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EVALUATION OF PRODUCTIVITY OF FOUR CEREALS SPECIES WITH UNDERSOWN SERRADELLA

Summary

The aim of the study was to evaluate the yielding, yield components and the level of weed infestation of four cereal species which were grown with undersown serradella, or without undersown crop, in organic farms. A field experiment was conducted in the years 2011-2013, in a split-plot design, with four replications. The experiment involved two factors. The first factor included four species of cereals: winter rye, spelt wheat, spring barley, oats, while the second factor - the method of cereal cultivation: pure sowing, or sowing with undersown serradella. The studies showed that oats yielded the best, both in pure sowings and with undersown serradella, while spring barley – the worst. Undersown serradella favorably affected the yield of oats, reduced yield of barley, but did not affect significantly the grain yield of winter rye or spelt wheat. Yielding of serradella depended on the species of cereal as a cover crop. Its highest yields were obtained when it was undersown into winter rye, significantly lower – into barley and spelt wheat, while the lowest - into oats. Undersown serradella generally positively affected the number and weight of grains per ear, and per plant, as well as thousand grain weight. A species of cereal and the method of its cultivation had a significant effect on the abundance of fresh and dry weight of weeds. The highest weed infestation was recorded for pure cereal sowings. Undersown serradella reduced a weight of weeds on average by 48%, and their number by 45%. Mixed sowings with oats and spelt wheat were more competitive against weeds, than sowings with barley and rye.
***Key words**: cereal, serradella, undersown crop, yield, yield structure, weed infestation*

OCENA PRODUKCYJNOŚCI CZTERECH GATUNKÓW ZBÓŻ Z WSIEWKĄ SERADELI

Streszczenie

Celem podjętych badań była ocena plonowania, elementów struktury plonu oraz poziomu zachwaszczenia czterech gatunków zbóż uprawianych z wsiewką seradeli w gospodarstwie ekologicznym. Doświadczenie polowe przeprowadzono w latach 2011-2013, w układzie losowanych podbloków (split-plot), w czterech powtórzeniach. W doświadczeniu dwuczynnikowym uwzględniono cztery gatunki zbóż: żyto ozime, pszenica orkisz, jęczmień jary, owies oraz sposób uprawy zbóż: siew czysty lub z wsiewką seradeli. W badaniach wykazano, że najwyżej plonował owies, zarówno w siewie czystym jak i z wsiewką seradeli, natomiast najniżej – jęczmień jary. Wsiewka seradeli korzystnie wpływała na plonowanie owsa, ograniczała plony jęczmienia, natomiast nie wpływała istotnie na plon ziarna żyta ozimego i pszenicy orkisz. Plonowanie seradeli było uzależnione od gatunku zboża, jako rośliny ochronnej. Największy plon uzyskano przy wsiewaniu jej w żyto ozime, istotnie mniejszy w jęczmień jary i pszenicę orkisz, a najmniejszy – w owies. Wsiewka seradeli na ogół korzystnie wpływała na liczbę i masę ziaren w kłosie i na roślinie oraz na masę tysiąc ziaren zbóż. Gatunek zboża oraz sposób jego uprawy miały istotny wpływ na zróżnicowanie świeżej i suchej masy oraz liczebności chwastów. Najbardziej zachwaszczone były czyste zasiewy zbóż, natomiast wsiewka seradeli ograniczała masę chwastów średnio o 48%, a ich liczebność o 45%. Bardziej konkurencyjne w stosunku do chwastów były zasiewy mieszane z pszenicą orkisz i z owsem, niż z jęczmieniem i żytem.
***Słowa kluczowe**: zboża, seradela, wsiewka, plon, struktura plonu, zachwaszczenie*

1. Introduction

Undersowing serradella into different plant species to cover crops has been a long well-known method for production of bulky feed on light soils. This provides valuable, easily digestible feed, with a favorable chemical composition, which is willingly consumed by animals. It yields well on sandy, slightly acidic soils, has low nutritional requirements, while it favorably affects the soil environment, and leaves a good situation for succeeding crops [1, 2]. Its sensitivity to water deficits in the soil, especially in the initial stages of growth is the limiting factor for serradella cultivation. Drought negatively affects the formation of lateral branches and pods, which, in turn, results in lower yielding of this species [3]. A pure sowing of serradella is not recommended due to strong lodging, and problems with combine harvesting. Good results, however, were obtained for the cultivation with cover crops, such as cereals [4]. Specific habitat requirements of serradella significantly reduce the list of plant species which can be used as a cover crop [5]. The best cover plant is winter rye, but according to different authors, it can also be undersown into winter triticale [6] and into some spring cereals such as: oats [7] or barley [8]. A proper selection of cover plants significantly reduces the risk of low yielding of serradella under adverse weather and habitat conditions [9, 10].

There is a growing interest in serradella results from the development of new trends in agricultural productions, which are oriented towards sustainable and organic farming. The emphasis is laid on growing this species in organic farms, which have a large percentage of light soils, and which keep ruminants. Serradella ensures an excellent feed and positively affects the soil environment. Also, growing cereals with undersown crops creates a higher competition

against weeds, which is important for organic management systems [11, 12, 13, 14, 15]. The aim of the study was to assess yielding, yield structure elements, and the level of weed infestation of four cereal species, grown in pure stands, or with undersown serradella in organic farms.

2. Material and methods

Field experiment was carried out in the years 2011–2013 on the certified organic farm of Agricultural Advisory Center in Szepietowo [53□12'N 22□16'E] (Podlaskie voivodeship), in split-plot design, in 4 replications. The studies concerned four species of cereals: winter rye (*Secale cereale* L.), spelt wheat (*Triticum spelta* L.), spring barley (*Hordeum vulgare* L.), oats (*Avena sativa* L.) and the method of cereal cultivation: pure swing, or sowing with undersown serradella (*Ornithopus sativus* L.) (in 2011 winter cereals were not included due to their thinned canopies after winter, and the need to plough the part of the treatment). The density of cereals was: oats, barley and spelt wheat – 500 plants·m^{-2}, barley – 300 plants·m^{-2}, and serradella - 60 kg·ha^{-1}. The experiments were carried out on good rye soil complex, class IVb. The size of the plot at the set-up of the experiment was 30.0 m^2, while at the harvest it was 27.6 m^2. The sowing of winter cereals was performed between 29.09 – 29.10, while spring cereals and serradella – between 9.04 and 26.04, depending on weather conditions at given year. The cereals were harvested at the stage of full maturity between 7.08 and 13.08, while serradella, between 23.09 and 20.10. Double harrowing was performed to remove weeds from the crops.

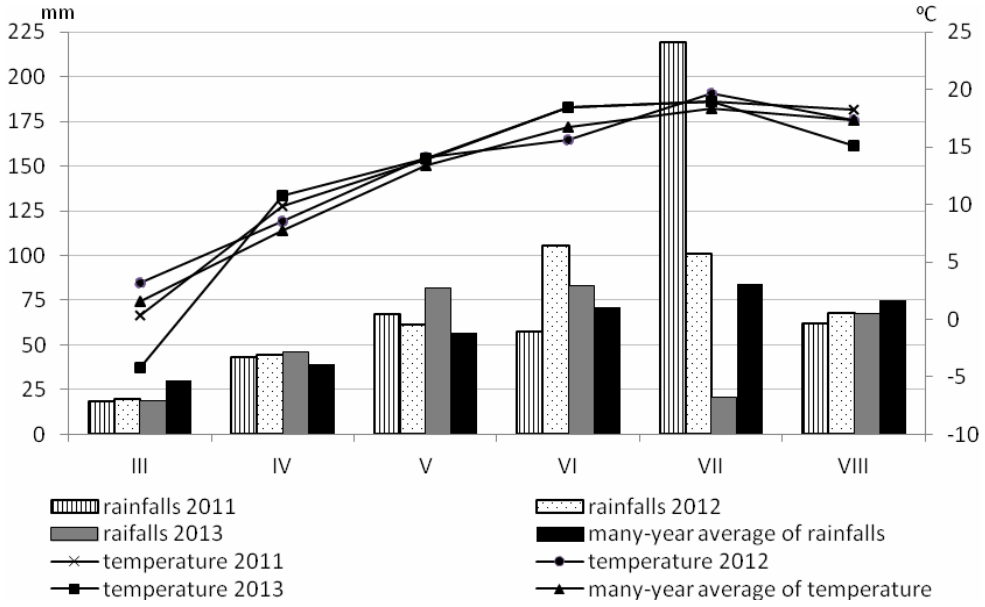
Cereal grain yields and the thousand grain weight were determined at 14% moisture, as well as the yield of green and dry matter of serradella. Also, the number of productive shoots, and the number of kernels per ear were determined. An analysis of the weed infestation of the mixed stands was performed a few days before the harvest, by a frame-weight method, from the area of 1 m^2, in three replications. Fresh and dry matter, species composition, and number of weeds were determined.

The impact of the tested experimental factors on the observed characteristics were assessed using the analysis of variance, setting Tukey's confidence half-intervals at significance level of $\alpha = 0.05$.

3. Results and discussion

Weather conditions at the time of the experiments were varied (fig. 1). The year 2011 was the least favorable to the growth and development of plants. In June there was a deficiency of moisture, while in July, heavy rains negatively affected the yielding of cereals. In 2012, both the sum of rainfalls, as well as distribution of rainfalls during the growing season were beneficial for the growth and development of mixed stand, but in 2013 high moisture deficits were reported in July (total rainfall amounted to 25% of many-year average), which negatively affected the yielding of serradella.

Among the tested species, the highest grain yields were obtained from oats, grown both in pure stands and with undersown crops. Winter rye and spelt wheat yielded significantly lower, while spring barley - the lowest. Undersown serradella generally favorably affected the yielding of oats, but reduced the yields of barley. It did not significantly affect the yielding of winter cereals (tab. 1). Lower yields of barley grown with undersown serradella were caused by lower tillering of this cereal, and its low competitiveness against legumes. Lower yielding of spring barley grown with undersown legumes, compared with a pure sowing were reported by Wanic et al. [16] as well as Sobkowicz and Lejman [17], but such relation was not recorded by Kuraszkiewicz [18]. Jaskulski [3] found that in the years with small amount of rainfall, serradella receded from the stand of spring barley, but at the same time its competitive force (expressed by the rate of the decrease of barley grain yields under 1 t of green mass of undersown crops) was the highest among the studied species (serradella, white clover, Italian ryegrass and chicory).



Source: own work / Źródło: opracowanie własne

Fig. 1. Meteorological conditions in the vegetation periods in the years 2011-2013
Rys. 1. Warunki meteorologiczne w okresie wegetacyjnym w latach 2011-2013

Table 1. Yield of grains cereals in pure sowing and with undersown serradella (t·ha^{-1})
Tab. 1. Plon ziarna zbóż uprawianych w siewie czystym i z wsiewką seradeli (t·ha^{-1})

Specification	2011	2012	2013	Mean
Oats	2.96 b	5.19 e	4.39 c	4.17
Oats+ serradella	3.08 b	4.89 d	4.71 d	4.23
Barley	2.78 b	3.74 c	4.11 b	3.54
Barley +serradella	2.23 a	2.85 a	3.71 a	2.93
Spelt wheat	-	3.21 b	4.19 b	3.70
Spelt wheat +serradella	-	3.37 b	4.10 b	3.74
Rye	-	3.91 c	3.54 a	3.72
Rye+serradella	-	3.42 b	3.74 a	3.58

Source: own work / Źródło: opracowanie własne

This confirms its high water requirements, and indicates its limited use as an undersown crop on the areas with periodical moisture deficits. Maciejewicz-Ryś et al. [19] recorded a positive impact of undersown serradella on the yielding of oats on light soils, but according to Tworkowski and Szczukowski [10], during dry years, in the sowings of oats and serradella, oats was more competitive against serradella than in the years with a higher amount of rainfall. It frequently outgrew, and suppressed this species.

The yielding of serradella depended on a cereal species, used as a cover crop. The most efficient was serradella undersown into winter rye, slightly less efficient - into spring barley and spelt wheat, and significantly less - into oats (tab. 2). The most favorable conditions for the cultivation of serradella occurred in 2012, when the yields of green mass were higher on average by 18% compared to 2011, and by 49% compared to 2013. Low yields of serradella in 2013 were due to the delayed term of seed sowing, rainfall deficits, and high air temperature in July, which caused a weaker development, and losses of undersown crop, especially after the harvest of cover crop. Sypniewski and Ignaczak [6] recorded higher yield of serradella when it was undersown into winter rye, compared to its undersowing into winter triticale. However, the results obtained by Paprocki and Zielińska [7] indicated that serradella grew and yielded best when it was undersown into spring rye, which overshaded serradella to the lowest extent and which was harvested about 2 weeks earlier than the legume-cereal mixtures and oats. At the same time, these authors pointed out that the species with flabby stems, such as peas or hairy vetch, lodged strongly, and due to that, they inhibited the growth of serradella. After their harvest, serradella was thinned, and grew back very slowly. According to Sypniewski and Ignaczak [6], the probability of obtaining economically significant yield of serradella undersown into rye, and winter triticale, in most regions of Poland amounts to 40-50%, and it is higher in the south, and the north-east of the country.

Table 2. Yield of green matter of serradella depending on cereals species (t·ha^{-1})
Tab. 2. Plon zielonej masy seradeli (t·ha^{-1})

Specification	2011	2012	2013	Mean
Oats+ serradella	4.00 a	4.30 a	1.89 a	3.40
Barley+serradella	4.67 b	4.67 b	2.29 b	3.88
Spelt wheat +serradella	-	5.02 c	2.17 b	3.60
Rye+serradella	-	6.54 d	1.87 a	4.20

Source: own work / Źródło: opracowanie własne

The studies evaluated more important morphological traits which determine cereal yields. It was shown that the undersown serradella had little impact on the tillering of cereals under favorable weather conditions (2012 and 2013), while its larger impact was observed in less favorable 2011, when it significantly reduced the number of productive shoots in oats and spring barley (tab. 3) .The highest number of grains per ear and per plant, and the largest grain weight were recorded for rye, and only slightly lower for oats, regardless of the cultivation method (tab. 4 and 5). The lowest number of grains per ear, and per plant was produced by spelt wheat. Regardless of weather conditions during the growing season, serradella generally favorably affected the number and weight of grains per plant, the number of grains per ear, and thousand grain weight.

Table 3. Number of production shoots of cereals depending on sowing method (unit)
Tab. 3. Liczba pędów produkcyjnych zbóż w zależności od sposobu uprawy (szt.)

Specification	2011	2012	2013	Mean
Oats	2.37	1.60	3.54	2.50
Oats+ serradella	1.60	1.43	3.76	2.26
Barley	2.98	2.57	3.60	3.05
Barley+serradella	1.74	2.30	3.78	2.61
Spelt wheat	-	2.87	2.10	2.48
Spelt wheat +serradella	-	2.90	2.00	2.45
Rye	-	2.67	1.92	2.30
Rye+serradella	-	2.54	1.80	2.17

Source: own work / Źródło: opracowanie własne

Table 4. Number of seeds per spike and thousand seed weight of cereals depending on sowing method
Tab. 4. Liczba ziaren w kłosie i masa tysiąca ziaren zbóż w zależności od sposobu uprawy

Specification	Number of seeds in spike (unit)				Thousand seed weight (g)			
	2011	2012	2013	Mean	2011	2012	2013	Mean
Oats	25.0	33.6	30.0	29.5	36.1	37.4	27.1	33.5
Oats+ serradella	31.0	39.1	22.9	31.0	38.2	41.0	22.1	33.8
Barley	15.1	15.5	15.4	15.3	43.1	46.5	38.9	42.8
Barley+serradella	18.2	21.2	15.8	18.3	45.2	48.6	39.8	44.5
Spelt wheat	-	13.9	-	13.9	-	44.2	-	44.2
Spelt wheat +serradella	-	14.7	-	14.7	-	45.3	-	45.3
Rye	-	39.5	32.4	36.0	-	38.2	30.0	34.1
Rye+serradella	-	42.2	27.1	34.6	-	39.1	30.9	35.0

Source: own work / Źródło: opracowanie własne

Table 5. Number and weight of grain per plant depending on sowing method
Tab. 5. Liczba i masa ziaren na roślinie zbóż w zależności od sposobu uprawy

Specification	Number of grain (unit)				Weight of grain (g)			
	2011	2012	2013	Mean	2011	2012	2013	Mean
Oats	57.1	54.1	107.2	72.7	2.06	2.28	2.90	2.41
Oats+ serradella	68.0	61.0	87.1	72.0	2.27	2.67	1.92	2.29
Barley	21.2	39.5	56.0	38.8	1.14	1.92	2.18	1.75
Barley+serradella	27.1	44.7	60.1	43.9	1.34	2.24	2.39	1.99
Spelt wheat	-	13.9	-	13.9	-	2.38	1.08	1.73
Spelt wheat +serradella	-	14.7	-	14.7	-	2.44	1.19	1.82
Rye	-	107.4	61.6	84.5	-	3.79	1.85	2.82
Rye+serradella	-	117.0	49.6	83.3	-	4.25	1.53	2.89

Source: own work / Źródło: opracowanie własne

A species of cereal and undersown serradella had a significant impact on the differentiation of fresh and dry matter, and the number of weeds. In all years of the studies, pure cereal sowings were more infested by weeds than cereal sowings with undersown. The highest fresh and dry matter of weeds (average from 3 years) was recorded in oats stand, while the lowest – in spelt wheat stand. (tab. 6). Undersown serradella significantly reduced the weight of weeds, on average by 48%. Mixed sowings with oats and spelt wheat were more competitive against weeds, than sowings with barley and rye. The number of weeds in cereal stands, and in mixed sowings varied in different years of the study (tab. 7). A significantly higher number of weeds per 1 m^2 were recorded in pure cereal sowings compared to the sowings with serradella. Undersown crop reduced a number of weeds on average by 45%. Sowings with spring cereals were more competitive against weeds (averagely 65%) compared to winter cereals (averagely 25%). The lowest number of weeds was found in the mixed sowings with barley (an average, 36 units per 1 m^2), while the largest - with rye (an average, 264 units per 1 m^2). Jędruszczak et al. [20] found that weed infestation of pure sowings of rye was by 61% higher than the one with serradella. They also observed a large variability in the number of weeds in the canopy in different years of the study, whereas the variability was higher in mixed sowings than in pure ones.

Weed species composition was similar in all years of the study. The largest species richness of weeds was recorded in 2012, which was largely due to the course of weather conditions (fig. 2). More weed species were observed in pure sowings of cereals. In oats stand, 22 weed species were identified, in barley – 25, in rye – 24, and in spelt wheat – 26 species. Nineteen taxa were common for all species of cereals, including 14 dicotyledonous ones. Serradella reduced the number of undesirable species, mostly in the sowings of spring cereals. When it was undersown into oats, it completely eliminated 10 taxa, and in the mixture with barley – 17. The number of weed species was similar in the studies of other authors. Jędruszczak et al. [20] found 28 taxa in the stand of rye with serradella, while Staniak and Księżak [21] recorded from 25 to 28 species in organic sowings of spring barley with legumes. The most numerous weed species in the sowings of spring cereals were: *Galinsoga parviflora* Cav., *Chenopodium album* L., *Equisetum arvense* L., *Plantago maior* L., *Sonchus arvensis* L., and *Echinochloa crus-galli* (L.) Pal. P.B., while in winter cereals: *Septaria glauca* (L.) P.B., *Agropyron repens* (L.) P.B., *Spergula arvensis* L., *Galinsoga parviflora* Cav., *Erigeron canadensis* L., *Echinochloa crus-galli* (L.) Pal. P.B., and *Stellaria media* (L.) Vill.

Table 6. Fresh and dry matter of weeds depending on cereal species and growing method
Tab. 6. Świeża i sucha masa chwastów w zależności od gatunku zboża i sposobu uporawy

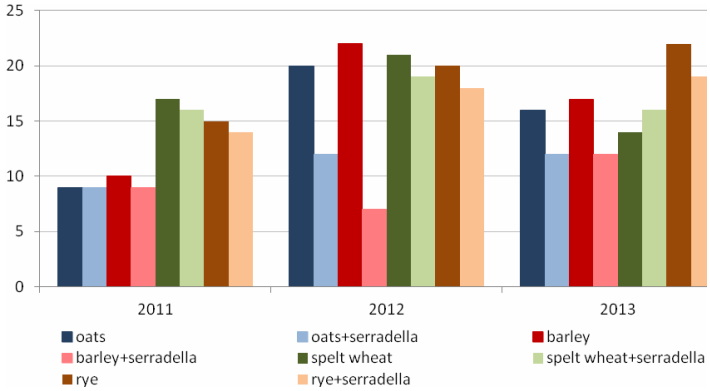
Specification	Fresh matter ($g \cdot m^{-2}$)				Dry matter ($g \cdot m^{-2}$)			
	2011	2012	2013	Mean	2011	2012	2013	Mean
Oats	382.4 b	338.4 ab	425.0 b	381.9	74.6 a	127.6 b	126.2 b	109.5
Oats+ serradella	78.2 a	162.0 ab	168.8 a	136.3	20.0 a	44.2 a	53.7 a	39.3
Barley	405.8 b	488.0 b	210.3 ab	368.0	51.9 a	119.8 b	62.9 a	78.2
Barley+serradella	170.9 ab	124.0 a	214.4 ab	169.8	50.9 a	35.4 a	64.9 a	50.4
Spelt wheat	-	276.0 ab	149.1 a	212.6	-	63.2 ab	61.4 a	62.2
Spelt wheat +serradella	-	178.1 ab	64.7 a	121.4	-	36.1 a	36.0 a	36.0
Rye	-	490.2 b	188.3 a	339.2	-	116.0 b	75.0 a	95.5
Rye+serradella	-	116.0 a	182.8 a	149.4	-	21.4 a	76.3 a	48.7

Source: own work / Źródło: opracowanie własne

Table. 7. The number of weeds per 1 m^2 depending on cereal species and growing method
Tab. 7. Liczebność chwastów na 1 m^2 w zależności od gatunku zboża i sposobu uprawy (szt.)

Specification	2011	2012	2013	Mean
Oats	68.6	119.5	160.1	116.0
Oats+ serradella	28.1	31.1	90.0	49.7
Barley	67.9	152.0	176.0	132.0
Barley+serradella	31.9	18.2	57.1	35.7
Spelt wheat	212.0	190.2	212.6	204.9
Spelt wheat +serradella	193.3	77.1	153.3	141.2
Rye	486.0	229.4	250.0	321.8
Rye+serradella	466.7	90.0	236.2	264.3

Source: own work / Źródło: opracowanie własne



Source: own work / Źródło: opracowanie własne

Fig. 2. Number of weeds species depending on cereal species and growing method (unit)
Rys. 2. Liczba gatunków chwastów w zależności od gatunku zboża i sposobu uprawy (szt.)

4. Conclusions

1. The highest grain yields were obtained from oats grown both in pure sowings, as well as with undersown serradella. Winter rye and spelt wheat yielded significantly lower, while spring barley – the lowest.
2. Undersown serradella favorably affected the yielding of oats, but it reduced the yielding of barley. However, it did not significantly affect the grain yields of winter rye and spelt wheat.
3. Yielding of serradella was dependent on the cereal species, which was used as a cover crop. The highest yield was obtained when it was undersown into winter rye, significantly lower – into spring barley and spelt wheat, and the lowest - in oats.
4. Undersown serradella had generally a positive impact on grain number and weight per ear and plant, as well as on the thousand grain weight.
5. A species of cereal and the method of cereal cultivation significantly affected variability of number, and fresh and dry matter of weeds. Pure sowings were the most infected with weeds. Undersown serradella reduced the weight of weeds on average by 48%, and their number by 45%. Mixed sowings with oats and spelt wheat were more competitive against weeds, than sowings with barley and rye.

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