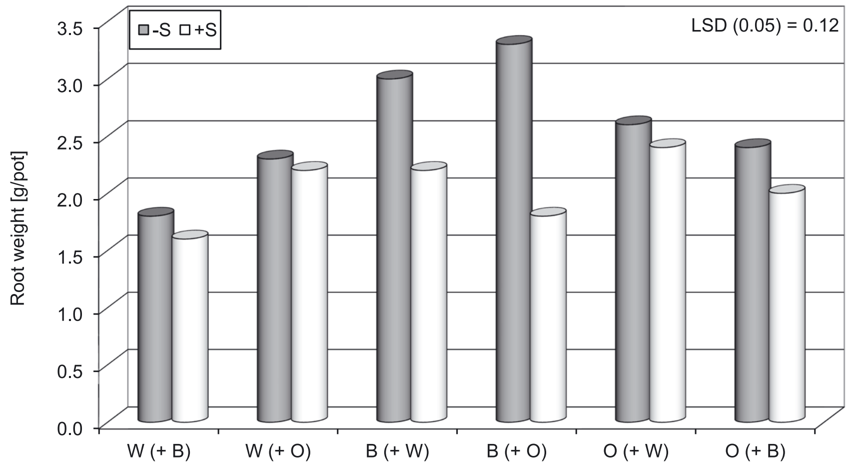

Fig. 4. Spring cereal root weights [g/pot] – weight
+S – objects with plastic sleeves, -S – objects without sleeves W – wheat, B – barley, O – oat

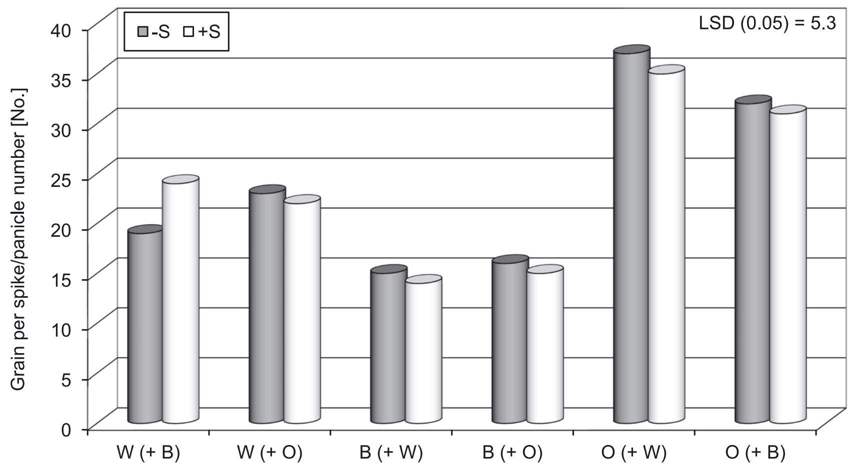

Fig. 5. Spring cereal grains per spike/panicle number [No.] – –
+S – objects with plastic sleeves, -S – objects without sleeves W – wheat, B – barley, O – oat

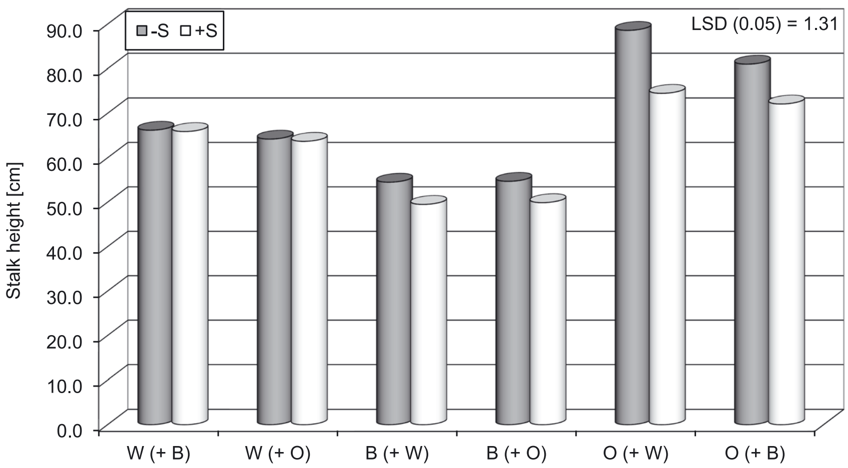

Fig. 6. Spring cereal stalk heights [cm] – height
+S – objects with plastic sleeves, -S – objects without sleeves W – wheat, B – barley, O – oat

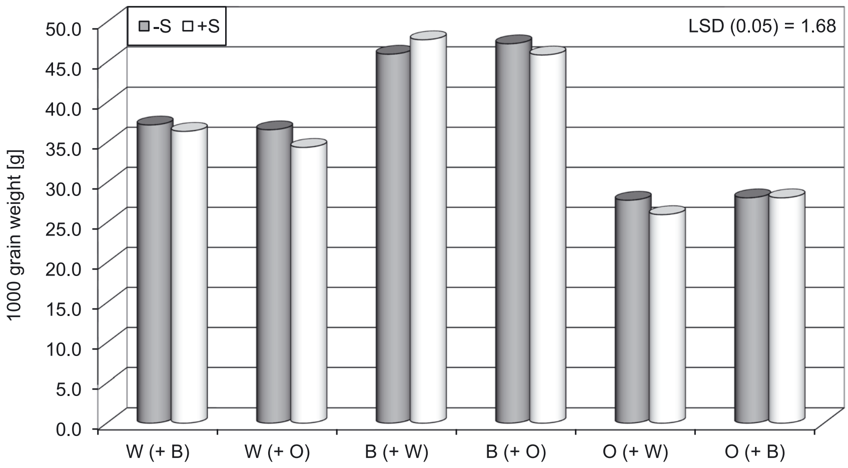

Fig. 7. Spring cereal 1,000 grain weights [g] – weight
+S – objects with plastic sleeves, -S – objects without sleeves W – wheat, B – barley, O – oat

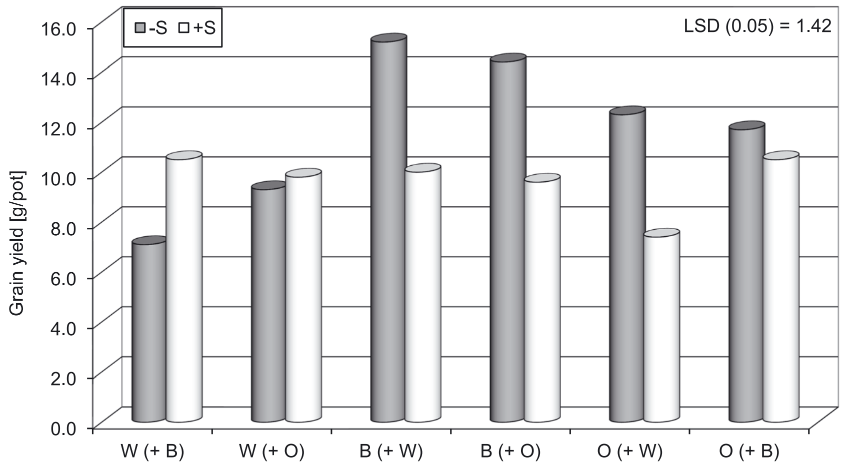

Fig. 8. Spring cereal grain yields [g/pot] – yield
+S – objects with plastic sleeves, -S – objects without sleeves W – wheat, B – barley, O – oat

CONCLUSIONS

1. Spring wheat reacted negatively to the presence of root systems of both species sown in mixtures (barley and oat), but on the basis of the yields it can be concluded that wheat's stronger competitor was barley.
2. The presence of both wheat and oat in the mixture, positively influenced spring barley. In the presence of both wheat and oat, the spring barley yield significantly increased (compared to the study objects in which the root systems of individual cereal species were separated).
3. On the basis of specific morphological and yield-producing characteristics, it can be stated that for oat, wheat was the more friendly mixture component. In the presence of wheat, oat showed a significant yield increase.

REFERENCES

Aerts R., Boot R.G.A., van der Aart P.J.M. 1991. The relation between above and belowground biomass allocation patterns and competitive ability. Oecologia 87: 551–559.

Ashrafi Z., Sadeghi S., Mashhadi H.R. 2007. Allelopathic effects of barley (*Hordeum vulgare*) on germination and growth of wild barley (*H. spontaneum*). Pak. J. Weed Sci. Res. 13 (1–2): 99–112.

Ashrafi Z., Sadeghi S., Mashhadi H.R. 2009. Inhibitive effects of barley (*Hordeum vulgare*) on germination and growth of seeding quack grass (*Agropyron repens*). Icel. Agric. Sci. 22: 37–43.

Barnes J.P., Putnam A.R. 1986. Evidence for allelopathy by residues and aqueous extracts of rye (Secale cereale). Weed Sci. 34 (3): 384–390.

Ben-Hammouda M., Ghorbal H., Kremer R.J., Queslati O. 2001. Allelopathic effect of barley extracts on germination and seedling growth of bread and durum wheat. Agronomie 21: 65–71.

Callaway R.M. 2002. The detection of neighbors by plants. Trends Ecol. Evol. 17 (3): 104–105.

Cousens R.D., Barnett A.G., Barry G.C. 2003. Dynamics of competition between wheat and oat: I. Effects of changing the timing of phonological events. Agron. J. 95 (5): 1295–1304.

Idziak R., Michalski T., Osiecka B. 2007. Zachwaszczenie i plonowanie mieszanek jęczmienia jarego z owsem w warunkach zróżnicowanej ochrony chemicznej. Zesz. Probl. Post. Nauk Rol. 516: 55–63.

De Kroon H., Mommer L., Nishiwaki A. 2003. Root competition: towards a mechanistic understanding. Root Ecol. 168: 215–234.

Kato-Noguchi H., Mizutani J., Hasegawa K. 1994. Allelopathy of Atos. 2. Allelochemical effect of L-tryptophan and its concentration in oat Root exudates. J. Chem. Ecol. 20 (2): 315–319.

Leszczyńska D. 1999. Wpływ wybranych czynników agrotechnicznych na plonowanie trójskładnikowej mieszanki zbożowej. Pam. Puł. 114: 233–354.

Leszczyńska D., Grabiński J. 2004. Kiełkowanie zbóż w układach mieszanych – aspekt allelopatyczny. Annales UMCS, Sec. E, 59 (4): 1977–1984.

Listowski A. 1975. Z zagadnień fizjologii plonowania. Post. Nauk Roln. 4 (153): 3–34.

Liu D.L., Lovett J.V. 1993. Biologically active secondary metabolities of barley II – Phytotoxicity of barley allelochemicals. J. Chem. Ecol. 19: 2231–2244.

Mahmoud A., Grime J.P. 1976. An analysis of competitive ability in three perenial grasses. New Phytol. 77 (2): 431–435.

Michalski T. 1991. Rozwój i plonowanie jęczmienia jarego i owsa w siewie czystym i w mieszankach. Rocz. AR Pozn. 226: 113–121.

Michalski T., Idziak R. 1999. Plonowanie owsa rosnącego w mieszankach i w siewie czystym w zależności od nawożenia azotowego. Kraków. Żywność, Nauka, Technologia, Jakość 1 (18): 38–45.

Noworolnik K. 2007. Wpływ gęstości siewu na strukturę plonu ziarna mieszanki jęczmienia z pszenicą w zależności od jakości gleb. Zesz. Prob. Post. Nauk Rol. 516: 145–152.

Perez F.J., Ormeno-Nunez J. 1991. Difference in hydroxamic acid content in roots and root exudates of wheat (*Triticum aestivum* L.) and rye (*Secale cereale* L.): possible role in alllelopathy. J. Chem. Ecol. 17: 1037–1043.

Rudnicki F., Wasilewski P. 1993. Badania nad uprawą jarych mieszanek zbożowych, II. Reakcja jęczmienia, owsa i pszenicy na uprawę w mieszankach. Rocz. AR Poznań CCXLIII: 65–72.

Rudnicki F. 1994. Biologiczne aspekty uprawy zbóż w mieszankach. p. 7–15. In: Mat. Konf. ,,Stan i perspektywy uprawy mieszanek zbożowych". Poznań, 2 grudnia 1994, 198 pp.

Rudnicki F., Wasilewski P. 1994. Porównanie wydajności jarych mieszanek zbożowych na glebie kompleksu żytniego dobrego. p. 81–87. In: Mat. Konf. „Stan i perspektywy uprawy mieszanek zbożowych". Poznań, 2 grudnia 1994, 198 pp.

Schenk H.J., Callaway R.M., Mahall B.E. 1999. Spatial root segregation: are plants territorial? Adv. Ecol. Res. 28: 145–180.

Sobkowicz P. 2001. Nadziemna i podziemna konkurencja między jęczmieniem i owsem w mieszance w początkowym okresie wzrostu. Frag. Agron. 2: 103–119.

Sobkowicz P. 2003. Konkurencja międzygatunkowa w jarych mieszankach zbożowych. Zesz. Nauk. AR Wrocław 458, 105 pp.

Szumiło G, Rachoń L. 2007. Siewy czyste i mieszane nagoziarnistych i oplewinych odmian jęczmienia jarego i owsa. Cz. II. Porównanie plonowania i zdrowotności. Zesz. Probl. Post. Nauk Rol. 516: 257–265.

Tobiasz-Salach R., Bobrecka-Jamro D., Buczek J. 2007. Plonowanie owsa w siewie czystym i w mieszankach ze zbożami jarymi. Fragm. Agronom. 4 (96): 218–223.

Taylor B. R. 1978. Studiem on a barley – oats mixture. J. Agric. Sci. Camb. 91 (3): 587–592.

Wanic M. 1994. Plonowanie mieszanki zbożowej w różnych układach płodozmianowych na glebie sredniej. p. 16–22. Mat. Kof. „Stan i perspektywy uprawy mieszanek zbożowych". Poznań, 2 grudnia 1994, 198 pp.

Vandermeer J. 1989. The Ecology of Intercropping. Cambridge University Press, Cambridge, p. 4.

Yuyan W., Fengzhi W. Shouwei L. 2009. Allelopathic effects of root exudates from wheat, poat and soybean on seed germination and growth of cucumber. Allelopathy J. 24 (1): 103–112.