ACTA AGROBOTANICA
Vol. 66 (3), 2013: 73–80
Original Research Paper
DOI: 10.5586/aa.2013.040

COMPETITION BETWEEN SPRING BARLEY (*Hordeum vulgare* L.) AND ITALIAN RYEGRASS (*Lolium multiflorum* Lam.) UNDER DIFFERENT WATER SUPPLY CONDITIONS

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Received: 18.01.2013

Abstract

A pot experiment with an additive design and three series was conducted to test competition between spring barley and Italian ryegrass under different soil moisture conditions. The experimental factors were as follows: 1. type of sowing – mixed sowing and pure sowing; 2. water supply – plants supplied with water to meet their full requirements and 50% water supply reduction. The study covered five phenological development stages (BBCH) of spring barley: emergence (10–13), tillering (22–25), stem elongation (33–37), heading (52–55), and ripening (87–91). The competitive effects were evaluated based on relative yield (RY), relative yield total (RYT), competitive balance (CB), and relative efficiency index (REI). Spring barley and Italian ryegrass competed for resources throughout the growing season. Competition intensity was found to increase until the heading stage, and it decreased towards the end of the growth cycle. More intense competition was observed under reduced water supply. Spring barley dominated over Italian ryegrass from the tillering stage to the ripening stage. In mixed populations, Italian ryegrass captured the available resources more effectively than spring barley from the stem elongation stage until the end of the growing season, particularly in the treatment with optimal water supply.

Key words: phenological development stages, relative yield, relative yield total, relative efficiency index, competitive balance index.

INTRODUCTION

Relationships between members of plants communities include negative interactions, such as competition. Competition is very common phenomenon that has the potential to alter the composition, structure and productivity of biocenoses. It occurs when individuals of the same or different species require a resource or resources that are in short supply, so that the availability of the resource to one individual or species is negatively influenced by the presence of the other individual or species [1,2]. The process starts at the beginning of the growth cycle and lasts, with various intensity, to its end [3–5]. Competition between different crop species, crop plants and weeds, and different weed species is well documented [4,6–10]. However, little attention has been paid to competition between cover crops and undersown crops [11]. The effect of water deficit on competition intensity during plant growth and development also remains poorly investigated [12]. In view of the above, the following research hypothesis was formulated: a cover crop (spring barley) and an undersown crop (Italian ryegrass) will compete for resources and water deficit will increase the intensity of competition between the species. The above hypothesis was verified during a pot experiment designed to evaluate the intensity of competition between spring barley and Italian ryegrass under abundant and deficient water supplies.

MATERIALS AND METHODS

A pot experiment with three series was conducted in 2009–2011 at the Greenhouse Lab. of the Faculty of Biology, University of Warmia and Mazury in Olsztyn. Spring barley (naked grain variety *Rastik*) and Italian ryegrass (var. *Gaza*) were grown in mixture and in pure stand under abundant and deficient water supplies. Pots were filled with proper brown soil developed from slightly loamy silty sand underlain by silty sand, collected at a depth of 0–25 cm.

The experimental factors were as follows:

1. type of sowing – mixed sowing and pure sowing;
2. water supply – plants supplied with water to meet their full requirements and 50% water supply reduction.

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In the treatments with optimal and reduced water supply, the total amount of water per pot over the growing season was 17 000 cm^3 and 8 500 cm^3, respectively. Water supply varied depending on the growth stage of plants and soil moisture content. The optimal amount of water supplied to the crops was determined during a trial which involved measuring soil moisture, the evaporation of water from soil, the rate of transpiration and the moisture content of plants.

An additive experimental design was used, according to which the number of plants in mixture was equal to the sum of crop densities in pure stands [13]. 120 Kick-Brauckmann pots with a diameter of 22 cm and a depth of 28 cm were used in each experimental series (3 sowing types – barley grown in pure stand, Italian ryegrass grown in pure stand, barley and Italian ryegrass grown in mixture x 2 levels of water supply x 5 growth stages x 4 replications). One week before sowing, each pot was filled with 8 kg soil mixed with mineral fertilizers (g × pot^{-1} on a pure ingredient basis): N – 0.5 (urea), P – 0.2 (monopotassium phosphate), K – 0.45 (potassium sulfate).

18 spring barley or Italian ryegrass seeds able to germinate were sown in each pot (in mixture, 18 barley seeds and 18 Italian ryegrass seeds were sown), 3 cm deep. Seeds were spaced at equal distances from each other within the pot using templates.

During the experiment, air temperature in the laboratory was maintained at 20–22 °C, and it was lowered to 6–8 °C at full emergence, for vernalization.

Competition between the analyzed species was studied at five phenological development stages (BBCH) of spring barley grown in pure stand under optimal soil moisture conditions: emergence (10–13), tillering (22–25), stem elongation (33–37), heading (52–55) and ripening (87–91). When barley had reached each of the above stages, all plants were removed from the pots (designated for a given stage), the aboveground parts were separated from the roots, air-dried and weighed. The data on aboveground dry weight biomass, presented by Wanic et al. [14], were used to determine:

– relative yield
  $RYi = Yij/Yii \qquad RYj = Yji/Yjj$
– relative yield total
  $RYT = RYi + RYj$
– competitive balance index
  $CB = \ln[(Yij/Yji)/(Yii/Yjj)]$
– relative efficiency index of species grown in mixture
  $REI = RGRij – RGRji$

where:

$RGR = 1/w \times dw/dt = d/dt (\ln w)$.

List of symbols:

RY*i* – relative yield of the *i-th* species (spring barley); RY*j* – relative yield of the *j-th* species (Italian ryegrass); Y*ii* – yield of the *i-th* species (spring barley) grown in pure stand; Y*jj* – yield of the *j-th* species (Italian ryegrass) grown in pure stand; Y*ij* – yield of the *i-th* species (spring barley) grown in mixture with the *j-th* species (Italian ryegrass); Y*ji* – yield of the *j-th* species (Italian ryegrass) grown in mixture with the *i-th* species (spring barley); RGR – relative growth rate of plants; w – aboveground dry weight biomass; dw – increase in aboveground dry weight biomass; dt – time interval at which the increase was determined (one day); ln – natural logarithm [15–18].

Mean values for three experimental series are presented. The results were processed statistically by factorial ANOVA, with two experimental factors: 1. growth stages of plants; 2. levels of water supply. The significance of differences between treatments was estimated by Duncan's test. The Student's t-test was used to check whether RYT values were different from 1, and whether CB and REI values were different from 0.

RESULTS

Table 1 data show that Italian ryegrass exerted a competitive effect on spring barley already at the beginning of the growth cycle. Relative yield (RY), determined for the total aboveground biomass of barley, was lower than 1, and it was not affected by water supply. At that stage, the adverse effect of Italian ryegrass on spring barley did not result from competition for limited resources (due to their small size, the plants also had low requirements), but from different types of interaction (e.g. allelopathy). Irrespective of water supply levels, the competitive effects of Italian ryegrass remained at a stable level until the stem elongation stage of barley (differences within the margin of error), they became stronger at the heading stage, and weakened again towards the end of the growth cycle. Throughout the growing season, an increase in aboveground biomass accumulation of barley was more restricted by Italian ryegrass in the treatment with 50% water supply reduction. The effect of restricted water supply was most noticeable during ripening. At that stage, the yield of barley grown in mixture was lower than its yield determined in pure stand, by 11% and 21% under abundant and deficient water supplies, respectively.

Spring barley also competed with Italian ryegrass for resources already at the emergence stage. The intensity of competition (with no significant effect of water supply) enhanced until the heading stage and weakened during ripening, similarly as the competitive effect of Italian ryegrass.

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Spring barley and Italian ryegrass competed for resources throughout the growing season. Regardless of water supply levels, the availability of 23% of environmental resources was limited already at the emergence stage. Over time, the species competed for a larger number of resources. At the tillering, stem elongation and heading stages, they competed over 68%, 86% and 95% of the available resources. Competition intensity was lower at the end of the growth cycle, when the species competed for 79% of resources, and they shared 21% of resources. Except for the emergence stage, more intense competition was observed in the water-restricted treatment.

At the emergence stage, the competitive effects of both species were similar (Table 2). During tillering, spring barley dominated over Italian ryegrass, and its advantage was increasing until the heading stage to decrease insignificantly towards the end of the growing season. At the emergence and stem elongation stages, water supply levels had no effect on the competitive advantage of barley over Italian ryegrass. During tillering, the dominance of barley was stronger in the water-deficient treatment, while during generative growth – in the water-abundant treatment.

Irrespective of water supply levels, the efficiency of one species relative to the other in mixture (measured as capture of resources per unit dry matter) remained at a similar level until the stem elongation stage of barley (Fig. 1); from that stage to the end of the growth cycle, Italian ryegrass was characterized by higher relative efficiency. Water supply levels had no significant effect on the values of the relative efficiency index. The resource use efficiency of spring barley and Italian ryegrass under different soil moisture conditions (dry and wet) varied across development stages. No significant differences were found between species in resource use efficiency per unit biomass until the stem elongation stage of barley in the water-abundant treatment and until the tillering stage in the water-deficient treatment. From that stage to the end of the growing season, Italian ryegrass exhibited an advantage over barley in resource use. In mixed populations, Italian ryegrass captured the available resources more effectively than spring barley, and its advantage was stronger in the treatment with optimal water supply. The resource use efficiency of Italian ryegrass decreased over time in the treatment with reduced water supply, while it remained stable in the treatment with optimal water supply.

Table 1
Relative yield (RY) and relative yield total (RYT) of plants

Spring barley development phases (BBCH)	RY						RYT		
	Spring barley			Italian ryegrass					
	water supply		average	water supply		average	water supply		average
	abundant	deficient		abundant	deficient		abundant	deficient	
Emergence (10-13)	0.85 abc	0.84 abc	0.85 ab	0.93 a	0.91 a	0.92 a	1.78* a	1.75* a	1.77 a
Tillering (22-25)	0.90 a	0.88 abc	0.89 a	0.46 b	0.39 bc	0.43 b	1.36* b	1.27* c	1.32 b
Stem elongation (33-37)	0.86 abc	0.78 bc	0.82 ab	0.34 c	0.30 c	0.32 c	1.20* c	1.08* d	1.14 cd
Heading (52-55)	0.80 bc	0.74 c	0.77 b	0.28 c	0.28 c	0.28 c	1.08* d	1.02 e	1.05 d
Ripeness (87-91)	0.89 a	0.79 bc	0.84 ab	0.36 c	0.37 c	0.37 c	1.25* bc	1.16* cd	1.21 bc
Average	0.86 a	0.81 b	0.83	0.47 a	0.45 a	0.46	1.33 a	1.26 b	1.30

a, b, c, d, e – homogeneous groups: values followed by the same letters within experimental factors and their interactions are not significantly different at p = 0.05

* – RYT different from 1 at p = 0.05

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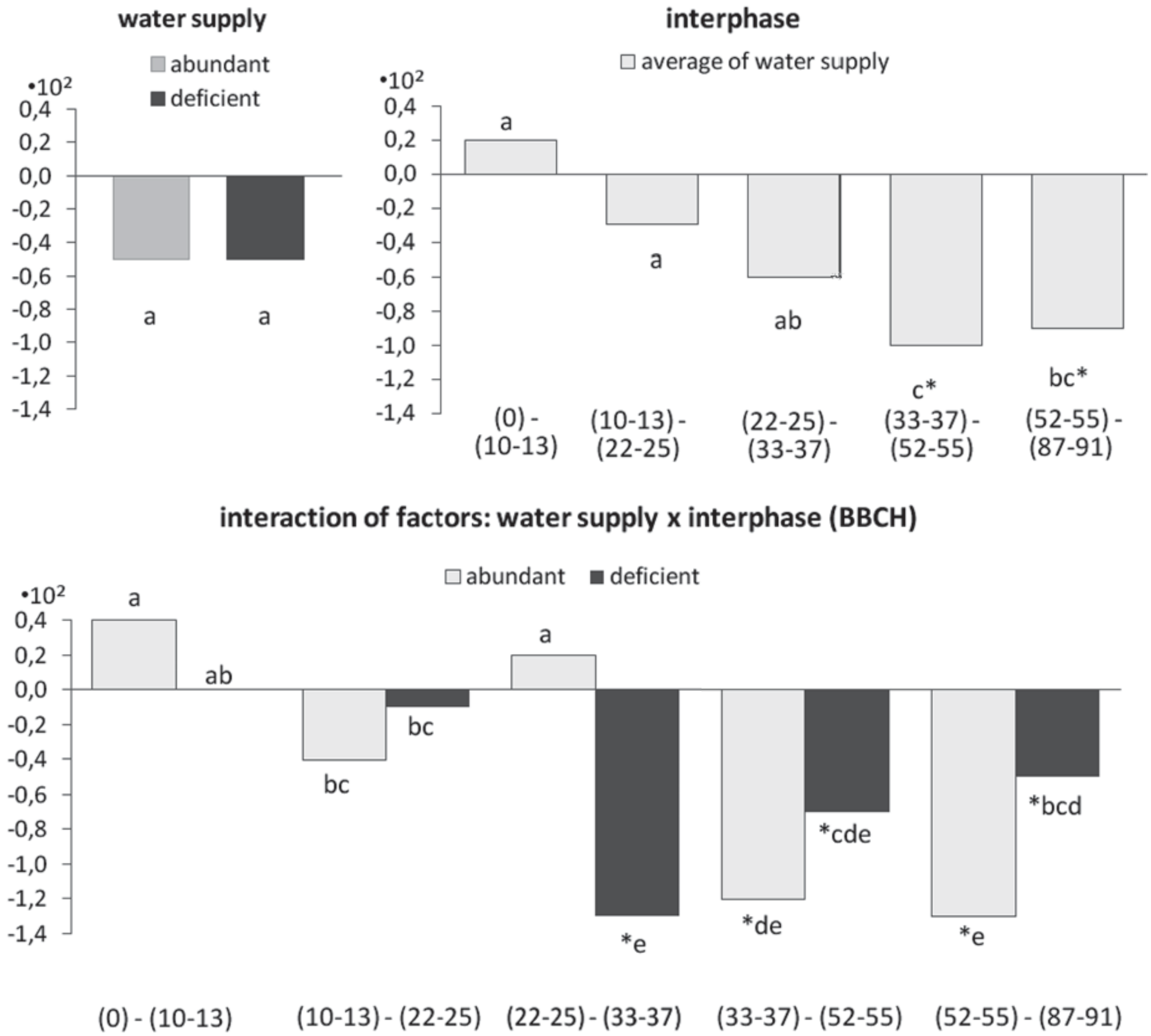

a, b, c, d, e – homogeneous groups: values followed by the same letters within experimental factors and their interactions are not significantly different at p = 0.05

*– REI different from 0 at p = 0.05

Fig. 1. Relative efficiency index (REI) of spring barley relative to Italian ryegrass.

Table 2

Competitive balance index (Cb)

Spring barley development phases (BBCH)	Water supply				Average of water supply	
	abundant		deficient			
Emergence (10-13)	-0.09	e	-0.08	e	-0.09	c
Tillering (22-25)	0.67*	d	0.81*	bc	0.74	b
Stem elongation (33-37)	0.92*	ab	0.94*	ab	0.93	ab
Heading (52-55)	1.05*	a	0.99*	b	1.02	b
Ripeness (87-91)	0.91*	b	0.75*	c	0.83	b

a, b, c – homogeneous groups: values followed by the same letters within experimental factors and their interactions are not significantly different at p = 0.05

* – Cb different from 0 at p = 0.05

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DISCUSSION

The results of this study indicate that spring barley and Italian ryegrass competed for limited resources throughout the growing season. Competition intensity was found to increase until the heading stage, and then it decreased insignificantly. The competitive effects of both species are weaker at the end of the growth cycle due to their uneven ripening [4,9,19]. In our experiment, the requirements of spring barley became much lower at the end of its development (loss of vegetative parts, leaves falling off, grain filling), whereas Italian ryegrass still captured resources to produce biomass [14].

In our study, spring barley dominated over Italian ryegrass from the tillering stage to the end of the growth cycle, and its competitive advantage was strongest at the heading stage. The dominance of barley over other species in the stand has been observed by numerous authors [3–5,9]. Molla and Sharaiha [19] demonstrated that barley was more competitive than wheat during generative growth. The competitive advantage of barley over other species is due to its faster initial growth rate, which increases its resource use efficiency with respect to both light and soil nutrients [4,19]. In the present experiment, the competitive advantage of spring barley over Italian ryegrass resulted from a better developed root system at the early stages of growth, a faster growth rate, higher plants and a larger surface area of leaves which probably enhanced photosynthesis. The dominance of barley decreased towards the end of the growing season, due to a slower rate of biomass accumulation and a decrease in leaf area, accompanied by an increase in the values of those parameters in Italian ryegrass [13,20,21].

In the current experiment, competition intensity was higher in the treatment with 50% water supply reduction (relative to the water requirements of both species) during almost all growth stages. Molla and Sharaiha [19], and Lucero et al. [22] also reported that competition intensity decreased with an increase in soil moisture content. However, in a study by Kolb et al. [23] water deficiency reduced the mutual competitive effects of barley and ryegrass. According to Casper and Jackson [24], competition for water among plants is not enhanced in water-deficient ecosystems. Tsialtas et al. [25] demonstrated that the species that form grassland communities in dry areas use water more efficiently, which reduces competition among them. In our study, the competitive effect of spring barley on Italian ryegrass was not influenced by different water supply conditions. Italian ryegrass was a stronger competitor of barley under water deficiency.

In the present experiment, Italian ryegrass was characterized by more efficient use of limited resources per unit dry matter (particularly in the water-abundant treatment), except for the early growth stages. This was reflected in the negative values of the relative efficiency index (REI) of barley relative to Italian ryegrass, which are also indicative of competitive asymmetry [26]. Italian ryegrass, dominated by barley, captured the available resources more effectively despite substantially lower aboveground biomass, which corroborates the findings of Sobkowicz [4] who studied barley grown in mixture with oat or triticale.

CONCLUSIONS

1. In mixture, spring barley and Italian ryegrass competed for resources throughout the growing season.
2. A higher decrease in biomass accumulation of spring barley grown with Italian ryegrass was noted in the treatment with a 50% reduction in water supply. Soil moisture content had no effect on biomass accumulation of Italian ryegrass grown with barley.
3. Competition intensity was found to increase until the heading stage, and it decreased towards the end of the growth cycle. More intense competition was observed under reduced water supply.
4. Spring barley dominated over Italian ryegrass from the tillering stage to the ripening stage. The competitive effect of barley on Italian ryegrass was stronger until the heading stage, and it weakened at the end of the growth cycle.
5. In mixed populations, Italian ryegrass captured the available resources more effectively than spring barley from the stem elongation stage until the end of the growing season, particularly in the treatment with optimal water supply.

Acknowledgements

The study was supported financially by the Ministry of Science and Higher Education in 2009–2012 (grant No. N N310 082836).

Authors' contributions

The following declarations about authors' contributions to the research have been made: concept of the study: MW, MKK; field research: MW, MJ, MKK, KT; data analyses: MW, MKK; writing of the manuscript: MW, MKK.

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Konkurencja między jęczmieniem jarym (*Hordeum vulgare* L.) i życicą wielokwiatową (*Lolium multiflorum* LAM.) w warunkach różnego zaopatrzenia roślin w wodę

Streszczenie

W doświadczeniu wazonowym, realizowanym w trzech seriach według schematu addytywnego, badano oddziaływania między jęczmieniem jarym i życicą wielokwiatową w zróżnicowanych warunkach uwilgotnienia gleby. Czynnikami doświadczenia były: 1. sposoby siewu roślin – w mieszance i w siewie czystym, 2. zaopatrzenie roślin w wodę – dawka zgodna z ich wymaganiami oraz obniżona w stosunku do niej o 50%. Badania wykonano w 5 okresach rozwojowych jęczmienia jarego (BBCH): wschody (10–13), krzewienie (22–25), strzelanie w źdźbło (33–37), kłoszenie (52–55) i dojrzewanie (87–91). Konkurencję oceniano na podstawie plonów względnych roślin (RY), całkowitego plonu względnego (RYT), wskaźnika równowagi konkurencyjnej (Cb) i indeksu efektywności względnej (REI). Wykazano, że jęczmień jary i życica wielokwiatowa konkurowały ze sobą o zasoby środowiska w całym okresie wegetacji. Proces ten nasilał się do fazy kłoszenia jęczmienia, po czym pod koniec wegetacji uległ osłabieniu. Konkurencja intensywniejsza była na obiekcie słabiej zaopatrywanym w wodę. Jęczmień dominował nad życicą od fazy krzewienia do dojrzewania. W mieszance życica efektywniej od jęczmienia pozyskiwała czynniki wzrostu od fazy strzelania w źdźbło do końca wegetacji, zwłaszcza na obiekcie obficiej zasilanym wodą.

Handling Editor: Elżbieta Weryszko-Chmielewska

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