POLISH JOURNAL OF NATURAL SCIENCES
Abbrev.: Pol. J. Natur. Sc., Vol 28(1): 7–16, Y. 2013

EFFECT OF ITALIAN RYEGRASS (*LOLIUM MULTIFLORUM* LAM.) GROWN AS AN INTERCROP ON MORPHOLOGICAL TRAITS OF SPRING BARLEY (*HORDEUM VULGARE* L.) UNDER WATER DEFICIT STRESS*

Marta K. Kostrzewska, Kinga Treder, Magdalena Jastrzębska, Maria Wanic

Department of Agriculture Systems
University Warmia and Mazury in Olsztyn

K e y w o r d s: spring barley, morphological traits, Italian ryegrass, water.

A b s t r a c t

A pot experiment, set up in an additive design, was run in order to assess the effect of Italian ryegrass on morphological traits of spring barley at different phases of its development under optimal and 50% lower soil moisture content. The following traits were measured: plant height, number of developed leaves per plant, length of ears, number of grains in an ear and length of roots. The assessment was completed during five development phases of barley (the BBCH scale): emergence (10–13), tillering (22–25), stem elongation (33–37), heading (52–55) and ripening (87–91). In 2009–2011, 3 cycles of the experiment were completed. It has been shown that Italian ryegrass did not have any significant negative effect on the morphology of spring barley's aerial organs, although it retarded the development of roots during emergence, as reflected by their length. Water supply differentiated demonstrably the rate of growth and development of crops. Its deficit restrained the growth of spring barley throughout the whole growing season. Besides, shortage of water was responsible for a smaller number of leaves and shoots on plants, shorter ears and less numerous grains in an ear. The presence of Italian ryegrass as an intercrop, in comparison with a spring barley pure stand, did not exacerbate the negative impact of water shortage on the morphological traits of this cereal.

Address: Marta K. Kostrzewska, University Warmia and Mazury in Olsztyn, Plac Łódzki 3, 10-718 Olsztyn, Poland, phone +48 (89) 523 37 91, e-mail: marta.kostrzewska@uwm.edu.pl
* This study was performed as part of the Ministry of Science and Higher Education research project no N N310 082836.

WPŁYW ŻYCICY WIELOKWIATOWEJ (*LOLIUM MULTIFLORUM* LAM.) JAKO WSIEWKI NA CECHY MORFOLOGICZNE JĘCZMIENIA JAREGO (*HORDEUM VULGARE* L.) W WARUNKACH STRESU WODNEGO

Marta K. Kostrzewska, Kinga Treder, Magdalena Jastrzębska, Maria Wanic

Katedra Systemów Rolniczych
Uniwersytet Warmińsko-Mazurski w Olsztynie

Słowa kluczowe: jęczmień jary, charakterystyka morfologiczna, życica wielokwiatowa, woda.

Abstrakt

W doświadczeniu wazonowym, założonym według schematu addytywnego, oceniano wpływ życicy wielokwiatowej na cechy morfologiczne jęczmienia jarego w różnych fazach jego rozwoju w warunkach optymalnego i zmniejszonego o 50% uwilgotnienia materiału glebowego. Badania obejmowały pomiary: wysokości roślin i liczby rozwiniętych liści na roślinie, długości kłosów, liczby zawiązanych ziaren w kłosie oraz długości korzeni. Ocenę przeprowadzano w pięciu fazach rozwojowych jęczmienia (skala BBCH): wschody (10–13), krzewienie (22–25), strzelanie w źdźbło (33–37), kłoszenie (52–55) i dojrzewanie (87–91). W latach 2009–2011 zrealizowano 3 cykle doświadczenia. Wykazano, że życica nie miała istotnego ujemnego wpływu na morfologię części nadziemnych jęczmienia jarego, jednak podczas wschodów osłabiała rozwój korzeni wyrażony ich długością. Czynnikiem silnie różnicującym tempo wzrostu i rozwoju roślin była dawka wody. Jej niedobór ograniczał wzrost jęczmienia jarego przez cały okres jego wegetacji, a ponadto redukował liczbę liści i pędów oraz powodował skrócenie kłosa i zmniejszenie liczby ziaren w kłosie. Obecność życicy wielokwiatowej jako wsiewki, w relacji do siewu czystego jęczmienia jarego, nie pogłębiała negatywnego oddziaływania niedoboru wody na cechy morfologiczne tego zboża.

Introduction

Currently, intercrops are less important as a source of animal feed, but their role as a factor enriching soil with organic matter gains in importance owing to improved physiochemical properties of soil and the biotic condition of the whole environment. The structure of grown intercrops is dominated by stubble-field catch crops. Intercrops sown between a main crop are far less common (JASKULSKA and GAŁĘZEWSKI 2009). There is a wealth of references discussing the multifaceted functions of intercrops, for example review papers by SONGIN (1998) and ANDRZEJEWSKA (1999) and more recent articles by GALON et al. (2011), JASTRZĘBSKA (2009), KOSTRZEWSKA et al. (2011), PAŁYS et al. (2009), PAWŁOWSKI and WOŹNIAK (2000), SOBKOWICZ (2009), WANIC et al. (2012), etc.

Legumes and grasses are recommended as intercrops, either as pure stands or mixed with winter or spring cereals. Italian ryegrass belongs to grass species sown as intercrops in cereal fields, including spring barley. However, in dry years, Italian ryegrass can heavily compete with a cereal crop for water (WANIC et al. 2006), which may cause a lower yield of the protective crop. The yielding success of a mixture components and catch crop has been frequently documented in the literature (JASKULSKI 2004, KURASZKIEWICZ 2004, PŁAZA and CEGLAREK 2004, PŁAZA et al. 2010, WOŹNIAK 2000). Other consequences of the competition between crops and intercrops are changes in the rhythm of development of plants, their altered density, fecundity and morphology, but articles dealing with these questions are rarer (CRALLE et al. 2003, SOBKOWICZ 2003, YACHI and LOREAU 2007). The purpose of this study has been to evaluate the effect of Italian ryegrass on morphology of spring barley at different phases of its development and under different soil moisture conditions.

Materials and Methods

The research was based on a strict pot experiment carried out at the Greenhouse Laboratory of the Faculty of Biology and Biotechnology, at the University of Warmia nad Mazury in Olsztyn. In 2009–2011, three cycles of the experiment were run. The evaluated plant was a hull-less cultivar of spring barley called Rastik.

The experimental factors:

First order – stand type: pure stand (C) and in a mixture with Italian ryegrass (M),

Second order – water supply to plants: sufficient to satisfy the requirements (W) and less by 50% (N).

The soil material was collected from the arable horizon of typical brown soil developed from weak loamy sand. The soil was slightly acid in reaction, contained 1.22–1.91% of humus and was moderately abundant in phosphorus, potassium and magnesium. One week before sowing, each pot was filled with 8 kg of soil material, which had been mixed with mineral fertilizers in the following amounts (pure component in g per pot^{-1}): 0.5 N (urea), 0.2 P (monopotassium phosphate), 0.45 K (potassium sulphate).

The total amount of water supplied to plants during the whole growing season was 17,000 cm^3 per pot in the optimum water supply variant and half of this amount, i.e. 8,500 cm^3 per pot in treatments with water deficit. The optimum amount of water had been established based on a preliminary experiment, in which soil moisture content, water evaporation from soil, transpiration from plants and water content in plants had been measured. During the plant growing season, water supply was varied depending on the development phase of the crops and soil moisture content.

The experiment was set up in an additive design, with four replicates (SEMERE and FROUD-WILLIMAS 2001). Eighteen germinating spring barley kernels were planted in each pot as well as 18 kernels of Italian ryegrass in pots with a mixed stand. Kernels were placed in soil 3 cm deep, at even distance from one another, using a template for that purpose.

Throughout the whole experiment, the ambient temperature in the laboratory was maintained at 20–22°C. In order to induce vernalization, the temperature was lowered to 6–8°C for 9 days when plants were in the full emergence period.

The morphological traits of spring barley were measured on five dates corresponding to five development phases of this cereals in a pure stand and under optimal soil moisture content, i.e. (on the BBCH scale) emergence (10–13), tillering (22–25), stem elongation (33–37), heading (52–55) and ripening phase (87–91). The measurements comprised height of plants, number of stems per plant, number of developed leaves per plant, and starting from the tillering phase, length of ears and number of grains in an ear. Because it was difficult to sort out roots of the protective crop and intercrop, the measurements of the root system included only the length of the longest root from each plant at the emergence phase.

The results in the tables are means for the three cycles of the experiment. The results from the experiment in a totally randomized design underwent statistical processing by analysis of variance and differences between treatments were estimated using Duncan's test. In all statistical analyses, the level of confidence was set at $p=0.05$.

Results

The stand type did not have any significant effect on height of spring barley plants at any of the analyzed plant development stages (Table 1). The lower water supply, however, significantly limited the growth of barley throughout the whole growing season. As a result, differences in plant height between pots with insufficient and optimal soil moisture content ranged from 4 cm (at emergence) to nearly 18 cm (at heading stage). The experiment has also shown that plant water supply had significant influence on the plant height irrespective of the stand type. When supplied with sufficient amounts of water, barley plants, whether sown as pure stand or mixture, were higher throughout the whole growing season than under water shortage conditions (differences statistically confirmed). This negative effect of water shortage on barley growth deepened at the end of the growing season.

The number of barley shoots at the analyzed development phases was similar for both stand types (Table 2). Less water in soil, however, significantly depressed the formation of lateral stems. Under water deficit in soil, barley plants sporadically grew non-productive lateral shoots, which dried out prema-

Table 1

Height of spring barley plants [cm]

Source of variability	Treatment	Spring barley development phases				
		emergence	tillering	stem elongation	heading	ripeness
Stand type	C	26.2[a]	42.0[a]	47.1[a]	51.9[a]	54.0[a]
	M	25.2[a]	42.1[a]	46.8[a]	51.4[a]	52.7[a]
Plant water supply	W	27.8[a]	48.2[a]	55.8[a]	59.0[a]	59.0[a]
	N	23.6[b]	35.9[b]	38.1[b]	44.2[b]	47.7[b]
Interaction of factors	C – W	28.7[a]	47.6[a]	56.2[a]	59.6[a]	61.2[a]
	C – N	23.7[b]	36.4[b]	37.9[b]	44.1[b]	46.8[c]
	M – W	26.9[a]	48.8[a]	55.3[a]	58.4[a]	56.7[ab]
	M – N	23.5[b]	35.3[b]	38.2[b]	44.3[b]	48.6[bc]

C – pure stand, M – mixed with Italian ryegrass, W – water supply satisfying requirements, N – water supply less by 50%
a, b, c – homogenous groups: values marked with the same letter within particular factors or their interactions do not differ significantly at $p = 0.05$

Table 2

Number of spring barley stems, stems plant^{-1}

Source of variability	Treatment	Spring barley development phases			
		tillering	stem elongation	heading	ripeness
Stand type	C*	1.5[a]	1.6[a]	1.6[a]	1.7[a]
	M	1.4[a]	1.5[a]	1.3[a]	1.4[a]
Plant water supply	W	1.7[a]	1.9[a]	1.6[a]	1.6[a]
	N	1.2[b]	1.2[b]	1.3[b]	1.4[a]
Interaction of factors	C – W	1.7[a]	1.9[a]	1.7[a]	1.8[a]
	C – N	1.2[b]	1.2[b]	1.4[ab]	1.5[a]
	M – W	1.7[a]	1.8[a]	1.5[a]	1.4[a]
	M – N	1.1[b]	1.1[b]	1.1[b]	1.3[a]

* key cf. the Table 1

turely. Until the heading phase, spring barley grown in pots with an optimal water dose produced significantly more shoots than plants grown on less moist soil. More extensive tillering of barley was observed in both pure and mixed stands.

The number of leaves on spring barley plants was similar in pure and mixed stands (Table 3). No differences were noticed during the whole vegetative season. However, this trait was significantly differentiated by the amount of water available to plants. From emergence to stem elongation, significantly fewer assimilatory organs were found on plants growing under water deficit than in treatments with an optimum water supply. However, the proportions

Table 3

Number of spring barley leaves, leaves plant^{-1}

Source of variability	Treatment	Spring barley development phases				
		emergence	tillering	stem elongation	heading	ripeness
Stand type	C*	2.8^{a}	5.7^{a}	7.7^{a}	6.7^{a}	7.1^{a}
	M	2.9^{a}	5.7^{a}	7.7^{a}	6.8^{a}	7.3^{a}
Plant water supply	W	3.1^{a}	6.8^{a}	9.2^{a}	5.9^{b}	6.3^{b}
	N	2.6^{b}	4.6^{b}	6.2^{b}	7.6^{a}	8.1^{a}
Interaction of factors	C – W	3.0^{ab}	6.6^{a}	9.0^{a}	5.8^{b}	6.4^{b}
	C – N	2.6^{b}	4.8^{b}	6.3^{b}	7.6^{a}	7.8^{a}
	M – W	3.1^{a}	6.9^{a}	9.3^{a}	5.9^{b}	6.2^{b}
	M – N	2.6^{b}	4.4^{b}	6.1^{b}	7.6^{a}	8.3^{a}

* key cf. the Table 1

were reverse during the two subsequent phases, i.e. heading and ripening. When analyzing the interactions between the examined factors, it was found out that during emergence significantly more water was held in leaves of barley grown in a mixed stand and with optimum water supply than in pots with insufficient soil moisture. During the tillering and stem elongation phases, water deficit in soil made barley plants form significantly fewer assimilatory organs (2–3 leaves fewer) in both stand types compared to barley cultivated on moist soil. During the two final phases, the situation was opposite: irrespective of the stand type, the treatments poorer in water produced barley plants with more leaves (differences statistically verified) than the pots in which soil was moist enough to sustain good development of the plants. This was most probably a consequence of the different barley development rates induced by different water availability; under the lower water supply, the consecutive development phases began with a delay. At the same time, when the soil moisture content was optimal, lower leaves on barley plants began to wilt.

The length of barley ears did not depend on the stand type (Table 4). Reducing the water supply to half the optimal level resulted in the formation of shorter ears, but this effect was significant only during the heading phase. The response of barley to water deficit consisted of a significant reduction in the number of grains (by about 8 to 4 grains) compared to the pots with an optimal water supply. Our analysis of the interactions between the factors did not reveal significant differences in the values of this trait, but when barley plants received as much water in soil as required, a tendency towards a higher number of grains in barley ears, both grown in a pure stand or mixture with Italian ryegrass, was observed.

Table 4

Length of ear [cm] and number of grains per ear

Source of variability	Treatment	Spring barley development phases		
		heading	ripeness	
		length of ear		number of grains
Stand type	C M	6.1^{a} 5.9^{a}	5.2^{a} 5.1^{a}	5.9^{a} 6.2^{a}
Plant water supply	W N	7.0^{a} 5.0^{b}	5.7^{a} 4.7^{a}	7.9^{a} 4.2^{b}
Interaction of factors	C – W C – N M – W M – N	7.0^{a} 5.1^{b} 6.9^{a} 4.8^{b}	5.8^{a} 4.6^{a} 5.3^{a} 4.8^{a}	8.0^{a} 3.7^{a} 7.7^{a} 4.7^{a}

* key cf. the Table 1

In the early growth, spring barley grown as a pure stand produced significantly longer roots (by an average of 3 cm for the three cycles of the experiment) than barley grown in a mixture with Italian ryegrass (Table 5). No significant effect of the soil moisture content of this trait was demonstrated. Our analysis of the interaction between the factors showed that during the emergence phase significantly longer roots were formed by barley growing alone under water deficit conditions than mixed with Italian ryegrass irrespective of the water supply.

Table 5

Length of spring barley roots [cm]

Source of variability	Treatment	Emergence
Stand type	C M	14.9^{a} 12.0^{b}
Plant water supply	W N	13.0^{a} 13.9^{a}
Interaction of factors	C – W C – N M – W M – N	14.0^{ab} 15.8^{a} 12.0^{b} 11.9^{b}

* key cf. the Table 1

Discussion

Competition is one of the major ecological processes present in nature. It shapes the dynamics, composition and structure of biocenoses. Bleasdeale (after CONNOLLY et al. 2001) defines competition as a phenomenon which results in a depressed or retarded growth of one or both competing plants and modification of their exterior shape relative to plants growing separately.

The response consisting of mutual interactions between components in a sowing mixture is expressed through changes in the development of not only aerial parts (height, surface area of leaves) but also root systems (length of roots). In this study, Italian ryegrass was not indicated to have caused an effect on the morphology of aerial organs of barley, but its presence resulted in shorter barley roots. However, GALON et al. (2011) concluded that although Italian ryegrass does not limit the height of barley, it can be highly competitive towards this cereal, reducing its tillering, surface area of leaves and accumulation of dry matter. Similar results were obtained by IGNACZAK (1995), who demonstrated less extensive tillering of a protective crop (barley) grown together with Westerwold ryegrass. According to CRALLE et al. (2003), the extent of mutual reactions between components of a sowing mixture depends on the proportions of plants of particular species sown on a field and on the soil's abundance in nutrients. PŁAZA and CEGLAREK (2004) claim that Italian ryegrass sown as an intercrop acts positively on barley only when mixed with papilionaceous plants, and the positive influence consists of improved density of ears before harvest, more grains per ear and higher weight of 1000 grains of barley.

Sensitivity of barley to variable moisture content in soil is a species-specific trait (WIELGO and DZIAMBA 2000, MARTYNIAK 2001). In this study, water deficit was shown to produce typically a significant negative effect on the examined spring barley traits from emergence to full grain ripeness. As stated by MARTYNIAK (2001), the response of barley to water deficit in the early vegetative season is weak, but any water shortage occurring at the early heading phase may cause the highest yield losses. Our results are highly congruent with the data reported by SAMARAH et al. (2009), who noticed depressed plant height and worse yield structure components (e.g. number of ears per plant and grains per ear, lower 1000 grains weight) in barley grown under water deficit stress in both laboratory and field experiments. Also, PŁAZA and CEGLAREK (2004) demonstrated significantly inferior yield characteristics of barley grown alone under precipitation shortage during the vegetative season, but showed a positive effect of intercrops such as mixed legumes and Italian ryegrass on yields of the protective crop, also in dry years. According to WIELGO and DZIAMBA (2000), when soil is less wet, crops grow shorter and produce shorter ears, whether or not grown in the presence of Italian ryegrass. Additionally, the number of ears and leaves as well as number of grains per ear decline, which means that the presence of Italian ryegrass as the intercrop did not matter in this respect under water deficit conditions. WANIC et al. (2006), who traced changes in the water content in soil cropped with spring barley and Italian ryegrass during a whole plant growing season concluded that the grass is too competitive towards barley during the stem elongation phase of this cereal.

Conclusions

1. The stand type did not have any effect on the morphology of aerial parts of spring barley, such as plant height, number of stems and number of leaves per plant, length of an ear and its content of grains.

2. Depressed water supply reduced the height of barley plants, number of leaves and shoots, length of an ear and number of grains in an ear.

3. Italian ryegrass as an intercrop in spring barley did not exacerbate the negative effect of water deficit on development of barley.

4. During the emergence phase of spring barley, the presence of Italian ryegrass had a negative effect on length of barley roots.

Translated by JOLANTA IDŹKOWSKA

Accepted for print 18.12.2013

References

ANDRZEJEWSKA J. 1999. *Międzyplony w zmianowaniach zbożowych*. Post. Nauk Rol., 1: 19–31.

CONNOLLY J., WAYNE P., BAZZAZ F.A. 2001. *Interspecific competition in plants: How well do current methods answer fundamental questions?* Am. Nat., 157(2): 107–125.

CRALLE H.T., FOJTASEK T.B., CARSON K.H., CHANDLER J.M., MILLER T.D., SENSEMAN S.A., BOVEY R.W., STONE M.J. 2003. *Wheat and Italian ryegrass (Lolium multiflorum) competition as affected by phosphorus nutrition.* Weed Sci., 51(3): 425–429.

GALON L., TIRONI S. P., ROCHA P.R.R., CONCENÇO G., SILVA A.F., VARGAS L., SILVA A.A., FERREIRA E.A., MINELLA E., SOARES E.R., FERREIRA F.A. 2011. *Habilidade competitiva de cultivares de cevada convivendo com azevém*. Planta Daninha, Viçosa-MG, 29(4): 771–781.

IGNACZAK S. 1995. *Plonowanie wybranych di- i tetraploidalnych odmian życicy wielokwiatowej, westerwoldzkiej i trwałej jako wsiewki poplonowej w jęczmień jary oraz jej wpływ na wydajność rośliny osłonowej*. Rocz. Nauk Rol., seria A, 111(3–4): 129–137.

JASKULSKA I., GAŁĘZEWSKI L. 2009. *Aktualna rola międzyplonów w produkcji roślinnej w środowisku.* Fragm. Agron., 26(3): 48–57.

JASKULSKI D. 2004. *Wpływ wsiewek międzyplonu na produkcyjność ogniwa jęczmień jary – pszenica ozima.* Acta Sci. Pol., Agricultura, 3(2): 143–150.

JASTRZĘBSKA M. 2009. *Mieszanki odmianowe pszenicy ozimej i jęczmienia jarego w płodozmianach zbożowych*. Wyd. UWM w Olsztynie, Rozprawy i Monografie, 152: 1–172.

KOSTRZEWSKA M.K., WANIC M., JASTRZĘBSKA M., NOWICKI J. 2011. *Wpływ życicy wielokwiatowej jako wsiewki międzyplonowej na różnorodność zbiorowisk chwastów w jęczmieniu jarym.* Fragm. Agron., 28(3): 42–52.

KURASZKIEWICZ R. 2004. *Następczy wpływ wsiewek międzyplonowych na plonowanie jęczmienia jarego na glebie lekkiej.* Ann. UMCS, Sec. E, 97: 1815–1821.

MARTYNIAK L. 2001. *A pot evaluation of the sensitivity of spring barley* (*Hordeum vulgare* L.) *to water stress applied at different growth stages*. J. Appl. Genet., 42(2): 145–151.

PAŁYS E., KURASZKIEWICZ R., KRASKA P. 2009. *Następczy wpływ wsiewek międzyplonowych i roślin ochronnych na chemiczne właściwości gleby lekkiej*. Ann. UMCS, Sec. E, 64: 81–90.

PAWŁOWSKI F., WOŹNIAK A. 2000. *Wpływ wsiewek poplonowych i nawożenia organicznego na plonowanie, zachwaszczenie i zdrowotność pszenżyta ozimego w monokulturze.* Cz. II. *Zachwaszczenie i zdrowotność.* Zesz. Probl. Post. Nauk Rol., 470: 83–89.

PŁAZA A., CEGLAREK F. 2004. *Wpływ wsiewki międzyplonowej i warunków pogodowych na plonowanie i jakość ziarna jęczmienia jarego.* Cz. I. *Plonowanie jęczmienia jarego.* Zesz. Nauk. AP w Siedlcach, Rolnictwo, 65: 33–41.

Płaza A., Ceglarek F., Królikowska M.A., Próchnicka M. 2010. *Działanie następcze wsiewek międzyplonowych i słomy jęczmienia jarego na plonowanie i elementy struktury plonu pszenżyta ozimego.* Folia Pomer. Univ. Technol. Stetin., Agric., Aliment., Pisc., Zootech., 276(13): 31–38.

Samarah N.H., Alqudak A.M., Amayreh J.A., McAndrews G.M. 2009. *The effect of late-terminal drought stress on yield components of four barley cultivars.* J. Agron. Crop Sci., 195: 427–441.

Semere T., Froud-Williams R.J. 2001. *The effect of pea cultivar and water stress on root and shot competition between vegetative plants of maize and pea*. J. Appl. Ecol., 38: 137–145.

Sobkowicz P. 2003. *Konkurencja międzygatunkowa w jarych mieszankach zbożowych*. Zesz. Nauk. AR we Wrocławiu, Rozprawy 458, 1–105.

Sobkowicz P. 2009. *Pobieranie i wykorzystanie azotu w uprawie jęczmienia jarego z wsiewką koniczyny perskiej i seradeli*. Problemy Inżynierii Rolniczej, 2: 99–106.

Songin W. 1998. *Międzyplony w rolnictwie proekologicznym*. Post. Nauk Rol., 2: 43–51.

Wanic M., Majchrzak B., Nowicki J., Waleryś Z., Orzech K. 2012. *Role of undersown catch crops and crop rotation in state of health of spring barley.* Acta Sci. Pol., Agricultura, 11(1): 113–124.

Wanic M., Michalska M., Treder K. 2006. *Spring barley overground biomass increase dynamics depending on sowing method and position in crops rotation system*. Pol. J. Natur. Sc., 20(1): 67–79.

Wielgo B., Dziamba S. 2000. *Wpływ zróżnicowanego nawożenia azotem i wilgotności gleby na plonowanie odmian jęczmienia jarego w siewie czystym i mieszanym*. Rocz. AR Pozn. CCCXXV, Roln., 58: 145–154.

Woźniak A. 2000. *Wpływ wsiewek poplonowych i nawożenia organicznego na plonowanie, zachwaszczenie i zdrowotność pszenżyta ozimego w monokulturze.* Cz. I. *Plon ziarna*. Zesz. Probl. Post. Nauk Rol., 470: 75–82.

Yachi S., Loreau M. 2007. *Does complementary resource use enhance ecosystem functioning? A model of light competition on plant communities*. Ecol. Lett., 10: 54–62.