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RESPONSE OF SPRING WHEAT TO THE GROWTH WITH UNDERSOWN OF PERSIAN CLOVER UNDER CONTROLLED CONDITIONS

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Abstract. In a pot experiment, carried out in three series in years 2010-2012 at the greenhouse laboratory of the University of Warmia and Mazury in Olsztyn, the effect of Persian clover undersown and plant density on the morphological characteristics of spring wheat was evaluated. Experimental factors were as follows: I) spring wheat (*Triticum aestivum* ssp. *vulgare* L.) sowing method: pure sowing and with Persian clover (*Trifolium resupinatum* L.) undersown, II) density of both species in agreement with the recommendations of agrotechnics (called "higher" in the present work) and lowered by 20% (called "lower"). In the pots of 22 cm in diameter, the following plants were sown: in the pots with higher density, 19 spring wheat grains and 12 seeds of Persian clover, and in the pots with lower density, 12 wheat grains and nine clover seeds. Measurements were undertaken at the following developmental stages of wheat (the BBCH scale): leaf development (12-14), tillering (21-23), straw shooting (31-32), earing (54-56), and ripening (87-89). The studied factors were: plant height, root length, number of straws per plant, leaf parameters (area, length, and width), spike parameters (length, grain number, and mass), and grain yield per pot. The studies demonstrated that undersown diversified plant height and straw number in spring wheat. Its roots in the combination with clover were shorter than in pure sowing only during earing. In the presence of undersown, wheat developed fewer leaves (by nearly 10%), shorter spikes (by 10%) with fewer grains (by 15.7%) of lower mass (by 28.6%) and smaller yield (by 29.7%). Sowing method, depending on the developmental stage, differently affected leaf parameters. Plant density had no effect on the scope of the differences between pure and mixed sowings in the morphology of the vegetative above-ground parts and roots of spring wheat. In the pots with higher density, mixed sowing limited spike length and grain number and mass more than in the pots with lower density.

Key words: developmental stages, grain number and mass per spike, leafage, spike length, *Trifoilum resupinatum*, undersown

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INTRODUCTION

In the interest of agroecosystem stability, more and more attention is paid to ecological management methods. Intercrop is a reliable method of its protection with simultaneous obtainment of high yield. Intercrop cultivation is related to, as it was many times underscored by numerous authors, environmental and economic benefits [Andrzejewska 1999, Jaskulski and Jaskulska 2006, Jaskulska and Gałęzewski 2009, Kostrzewska *et al*. 2013]. Undersown is a form of intercrop. It grows on the field with the cultivated plant and then after harvest in the autumn it is ploughed for green mass (most often) or collected for fodder. Legumes (including clover) are good undersown, due to their positive effect on the environment [Känkänen *et al*. 2001, 2003]. Among them, red clover (*Trifolium pratense*) and white clover (*Trifolimm repens*) are sown the most often and it is those two plants that receive the most attention in literature [Känkänen and Eriksson 2007]. Definitely less information can be found on Persian clover (*T. resupinatim*), whereas this is an annual plant that, in the conditions of good water supply, forms high biomass yield, and its usefulness as undersown confirmed by the studies of Płaza *et al*. [2013] and Zarea *et al*. [2010].

It ought to be remembered, however, that between the plant from the main yield and undersown many interactions occur, the effect of which is changes in the rhythm of their development, morphological characteristics, and yield [Sheaffer *et al*. 2002]. Their direction and intensity, depending on plant density and developmental stage, may be varied [Thorsted *et al*. 2006, Treder *et al*. 2008]. An important issue is establishing the sowing density of the plants which, on the one hand, will not make it possible for the undersown to dominate in the lowland meadow, and, on the other hand, protection of the plant will not stifle or push out the undersown from the lowland meadow.

Taking the above into consideration, a study hypothesis was put forward which assumed that Persian clover undersown (*T. resupinatum*) would cause changes in the morphological characteristics and yield of spring wheat (*Triticum aestivum* ssp. *vulgare*), and the scale of those modifications would depend on plant density. Its verification was carried out on the basis of a pot experiment, the aim of which was the evaluation of the effect of Persian clover undersown on the changes in the morphological characteristics of the above-ground parts and roots of spring wheat and its yield in the entire period of joint growth of both species in the conditions of different plant density.

MATERIAL AND METHODS

The basis of the experiment consisted of three series of strict pot experiment, carried out at the greenhouse laboratory at the Department of Biology and Biotechnology of the University of Warmia and Mazury in Olsztyn. The series were carried out on the following dates: 12.04-19.07.2010, 24.03-30.06.2011, and 26.03-28.06.2012. Spring wheat (cultivar Nawra) was sown in pure and mixed sowings with Persian clover (cultivar Gobry) at two densities: the recommended one (called "higher" in the present work) and one lowered by 20% in relation to the recommended one ("lower").

The factors of the experiment were:

I) spring wheat sowing method:
  - pure sowing,
  - mixture with Persian clover;

II) diversified plant density:
   – higher (according to the recommendations of agrotechnics),
   – lower (lowered by 20% in relation to the above).

Studies were carried out in five periods, set by the developmental stages of spring wheat sown in the pot as pure sowing of recommended density, namely in the phases, according to the BBCH scale: leaf development (12-14), tillering (21-23), straw shooting (31-32), earing (54-56), and ripening (87-89).

The experiment was made of 120 pots (wheat and clover in pure sowing and in a mixture x two sowing densities x five developmental stages x four repetitions). In the experiment, Kick-Brauckmann pots were used with the diameter of 22 cm and the depth of 25 cm, in which grains and seeds were sown within equal distance from one another (thanks to the templates) in the soil at the depth of 3 cm for spring wheat and 1 cm for Persian clover.

In the pots with higher density, for both sowing methods, 19 spring wheat grains were sown, and with lower density, 15. In the mixture, in the pots with higher density, 12 seeds of Persian clover were added, and with lower density, 9. This corresponded to plant density per $1m^2$: spring wheat: higher density – 500, lower density – 400; Persian clover, respectively: 300 and 240.

Bedding for the plants was brown leached soil formed from heavy loam with the contents of floatable parts 64%, silt 12%, and sand 24%. The soil was characterized by the content of total organic carbon from 1.06% to 1.46%, slightly acid pH (pH in 1 M KCl from 5.6 to 6.2), and the contents of (mg·100 g^{-1} soil): high of phosphorus (9.2--11.6) and magnesium (8.8-9.1) and average of potassium (12.9-14.5). For filling the pots, the soil was uptaken from the depth of 0-25 cm.

PK mineral fertilization was not diversified depending on the wheat sowing method or plant density. It amounted to (g·pot^{-1}) P 0.200 and K 0.450. Size of the N dose was: for spring wheat in pure sowing 0.500, and for the mixture with Persian clover 0.300 (g·pot^{-1}). The fertilizers were applied one week before plant sowing.

Soil humidity during growth was kept at the constant level of 60% of maximum water capacity and, if necessary, shortages were filled up daily. In the laboratory, almost throughout the whole duration of the experiment, temperature between 20 and 22^{o}C was secured. It was lowered at full wheat emergence to 6-8^{o}C, in order to make it possible for the wheat to go through vernalization. The experiment was carried out in natural light.

Moment of detailed measurement was indicated by the spring wheat in pure sowing with higher density. The following characteristics were studied: plant height and root length (all developmental stages), straw number (from straw shooting to ripening), and leaf parameters that included: leaf area, length, and width (phases: leaf development, tillering, straw shooting and earing) and spike: length (earing and ripening), number of grains per spike and their mass (ripening), and grain yield per pot (ripening). Measurements were carried out on all the plants in a given pot, and for leafage evaluation, three leaves from every plant were uptaken (from straw shooting the ones situated the highest). Leaf parameters were evaluated with the use of a laser leaf area meter (CI – 202 Portable Laser Leaf Area Meter).

The obtained results are presented as mean values from the three series of the experiment. They were evaluated statistically, with the analysis of variance according to the model for totally random design, calculating LSD at the significance level of P = 0.05, with the use of Newman-Kuels test. The calculations were made with the use of the computer program Statistica.

RESULTS

It results from the data in Table 1 that spring wheat did not change significantly its height in relation to the applied sowing method. Plant density affected significantly wheat height only during tillering. Wheat sown at lower density formed higher plants than the one sown at higher density (by 2 cm). Also the interaction between the study factors had no effect on cereal height.

Table 1. Spring wheat height, cm
Tabela 1. Wysokość pszenicy jarej, cm

Plant density (A) Zagęszczenie roślin (A)	Sowing method (B) Sposób siewu (B)	Developmental stage (BBCH) – Faza rozwojowa (BBCH)				
		leaf development 12-14 rozwój liści 12-14	tillering 21-23 krzewienie 21-23	straw shooting 31-32 strzelanie w źdźbło 31-32	earing 54-56 kłoszenie 54-56	ripening 87-89 dojrzałość 87-89
A1	B1	37.6	43.2	52.4	55.0	54.4
	B2	37.3	42.2	51.4	52.2	51.3
Mean for A1 – Średnio dla A1		37.5	42.7	51.9	53.6	52.9
A2	B1	39.0	45.1	55.2	55.2	56.9
	B2	39.8	44.2	53.0	54.6	55.9
Mean for A2 – Średnio dla A2		39.4	44.7	54.1	54.9	56.4
Mean for A Średnio dla A	B1	38.3	44.1	53.8	55.1	55.7
	B2	38.6	43.2	52.2	53.4	53.6
Mean – Średnio		38.5	43.7	53.0	54.3	54.7
$LSD_{0.05}$ $NIR_{0,05}$	A	ns – ni	1.72	ns – ni	ns – ni	ns – ni
	B	ns – ni	ns – ni	ns – ni	ns – ni	ns – ni
	A × B	ns – ni	ns – ni	ns – ni	ns – ni	ns – ni

A – plant density – zagęszczenie roślin: A1 – higher – większe, A2 – lower – mniejsze
B – sowing method – sposób siewu: B1 – pure – czysty, B2 – mixed – mieszany
ns – ni – non-significant differences – różnice nieistotne

Sowing method significantly differentiated spring wheat straw number only during straw shooting (Table 2). At that developmental stage, in the pots with mixed sowing, plants produced fewer straws than in pure sowing (by 20.1%). The second study factor also had a significant effect on the number of stems of spring wheat only in one case. During earing, a significantly higher number of straws was formed by plants with lower density (by 14.2% in relation to the recommended density). Interaction between the experimental factors in relation to the discussed characteristic became visible at the straw-shooting stage. At that stage, mixed sowing affected unfavourably the number of straws at both plant density combinations.

Mixed sowing was of no significant effect on the number of wheat leaves at the stages of leaf development and tillering (Table 3). At the subsequent stages of growth, it affected considerably negatively the studied characteristics. Poorer leafage, in comparison with pure sowing, amounted to: straw shooting by 10.0%, earing by 10.9%, and ripening by 7.5%. Plant density significantly diversified the number of leaves of the cereal only at earing and ripening. In the pots with lower density, greater leafage was noted than in the one with higher density: at earing by 11.1%, and at ripening by 7.9%.

Relations between the factors came out during straw-shooting, tillering, and ripening in the combination with higher density. in that period, significantly fewer leaves were formed in the straws in mixed sowing than in pure sowing. In the variant with lower density, poorer leafage in the mixture was found only at the straw-shooting stage. In this treatment, no significant differences between the sowing methods were found in the remaining periods.

Table 2. Straw number per one spring wheat plant, straw
Tabela 2. Liczba źdźbeł 1 rośliny pszenicy jarej, szt.

Plant density (A) Zagęszczenie roślin (A)	Sowing method (B) Sposób siewu (B)	Developmental stage (BBCH) – Faza rozwojowa (BBCH)				
		leaf development 12-14 rozwój liści 12-14	tillering 21-23 krzewienie 21-23	straw shooting 31-32 strzelanie w źdźbło 31-32	earing 54-56 kłoszenie 54-56	ripening 87-89 dojrzałość 87-89
A1	B1	1.00	1.90	1.61	1.10	1.05
	B2	1.00	1.64	1.32	1.29	1.04
Mean for A1 – Średnio dla A1		37.5	1.00	1.77	1.47	1.20
A2	B1	1.00	2.12	1.87	1.31	1.14
	B2	1.00	1.64	1.46	1.42	1.12
Mean for A2 – Średnio dla A2		39.4	1.00	1.88	1.67	1.37
Mean for A Średnio dla A	B1	1.00	2.01	1.74	1.21	1.10
	B2	1.00	1.64	1.39	1.36	1.08
Mean – Średnio		38.5	1.00	1.83	1.57	1.29
$LSD_{0.05}$ $NIR_{0,05}$	A	ns – ni	ns – ni	ns – ni	0.16	ns – ni
	B	ns – ni	ns – ni	ns – ni	ns – ni	ns – ni
	A × B	ns – ni	ns – ni	0.28	ns – ni	ns – ni

for explanations, see Table 1 – objaśnienia pod tabelą 1

Plant sowing method affected the leaf area of wheat depending on the developmental stage (Table 4). At leaf development and earing, joint growth with clover attributed to producing greater leaves than in pure sowing (respectively by 68.7% and 20.0%). Opposite situation was noted during tillering and straw-shooting, in which wheat that grew with undersown decreased assimilation area, in comparison with pure sowing, by 17.0% and 22.6%. Leaf area to a significant degree depended on plant density at tillering and straw shooting. In both periods, a decrease in the number of plants per pot by 20% contributed to increasing the assimilation area of spring wheat by, respectively, 5.4% and 8.7%. Also interaction between the sowing method and plant density affected their area during growth in a different way. At the beginning of development, clover positively affected wheat leafage in both density options, whereas at tillering and straw shooting the effect was negative. During earing, wheat leaf area in the pots with low sowing density in the mixture was significantly higher than in pure sowing, whereas with higher density it did not show any differences under the effect of the sowing method.

Table 3. Leaf number per one spring wheat plant, leaf
Tabela 3. Liczba liści na 1 roślinie pszenicy jarej, szt.

Plant density (A) Zagęszczenie roślin (A)	Sowing method (B) Sposób siewu (B)	Developmental stage (BBCH) – Faza rozwojowa (BBCH)				
		leaf development 12-14 rozwój liści 12-14	tillering 21-23 krzewienie 21-23	straw shooting 31-32 strzelanie w źdźbło 31-32	earing 54-56 kłoszenie 54-56	ripening 87-89 dojrzałość 87-89
A1	B1	3.58	8.81	9.00	8.19	7.30
	B2	3.67	8.23	8.13	6.80	6.69
Mean for A1 – Średnio dla A1		37.5		8.52	8.57	7.50
A2	B1	3.65	9.21	9.68	8.56	7.82
	B2	3.80	8.73	8.68	8.10	7.28
Mean for A2 – Średnio dla A2		39.4		8.97	9.18	8.33
Mean for A Średnio dla A	B1	3.62	9.01	9.34	8.37	7.56
	B2	3.74	8.48	8.41	7.46	6.99
Mean – Średnio		38.5		8.75	8.88	7.92
$LSD_{0.05}$ $NIR_{0,05}$	A	ns – ni	ns – ni	ns – ni	0.47	0.43
	B	ns – ni	ns – ni	0.76	0.55	0.46
	A × B	ns – ni	ns – ni	0.81	0.66	ns – ni

for explanations, see Table 1 – objaśnienia pod tabelą 1

Table 4. Spring wheat leaf area, cm^2
Tabela 4. Powierzchnia liścia pszenicy jarej, cm^2

Plant density (A) Zagęszczenie roślin (A)	Sowing method (B) Sposób siewu (B)	Developmental stage (BBCH) – Faza rozwojowa (BBCH)			
		leaf development 12-14 rozwój liści 12-14	tillering 21-23 krzewienie 21-23	straw shooting 31-32 strzelanie w źdźbło 31-32	earing 54-56 kłoszenie 54-56
A1	B1	7.6	25.6	26.2	23.3
	B2	14.2	22.4	21.1	25.6
Mean for A1 – Średnio dla A1			24.0	23.7	24.5
A2	B1	7.5	28.3	29.4	21.5
	B2	11.3	22.4	22.0	28.1
Mean for A2 – Średnio dla A2			25.4	25.7	24.8
Mean for A Średnio dla A	B1	7.6	27.0	27.8	22.4
	B2	12.8	22.4	21.6	26.9
Mean – Średnio			24.7	24.7	24.7
$LSD_{0.05}$ $NIR_{0,05}$	A	ns – ni	1.19	1.78	ns – ni
	B	1.91	1.21	1.83	2.35
	A × B	2.70	1.68	2.52	3.32

for explanations, see Table 1 – objaśnienia pod tabelą 1

Mixed sowing had a favourable effect on the leaf length of spring wheat during leaf development, and at the subsequent two developmental stages pure sowing was of favourable effect (Table 5). At the initial stage of growth, the presence of Persian clover, in comparison with pure sowing, contributed to leaf elongation by 38.7%, but in the following period it shortened the leaves by 9.7% (at tillering) and by 23.4% (at straw shooting), and did not diversified their length at earing. On the other hand, plant density during the entire growth had no effect on the analyzed characteristic. Significant interaction of both study factors was marked at leaf development, tillering, and straw shooting. At the beginning of growth, joint sowing of the cereal with Persian clover stimulated the production of longer leaves in the pots with higher density. At the two subsequent stages, it transferred in favour of pure sowing with lower density, and at straw shooting, also to the variant with higher density. The existing differences between the sowing methods of wheat, in both plant density variants, equalized at earing.

Table 5. Spring wheat leaf length, cm
Tabela 5. Długość liścia pszenicy jarej, cm

Plant density (A) Zagęszczenie roślin (A)	Sowing method (B) Sposób siewu (B)	Developmental stage (BBCH) – Faza rozwojowa (BBCH)			
		leaf development 12-14 rozwój liści 12-14	tillering 21-23 krzewienie 21-23	straw shooting 31-32 strzelanie w źdźbło 31-32	earing 54-56 kłoszenie 54-56
A1	B1	15.2	25.4	27.1	26.1
	B2	23.1	26.1	21.8	24.3
Mean for A1 – Średnio dla A1				25.8	24.5
A2	B1	15.2	30.3	29.7	24.5
	B2	19.1	24.2	21.7	23.9
Mean for A2 – Średnio dla A2				27.3	25.7
Mean for A Średnio dla A	B1	15.2	27.9	28.4	25.3
	B2	21.1	25.2	21.8	24.1
Mean – Średnio				26.7	25.1
$LSD_{0.05}$ $NIR_{0,05}$	A	ns – ni	ns – ni	ns – ni	ns – ni
	B	2.32	1.76	1.94	ns – ni
	A × B	4.28	2.49	2.75	ns – ni

for explanations, see Table 1 – objaśnienia pod tabelą 1

Another analyzed leaf parameter was leaf width (Table 6). It changed under the effect of the sowing method at leaf development and straw shooting. In the first period, the leaves were wider (by 19.6%) in the variant of wheat growth with Persian clover undersown, and in the second one, by 13.2% in pure sowing. At tillering and earing, no significant differences between the sowing methods were found. At the early stages of development, leaf width changed also under the effect of sowing density. Decrease in the amount of plant sowing caused a decrease in leaf width at leaf development (by 19.6%), and its increase (by 8.1%) at tillering. During further growth, density had no effect on the studied characteristics. Spring wheat leaves reached different width under the effect of joint impact of the sowing method and density. At the stage of leaf development, no differences between the sowing methods were found in both density variants. At the subsequent stages, in the pots with greater density, the presence of Persian clover caused the leaves to be more narrow than in pure sowing. On the other hand, in the pots with lower density, wheat leaves in the mixture were characterized by greater width than in pure sowing during tillering, and lower during straw shooting.

Table 6. Spring wheat leaf width, cm
Tabela 6. Szerokość liścia pszenicy jarej, cm

Plant density (A) Zagęszczenie roślin (A)	Sowing method (B) Sposób siewu (B)	Developmental stage (BBCH) – Faza rozwojowa (BBCH)			
		leaf development 12-14 rozwój liści 12-14	tillering 21-23 krzewienie 21-23	straw shooting 31-32 strzelanie w źdźbło 31-32	earing 54-56 kłoszenie 54-56
A1	B1	1.03	1.57	1.47	1.67
	B2	1.21	1.38	1.32	1.48
Mean for A1 – Średnio dla A1				1.48	1.40
A2	B1	0.81	1.54	1.45	1.57
	B2	0.99	1.66	1.25	1.66
Mean for A2 – Średnio dla A2				1.60	1.35
Mean for A Średnio dla A	B1	0.92	1.56	1.46	1.62
	B2	1.10	1.52	1.29	1.57
Mean – Średnio				1.54	1.38
$LSD_{0.05}$ $NIR_{0,05}$	A	0.13	0.05	ns – ni	ns – ni
	B	0.11	ns – ni	0.08	ns – ni
	A × B	ns – ni	0.08	0.12	0.11

for explanations, see Table 1 – objaśnienia pod tabelą 1

Introduction of Persian clover into the lowland meadow caused a significant shortening of spring wheat spike length during earing (by 11.3%) and ripening (by 8.7%) in relation to pure sowing (Table 7). Also, significant changes of this characteristic were noted depending on plant density. Decreasing density by 20% resulted in spike elongation. During earing, the spikes were longer by 6.8%, and at the final stage by 14.4% in comparison with higher density. Interaction between the study factors showed that during earing and ripening, spike shortening took place in the mixture for both density options.

Table 7. Spring wheat spike length, cm
Tabela 7. Długość kłosa pszenicy jarej, cm

Plant density (A) Zagęszczenie roślin (A)	Sowing method (B) Sposób siewu (B)	Developmental stage (BBCH) – Faza rozwojowa (BBCH)	
		earing 54-56 kłoszenie 54-56	ripening 87-89 dojrzewanie 87-89
A1	B1	9.26	8.20
	B2	8.07	7.38
Mean for A1 – Średnio dla A1			7.79
A2	B1	9.73	9.26
	B2	8.79	8.56
Mean for A2 – Średnio dla A2			8.91
Mean for A Średnio dla A	B1	9.50	8.73
	B2	8.43	7.94
Mean – Średnio			8.35
$LSD_{0.05}$ $NIR_{0,05}$	A	0.29	0.59
	B	0.33	0.55
	A × B	0.41	0.69

for explanations, see Table 1 – objaśnienia pod tabelą 1

During ripening, the presence of Persian clover in the lowland meadow caused a significant decrease in the number of grains per spike (by 15.7%), lowering the mass of grains per spike (by 28.6%), and a decrease in grain yield in the pots (by 29.7%) in relation to pure sowing of this cereal (Table 8). Among the tested characteristics, plant density only had a significant effect on grain number per spike. Decreasing plant density caused on average 4.25 more grains to form in wheat spike. Plant density in the pot was of no significant effect on the scope of differences between the sowing methods in grains number per wheat spike. Interaction between the factors showed, however, its significant effect on the mass of 1000 grains and grain yield in the pots with higher density. In the mixture, the above parameters reached lower quantities than in pure sowing.

Table 8. Spring wheat grain number per spike (grain), grain mass per one spike (g), and grain yield per pot (g)
Tabela 8. Liczba ziaren w kłosie (szt.), masa ziarna z 1 kłosa (g) i plon ziarna z wazonu (g) pszenicy jarej

Plant density (A) Zagęszczenie roślin (A)	Sowing method Sposób siewu (B)	Grain number per spike Liczba ziaren w kłosie	Grain mass per spike Masa ziarna z kłosa	Grain yield per pot Plon ziarna z wazonu
A1	B1	24.4	0.92	17.6
	B2	18.7	0.58	11.1
Mean for A1 – Średnio dla A1			0.75	14.4
A2	B1	27.0	1.03	15.9
	B2	24.6	0.81	12.5
Mean for A2 – Średnio dla A2			0.92	14.2
Mean for A Średnio dla A	B1	25.7	0.98	16.8
	B2	21.7	0.70	11.8
Mean – Średnio			0.84	14.3
$LSD_{0.05}$ $NIR_{0,05}$	A	1.99	ns – ni	ns – ni
	B	2.04	0.18	2.57
	A × B	ns – ni	0.26	4.20

for explanations, see Table 1 – objaśnienia pod tabelą 1

It results from the data in Table 9 that the sowing method significantly differentiated the root length of spring wheat only at tillering. In mixed sowing, poorer development of roots was found (by 11.7%) in comparison with pure sowing. Plant density and interaction between the two experimental factors were of no modifying effect to root length.

Persian clover grown with spring wheat throughout the entire period of joint cultivation produced lower dry matter yield than in pure sowing (Table 10). At the end of growth, it amounted to 6·g pot^{-1} and was lower than in pure sowing by over 70%, without the modifying effect of plant density. Persian clover plants, during the entire growth period, were characterized by a slower growth rate, lower plants, richer leafage, and more poorly-developed roots than spring wheat. Their form did not change under the effect of sowing density.

Table 9. Spring wheat root length, cm
Tabela 9. Długość korzeni pszenicy jarej, cm

Plant density (A) Zagęszczenie roślin (A)	Sowing method (B) Sposób siewu (B)	Developmental stage (BBCH) – Faza rozwojowa (BBCH)				
		leaf development 12-14 rozwój liści 12-14	tillering 21-23 krzewienie 21-23	straw shooting 31-32 strzelanie w źdźbło 31-32	earing 54-56 kłoszenie 54-56	ripening 87-89 dojrzałość 87-89
A1	B1	18.7	27.4	26.8	26.2	20.0
	B2	18.5	24.3	26.4	26.7	20.7
Mean for A1 – Średnio dla A1			25.9	26.6	26.5	20.4
A2	B1	15.9	27.1	27.3	26.5	23.0
	B2	18.5	23.8	26.7	25.5	21.7
Mean for A2 – Średnio dla A2			25.5	27.0	26.0	22.4
Mean for A Średnio dla A	B1	17.3	27.3	27.1	26.4	21.5
	B2	18.5	24.1	26.6	26.1	21.2
Mean – Średnio			25.7	26.9	26.3	21.4
$LSD_{0.05}$ $NIR_{0,05}$	A	ns – ni	ns – ni	ns – ni	ns – ni	ns – ni
	B	ns – ni	2.46	ns – ni	ns – ni	ns – ni
	A × B	ns – ni	ns – ni	ns – ni	ns – ni	ns – ni

for explanations, see Table 1 – objaśnienia pod tabelą 1

Table 10. Dry matter of the above-ground parts of Persian clover, $g \cdot pot^{-1}$
Tabela 10. Sucha masa części nadziemnych koniczyny perskiej, $g \cdot wazon^{-1}$

Plant density (A) Zagęszczenie roślin (A)	Sowing method (B) Sposób siewu (B)	Developmental stage (BBCH) – Faza rozwojowa (BBCH)				
		leaf development 12-14 rozwój liści 12-14	tillering 21-23 krzewienie 21-23	straw shooting 31-32 strzelanie w źdźbło 31-32	earing 54-56 kłoszenie 54-56	ripening 87-89 dojrzałość 87-89
A1	B1	0.39	2.14	5.76	14.33	20.09
	B2	0.14	0.57	0.69	2.90	7.18
Mean for A1 – Średnio dla A1			1.36	3.22	8.62	13.64
A2	B1	0.18	1.86	5.06	13.84	17.67
	B2	0.08	0.52	1.04	2.69	4.94
Mean for A2 – Średnio dla A2			1.19	3.05	8.27	11.31
Mean for A Średnio dla A	B1	0.27	2.00	5.41	14.09	18.88
	B2	0.11	0.55	0.87	2.80	6.06
Mean – Średnio			1.28	3.14	8.45	12.47
$LSD_{0.05}$ $NIR_{0,05}$	A	0.08	ns – ni	ns – ni	ns – ni	ns – ni
	B	0.11	0.99	2.76	4.16	5.53
	A × B	ns – ni	1.23	3.92	6.65	7.45

for explanations, see Table 1 – objaśnienia pod tabelą 1

DISCUSSION

In the present study, spring wheat height was not diversified by the sowing method, and the plant grown with Persian clover undersown formed fewer straws than in pure sowing only at straw shooting. The presence of undersown caused wheat to form fewer leaves in the second half of growth than in pure sowing, which caused greater access of sunlight to the inside of its meadow. Also Zając [2007] described spring wheat as "wonderful protective plant", among others thanks to its relatively low number of stems, and also thanks to low growth and forming few leaves. These characteristics make it compete for light and space with undersown to a lesser extent than other plants, thanks to which they may develop more abundantly. Different results are presented by Sobkowicz and Lejman [2011], who stated that, during tillering and the second node detectable, spring barley grown with Persian clover, seradella, or Persian clover and seradella undersown produced elongated straws in relation to its pure sowing. The authors demonstrated that, during full ripeness, the cereal only grew significantly longer shoots in the mixture with Persian clover and seradella than in pure sowing.

Decrease in density resulted in developing higher wheat plants only at tillering. At the remaining developmental stages, no effect of density on that characteristic was found. Also in the studies by Kulig *et al*. [2007], diversified sowing density was of no effect on the plant height of spring barley. This was also confirmed by Jaśkiewicz [2004] in the experiment on winter triticale. However, Sekimura *et al*. [2000] are of different opinion. In model studies, they showed that plant height increased with the increase in plant density. In the objective experiment, lower density only at one developmental stage, namely earing, caused the cereal to produce noticeably more straws. Increase in spike density in the conditions of lower sowing density was proved also by Jaśkiewicz [2004] and Thorsted *et al*. [2006].

In the present experiment, it was proved that in mixed sowing, at the beginning of development, wheat produced leaves with greater area, which at the same time were longer and wider than in pure sowing. This was most likely related to the allylic compounds secreted by clover to the environment, which stimulated initial cereal development. Positive effect of the seedling root secretion of *T. pratense* on grass germination was noted also in the research by Harkot and Lipińska [1996]. On the other hand, at tillering, the presence of undersown caused a decrease in leaf area and leaf shortening, although the width was not diversified. In that period, in the described experiment, Persian clover in the mixture was characterized by more abundant leafage than wheat [Myśliwiec 2013], which gave it a competitive advantage over the cereal in the use of light [Grist 1999]. Thorsted *et al*. [2006] inform that up to the lowland meadow height of 20 cm, clover dominates over wheat in regard to light interception, and when cereal reaches greater height than clover, the opposite occurs. At the subsequent developmental stage, effect of clover on leaf decrease (in length and width) was still present. At earing, interspecies competition in mixed sowing stimulated cereal to produce leaves with greater area. Similar results were obtained by Szmigiel and Oleksy [2004]. The authors proved that the leaf blade area of spring wheat grown in a mixture with triticale was greater than in pure sowing at earing.

In the present experiment, the number of leaves of spring wheat was higher at earing and ripening in the pots with lower density. Lower lowland meadow content, and consequently greater living space for the particular wheat plants, caused more growth factors to be at their disposal, which led to a decrease in the intraspecies competition between them [Thorsted *et al*. 2006]. Moreover, limiting mutual shade-throwing allowed greater access of light to the inside of the lowland meadow, and consequently the production of more abundant leafage. At earlier developmental stages, this factor did not differentiate the studied characteristic, although it caused significant changes in its parameters. Already at leaf development, at higher density, the cereal produced wider leaves in comparison with plants at lower density. On the other hand, at tillering, growth at lower density caused the production of greater and wider leaves, and at straw shooting also wider leaves. However, Sekimura *et al*. [2000] stated that the increase in sowing density causes the increase in the area of assimilatory apparatus.

In the presence of Persian clover undersown, spikes were shorter and less well filled with more diminutive grain than in pure sowing, which is convergent with the results by Sułek and Podolska (2008). Also Sobkowicz and Lejman [2011] demonstrated that the growth of spring barley with Persian clover resulted in significant shortening of the spike of this cereal. Undersown also caused a decrease in the number of grains per spike and decreased their mass, which consequently led to a decrease in the yield of the cereal. Decrease in winter wheat grain mass under the effect of undersowns *T. resupinatum* and *Medicago lupulina* was also demonstrated by Hartl [1989]. Thorsted *et al*. [2006] demonstrated that mixed sowing of winter wheat with white clover more strongly negatively affected the development of generative than vegetative parts of this cereal. In the mixture, this may result from both assimilation limitation and increased transpiration (as a result of greater leaf area, which was confirmed in the present study), which leads to water shortages for the plants at spike development and grain filling. According to Olesen *et al*. [2000], assimilation during generative development has a greater effect on grain yield than during earlier growth. Meanwhile, in the field experiment by Wanic *et al*. [2012] it was demonstrated that red clover undersown decreased the number of grains per spike in spring barley but at the same time positively affected grain shapeliness. In the analyzed experiment, grain yield of spring wheat grown with undersown was lower than in pure sowing, which was confirmed also by Thorsted *et al*. [2006]. Opposite opinion was presented by Bergkvist *et al*. [2011], Garand *et al*. [2001], Känkänen and Eriksson [2007], Känkänen *et al*. [2001], and Spaner and Todd [2003], who demonstrated that legume undersown are of no effect on cereal grain yield or decrease it slightly.

Spring wheat produced definitely longer spikes in the conditions of decreased density in comparison with the variant with higher density. At the same time, more grains were situated in the spikes, which is convergent with the results by Thorsted *et al*. [2006]. In the experiment by Jarecki *et al*. [2012], increasing sowing density of spring wheat from 450 to 650 plants·m^{-2} caused a significant decrease in the number of grains per spike and the mass of 1000 grains. Similar relations for spring wheat were demonstrated by Sułek and Mazurek [2001], Chrzanowska-Drożdż and Kaczmarek [2006], and Jaśkiewicz [2008]. On the other hand, Wesołowski *et al*. [2005] obtained a greater number of grains per spike on the plot with lower sowing density. Grain mass, however, like in the present experiment, did not depend on plant density. Studies by Thorsted *et al*. [2006] demonstrated that the increase in row spacing decreases competition for light between the wheat plants, which results in the production of spikes better filled with grain. Grain mass was, however, slightly lower. In the present studies, the lack of differences in grain mass may be related to limiting photosynthesis at the final growth stage, where the sowing density has little effect on the course of this process.

In the objective experiment, decrease in plant density by 20% was of no effect on the grain yield of spring wheat, which is convergent with the results by Känkänen and Eriksson [2007] and Kulig *et al*. [2007]. Noworolnik [2007], however, obtained a significant increase in the yield of spring barley by increasing density from 280 to 330 plants·m^{-2}, although further density change from 330 to 380 grains per m^2 did not cause significant changes in that value. Similar results were presented by Thorsted *et al*. [2006] in the studies on winter wheat, by Jaśkiewicz [2008] on winter triticale, and by Rudnicki and Kotwica [1994] on spring triticale.

Spring wheat formed roots of similar lengths in both sowing methods. Throughout the entire growth period, they were better-developed than the roots of Persian clover [Myśliwiec 2013], thanks to which cereal obtained water and biogenes more effectively than clover, which gave it a competitive advantage from the beginning of growth. Greater competitive ability of cereal roots than legume roots was confirmed by Mariotti *et al*. [2009] and Michalska and Wanic [2008]. According to Snaydon and Howe [1086], competition between roots starts earlier than competition between shoots. It comes out when the roots of one plant start to mix with the roots of the other plant, which usually occurs before leaf development. Wilson [1988], on the basis of the analysis of many experiments, demonstrated that root competition affects plant form to a greater extent than above-ground competition.

CONCLUSIONS

1. Persian clover undersownundersown affects unfavourably the leafage, spike length and its filling with grain, as well as grain yield of spring wheat.
2. Undersownsown limited spike development and grain yield of spring wheat to a greater extent when thehigher density was applied. In the conditions of higher plant density, poorer response to joint growth with Persian clover was shown by the vegetative parts of this cereal than by its spikes and grain.
3. Response of spring wheat to the presence of Persian clover undersownundersown found in the pot experiment constitutes an introductory stage of the research, the effects of which are going to be verified in field conditions.

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REAKCJA PSZENICY JAREJ NA UPRAWĘ Z WSIEWKĄ KONICZYNY PERSKIEJ W WARUNKACH KONTROLOWANYCH

Streszczenie. W doświadczeniu wazonowym, zrealizowanym w trzech seriach w latach 2010-2012 w laboratorium szklarniowym UWM w Olsztynie, oceniano wpływ wsiewki koniczyny perskiej (*Trifolium resupinatum* L.) oraz zagęszczenia roślin na cechy morfologiczne pszenicy jarej (*Triticum aestivum* ssp. *vulgare* L.). Czynnikami doświadczenia były: I) sposób siewu pszenicy jarej – siew czysty oraz z wsiewką koniczyny perskiej, II) zagęszczenie obu gatunków – zgodne z zaleceniami agrotechniki (nazywane w pracy „większe") oraz obniżone w stosunku do niego o 20% („mniejsze"). W wazonach (o średnicy 22 cm) wysiano: na obiekcie z zagęszczeniem większym 19 ziarniaków pszenicy jarej i 12 nasion koniczyny perskiej a z zagęszczeniem mniejszym 12 ziarniaków pszenicy i 9 nasion koniczyny. Pomiary przeprowadzono w fazach rozwojowych pszenicy (BBCH): rozwój liści (12-14), krzewienie (21-23), strzelanie w źdźbło (31-32), kłoszenie (54-56) i dojrzewanie (87-89). Badano: wysokość roślin, długość ich korzeni, liczbę źdźbeł 1 rośliny, parametry liści (powierzchnia, długość, szerokość), kłosa (długość, liczba i masa ziaren) oraz plon ziarna z wazonu. Badania wykazały, że wsiewka nie różnicowała wysokości roślin i liczby źdźbeł pszenicy jarej. Jej korzenie w mieszance z koniczyną były krótsze niż w siewie czystym w fazie kłoszenia. W obecności wsiewki pszenica wykształciła mniej liści (o prawie 10%), krótsze kłosy (o 10 %), słabiej wypełnione ziarnem (o 15,7 %) o mniejszej masie (o 28,6%) i mniejszym plonie (o 29,7%). Różnice między siewem czystym i mieszanym w morfologii wegetatywnych części pszenicy jarej w obu gęstościach siewu były podobne. Na obiekcie z zagęszczeniem większym siew mieszany bardziej ograniczał długość kłosa, liczbę ziaren w kłosie oraz masę ziarna pszenicy jarej niż na obiekcie z zagęszczeniem mniejszym.

Słowa kluczowe: długość kłosa, fazy rozwojowe, liczba i masa ziaren w kłosie, *Trifoilum resupinatum*, ulistnienie, wsiewka

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