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THE EFFECTS OF STRIP CROPPING AND WEED CONTROL METHODS ON YIELD AND YIELD COMPONENTS OF DENT MAIZE, COMMON BEAN AND SPRING BARLEY

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Key words: strip cropping, weed control, maize, spring barley, common bean.

Abstract

A field experiment was conducted in the years 2008–2010 at the Experimental Station of the Faculty of Agricultural Sciences, University of Life Sciences in Lublin. The experiment evaluated the effect of cropping systems (sole cropping and strip cropping) and weed control (mechanical and chemical) on the yield and yield components of maize, common beans, and spring barley. Strip cropping significantly increased the yield of maize and the percentage of ears in the total biomass. The beneficial effect of strip cropping on common bean seed yield was significant in conditions of mechanical weed control. Strip cropping increased the number of pods per plant, seed weight per plant, and 1,000 seed weight. Spring barley yield was slightly higher in the strip cropping than in the sole cropping. Strip cropping increased the number and weight of seeds per spike.

WPŁYW UPRAWY PASOWEJ I METOD REGULACJI ZACHWASZCZENIA NA ELEMENTY STRUKTURY I PLON KUKURYDZY PASTEWNEJ, FASOLI ZWYCZAJNEJ I JĘCZMIENIA JAREGO

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Słowa kluczowe: uprawa pasowa, regulacja zachwaszczenia, kukurydza, jęczmień jary, fasola zwyczajna.

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Abstrakt

Eksperyment polowy przeprowadzono w latach 2008–2010 w Stacji Doświadczalnej Wydziału Nauk Rolniczych (50°42'N, 2316'E) Uniwersytetu Przyrodniczego w Lublinie. W doświadczeniu oceniano wpływ metod uprawy (siew czysty i uprawa pasowa) i regulacji zachwaszczenia (mechaniczna i chemiczna) na strukturę i wielkość plonów kukurydzy pastewnej, fasoli zwyczajnej i jęczmienia jarego. Uprawa pasowa zwiększała istotnie wielkość plonu kukurydzy pastewnej i udział kolb w plonie. Korzystny wpływ uprawy pasowej na wielkość plonu nasion fasoli zwyczajnej był istotny w warunkach mechanicznej metody regulacji zachwaszczenia. Uprawa pasowa zwiększała liczbę strąków i nasion z rośliny oraz masę nasion z rośliny i masę tysiąca nasion. Jęczmień jary plonował nieco wyżej w uprawie pasowej niż w uprawie jednogatunkowej. Uprawa pasowa wpływała korzystnie na elementy struktury plonu, tj. liczbę i masę ziarniaków z kłosa.

Introduction

Intercropping, has been used in numerous parts of the world (ZHANG and LI 2003, ARLAUSKIENÉ et al. 2011, DORDAS 2012). When crops are planted together, competition and facilitation can occur simultaneously (MARIOTTI et al. 2009). According to WU et al. (2012), when we increase facilitation and decrease competition between crops, multi-cropping systems can use environmental resources more effectively and can reduce costs, which improves the sustainability of crop production. Strip cropping is a form of intercropping used in many regions of the world (ANDRADE et al. 2012, HAUGGAARD-NIELSEN et al. 2012, COLL et al. 2012). This system protects the soil from water and wind erosion and reduces nutrient and pesticides leaching (ZHANG and LI 2003, ROGOBETE and GROZAV 2011). Strip cropping can also limit the occurrence of pests, diseases, and weeds, so that the use of pesticides can be reduced (MA et al. 2007, GŁOWACKA 2013a). Placing plants in strips minimizes competition between them for water, light, and nutrients, while greater diversity increases the stability of the agro-ecosystem. Numerous studies have demonstrated that the combined yields in strip cropping exceed the sum of the component species grown alone, as a result of complementary use of available growth resources (BORGHI et al. 2012, COLL et al. 2012, GŁOWACKA 2013b). Strips of maize and soybeans or dry beans have been used by farmers in the Eastern and Midwest U.S. because of higher yields and greater economic stability of this system (HAUGGAARD-NIELSEN et al. 2012). In Poland, the most commonly used form of intercropping is the cultivation of mixed cereals or of cereals with legumes (TOBIASZ-SALACH et al. 2011). Strip cropping is an alternative offering more possibilities, as different species are sown and harvested individually and therefore may be more useful in growing plants for different purposes. This system can be regarded as the adaptation of the more traditional intercropping systems but allowing the use of modern farm machinery (HAUGGAARD-NIELSEN et al. 2012). In the few research on strip cropping conducted in Poland it has been found to reduce the number of weeds in common bean and dent maize and to increase the trade yield of common bean and the percentage of ears in the total maize biomass. This effect of strip cropping system was particularly pronounced when used in combination with mechanical weed control (GŁOWACKA 2008, 2011). The efficiency of strip cropping depends on the choice of plant species, weed control methods, and weather conditions. The aim of this study was to evaluate the impact of strip cropping and varied weed control methods on the yield and yield components of maize, common beans, and spring barley.

Materials and Methods

A field experiment was conducted in the years 2008–2010 at the Experimental Station of the Faculty of Agricultural Sciences in Zamość, University of Life Sciences in Lublin (50°42'N, 23°16'E), on brown soil of the group Cambisols which was slightly acidic (pH_{KCl} – 6.2), with average content of organic matter (19 g kg^{-1}), high content of available phosphorus and potassium (185 mg P kg^{-1} and 216 mg K kg^{-1}), and average magnesium content (57 mg kg^{-1}). The subject of the study was the Celio variety of dent maize, the Aura variety of common bean, and the Start variety of spring barley. The experiment was carried out in a split-plot design in four replications. The factors analyzed were: I. Cropping method (CM). 1. Sole cropping of a single species, in which the size of one plot of each crop was 26.4 m^2 for sowing and 22.0 m^2 for harvesting; 2. Strip cropping, in which three crops – dent maize (*Zea mays* L. conv. *dentiformis*), common bean (*Phaseolus vulgaris* L.), and spring barley (*Hordeum vulgare* L.) – were grown side-by-side, each in separate strips 3.3 m wide. The size of the plots was 13.2 m^2 for sowing and 11 m^2 for harvesting. II. Weed control method (WC); *A* – mechanical: maize – weeding of interrows twice (first in the 5–6 leaf stage – BBCH 15/16 – and again two weeks later); common bean – weeding of interrows twice (first 4–5 weeks after sowing, then 3 weeks later); spring barley – harrowing twice (first in the one-leaf stage – BBCH 10 – and again in the 5-leaf stage – BBCH 15); *B* – chemical: maize – a.i. bromoxynil + terbuthylazine at 144 g ha^{-1} + + 400 g ha^{-1} at the 4–6 leaf stage (BBCH 14/16); common bean – a.i. trifluralin before sowing at 810 g ha^{-1} + bentazon at 1,200 g ha^{-1} after emergence, when the first pair of trifoliate leaves had unfolded in the bean plants (BBCH 13–14); spring barley – a.i. 4-chloro-2-methylphenoxyacetic acid at 500 g ha^{-1} at the full tillering stage (BBCH 22–23).

Dent maize was grown for silage with spring barley as a forecrop. Maize was sown on 28th April and 2nd and 5th May. The sowing rate was 11 plants per m^2, and the spacing between rows was 65 cm. In the sole cropping 10 rows of maize were planted on each plot, while in the strip cropping 5 rows were planted. The maize was harvested at the milky-wax stage (BBCH 79/83). Common bean was grown for dry seeds with maize as a forecrop. In the successive years of the study, beans were sown on 28th April and 2nd and 5th May. The distance between rows was 47 cm and the density was 35 plants per m^2. In the sole cropping 14 rows of beans were planted on each plot, while in the strip cropping 7 rows were planted. Beans were harvested by hand in the third week of August or first week of September. Spring barley was grown on a site where the previous crop was common bean. In the successive years, barley was sown on 12th, 15th, and 19th April at a rate of 350 seeds per m^2, the spacing between rows was 15 cm. In strip 22 rows of barley were planted. Barley was harvested in the first or second third of August (BBCH 89).

In strip cropping system strips followed a north-south orientation, and their arrangement is shown in Figure 1. Weather conditions varied over the years of the study (Table 1). A detailed description of the agriculture procedures for each crop was given in an earlier paper (GŁOWACKA 2013a).

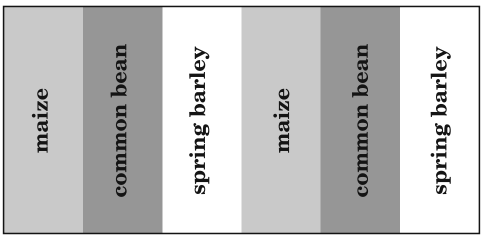

Fig. 1. The arrangement of strips in strip cropping system

Table 1

Rainfall and air temperature in months IV–IX as compared to the long-term means (1971–2010), according to the Meteorological Station in Zamość

Years	Rainfall [mm]						
	April	May	June	July	August	September	Sum
2008	71.5	74.8	48.9	104.6	69.7	80.4	449.9
2009	15.5	102.6	124.4	24.2	48.9	34.5	350.1
2010	30.7	106.7	62.9	143.5	86.1	25.4	455.3
Means for 1971–2010	41.8	70.7	72.8	91.2	65.3	52.1	393.9
Temperature [°C]							
2008	10.7	15.5	19.4	20.2	20.6	19.7	3031
2009	11.3	13.8	20.2	20.0	20.1	16.9	3122
2010	11.0	15.1	18.4	21.5	20.2	16.6	3141
Means for 1971–2010	9.0	14.6	17.9	19.5	18.4	13.7	2849

Before the maize harvest, plant densities, plant height, and the percentage of ears, stems, and leaves in the green matter were determined. For the sole cropping, the designated test area consisted of 2 m sections from three inner rows. In the strip cropping, plants were picked from a 2 m of each row and yield and its structure were determined. After mechanical harvesting, yield of dry matter was determined. Before the bean harvest determinations were made of plant density, number of pods per plant, number and weight of seeds per pod and per plant, and 1,000 seed weight. For the sole cropping, plants were picked from two randomly designated sampling areas of 1 m^2 on each plot. In the strip cropping, plants were picked from a 2 m length of each row and yield and yield structure were determined. After hand harvesting, seed yield was determined at 15% moisture. In the spring barley grown in sole cropping, plants were picked by hand from two randomly designated sampling areas of 1 m^2 on each plot. For the strip cropping, the sampling areas were sections 2 m long from the three rows nearest the maize strip, the middle three rows, and the three rows next to the strip of beans. In the plants from the sampling areas, determinations were made of the number of spikes per unit area, culm and spike length, seed number and weight per spike, and 1,000 grain weight. After harvesting with a plot combine, barley grain yield was determined at 15% moisture content.

LER – the land equivalent ratio – was also calculated according to the formula:

$$LER = \Sigma \, (Ysi/Ymi)$$

where:
Ysi is the yield of each species in strip cropping (per 0.33 ha),
Ymi is the yield of each species in sole cropping (per ha).

This ratio was calculated for all species (i) to determine the partial LER, and the partial LERs were summed to obtain the total LER for the strip cropping. A total LER < 1 means that the strip cropping is less efficient than sole cropping, while a total LER > 1 indicates that strip cropping is more efficient than growing a single species alone.

The results were analysed by analysis of variance ANOVA using STATISTICA PL. The differences between averages were evaluated using Tukey's test, at $P < 0.05$.

Results and Discussion

Maize is a species often chosen for cultivation in strip cropping, as it is highly responsive to edge effect, and as a tall, C4 photosynthesis plant, it efficiently utilizes the greater quantity of available sunlight (GHAFARZADEH et al. 1997). NING et al. (2012) states that intercropping using spring- and summer-sown maize presents advantages in terms of biomass yield and gross energy as compared to sole cropping. However, COLL et al. (2012) reported that maize, as a sole crop, showed the highest resource productivity (water and radiation) as compared to maize-soybean intercrop. In various experiments, a significant increase in maize yield in border rows has been noted (by 50%), and consequently overall yield in the strip was higher (CRUSE and GILLEY 1996, LESOING and FRANCIS 1999). In the present study maize yield in the strip cropping was on average 11% higher than in the sole cropping (Table 2). This resulted from a significant increase in yield in the maize border rows – by 26.0–29.6% in the row adjacent to the common beans, and by 17.0–21.5% in the row next to barley (Figure 2 and Figure 3). These differences were due to the neighboring plant species. When IRAGAVARAPU and RANDALL (1996) grew maize in strips with soy and wheat, they noted a 23% increase in maize yield in the extreme row adjacent to the wheat, and a 27% increase in the row adjacent to the soy strip. In intercropping, plant species can be complementary in chemical, spatial and temporal resource use (FOX 2005). Moreover, species can facilitate each other by creating the habitat and/or increasing nutrient availability for co-occurring species (EISENHAUER 2012). WU et al. (2012) suggested that in intercropping system two or more species differ in growth forms and physiological parameters. Thus, resources are used in a complementary fashion, in both time and space, due to niche partitioning. The effectiveness of strip cropping is also affected by how the strips are arranged. Plants in the eastern border rows produced higher yield than the rows on the western border. This is due to the faster rate of photosynthesis in the cooler mornings, when the sunlight reaches the eastern edge, than in the hot afternoons, when it falls on the western edge of the strip and may not be fully utilized by maize plants due to water stress and wilting.

Strip cropping significantly increased weight per plant, but decreased plant height by an average of 23 cm. The reduction in plant height may be due to greater access to photosynthetically active light and shortened internodes (JURIK and VAN 2004). This system also increased the percentage of ears in the total yield, while the share of stalks decreased and the share of leaves remained at a similar level (Table 3). A particularly significant increase in the percentage of ears was observed in the border rows of the maize strips (Figure 4). A similar

Table 2

Effect of cropping method and weed control method on the yield of dent maize, spring barley and common bean (dt ha^{-1})

I. Cropping method (CM)	II. Weed control (WC)	Maize biomass (d.m.)				Grain of spring barley				Common bean seeds			
		years			mean	years			mean	years			mean
		2008	2009	2010		2008	2009	2010		2008	2009	2010	
Sole cropping (1)	*A**	160	139	151	150	53.3	40.5	37.7	43.8	9.6	8.6	10.2	9.5
	B	186	166	178	177	61.0	46.6	45.5	51.0	17.6	16.4	16.5	16.8
Strip cropping (2)	*A*	177	156	168	167	57.4	45.1	38.9	47.1	13.4	10.4	11.4	11.9
	B	206	184	197	196	64.1	47.9	44.9	52.3	18.9	17.0	17.3	17.7
$LSD_{0.05}$ for CM · WC		n.s.	n.s.	n.s.	n.s.	n.s.	1.3	1.1	0.81	1.9	n.s.	1.5	1.8
Average for factors													
Averages CM	sole cropping	173	153	165	162	57.1	43.6	41.6	47.4	13.6	12.5	13.4	13.2
	strip cropping	192	100	183	181	60.7	46.5	41.4	49.7	16.2	13.7	14.4	14.8
$LSD_{0.05}$ for CM		5.0	6.0	5.0	16.0	1.7	1.2	n.s.	1.1	0.8	1.0	0.4	0.8
Averages WC	*A*	16.9	148	160	159	55.3	42.8	38.3	45.5	11.5	9.5	10.8	10.7
	B	193	175	188	185	62.5	47.2	45.2	51.7	18.2	16.7	16.9	17.3
$LSD_{0.05}$ for WC		4.0	5.0	11.0	12.0	1.3	0.9	0.8	1.2	0.6	0.8	0.3	0.6
Years		182	161	17.3	–	58.9	45.0	41.8	–	14.9	13.1	13.9	–
$LSD_{0.05}$ for years		14.0				3.6				0.8			

* weed control: *A* – mechanical, *B* – chemical

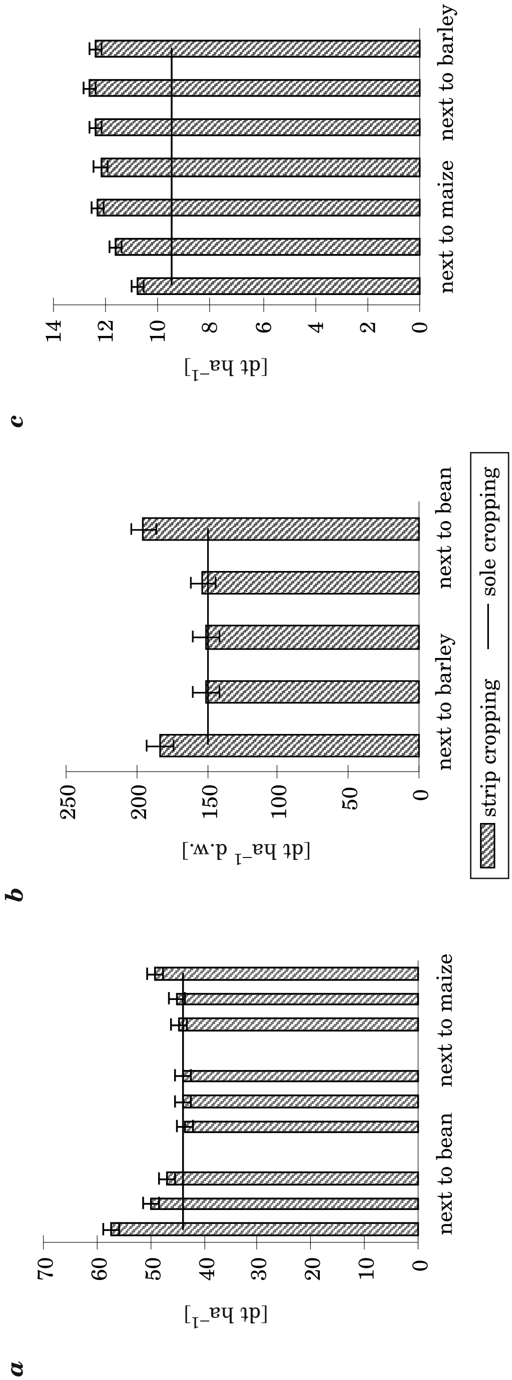

Fig. 2. The influence of row position in the strip on the yield of spring barley (*a*), maize (*b*), common bean (*c*) in conditions of mechanical weed control; note: bars represent the standard errors

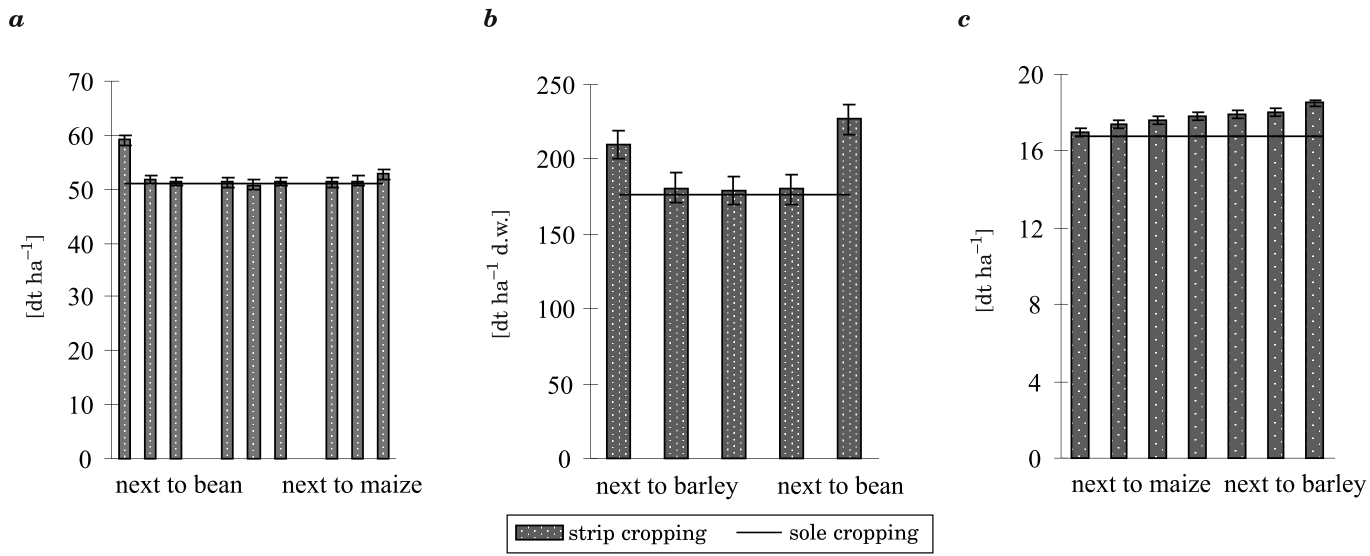

Fig. 3. The influence of row position in the strip on the yield of spring barley (*a*), maize (*b*), common bean (c) in conditions of chemical weed control; note: bars represent the standard errors

Table 3

Plant height, density and chosen yield components of maize (mean from 2008–2010)

I. Cropping method (CM)	II. Weed control (WC)	Weight of one plant [g]	Plant densities [per 1 m^2]	Plant height [cm]	Percentage share in green matter [%]		
					ears	stems	leafs
Sole cropping (1)	*A* *B*	517.6 670.3	10.6 9.8	236.0 257.0	36.5 34.9	46.9 48.2	16.6 16.9
Strip cropping (2)	*A* *B*	604.1 718.6	9.8 9.2	210.0 238.0	37.1 37.3	46.1 45.8	16.8 17.1
$LSD_{0.05}$ for CM · WC		n.s.	n.s.	5.0	n.s.	0.97	n.s.
Average for factors							
Averages CM	sole cropping strip cropping	593.9 661.3	10.2 9.5	247.0 224.0	35.7 37.2	47.5 46.0	16.7 16.9
$LSD_{0.05}$ for CM		48.5	0.6	4.6	1.2	0.89	n.s.
Averages WC	*A* *B*	560.8 694.4	10.2 9.5	223.0 248.0	36.8 36.1	46.5 47.0	16.7 17.0
$LSD_{0.05}$ for WC		37.3	0.6	3.5	n.s.	n.s.	n.s.
Years	2008 2009 2010	753.0 577.0 552.0	10.0 9.3 10.1	246.0 242.0 218.0	36.5 33.1 39.7	49.2 50.1 40.9	14.3 16.8 19.3
$LSD_{0.05}$		43.7	n.s	6.4	2.4	1.8	2.3

Explanations as in Table 2

trend of reduced plant height and increased share of ears in the yield was observed in spring wheat/maize/common bean strip cropping (GŁOWACKA 2008).

GARCIA-PRÉCHAC (1992) states that maize/soy/oats strip cropping are more efficient than the cultivation of each species separately in conditions of moderate or high humidity. In the present study, irrespective of the tested factors, the lowest yield with the smallest share of ears was obtained in the year with the least rainfall, which, moreover, was unevenly distributed over the season (Table 2). However, in this growing season the yield increase in strip cropping in comparison to sole cropping was 11.8%, which was the highest increase of all the years of the research. This may be due to the fact that barley and bean plants are less competitive in water uptake than maize. Moreover, there were significant shortages of rainfall in July, August, and September, months in which the plants accompanying the maize, especially barley, need less water.

Maize, due to the cultivation of a wide inter-row spacing and relatively slow growth in the early stages, is quite sensitive to competition from weeds. Worldwide yield losses in maize due to weeds are estimated to be around 37% (OERKE and DEHNE 2004). It was observed and discussed in other paper that weed infestation of maize was significantly higher in the case of the mechanical

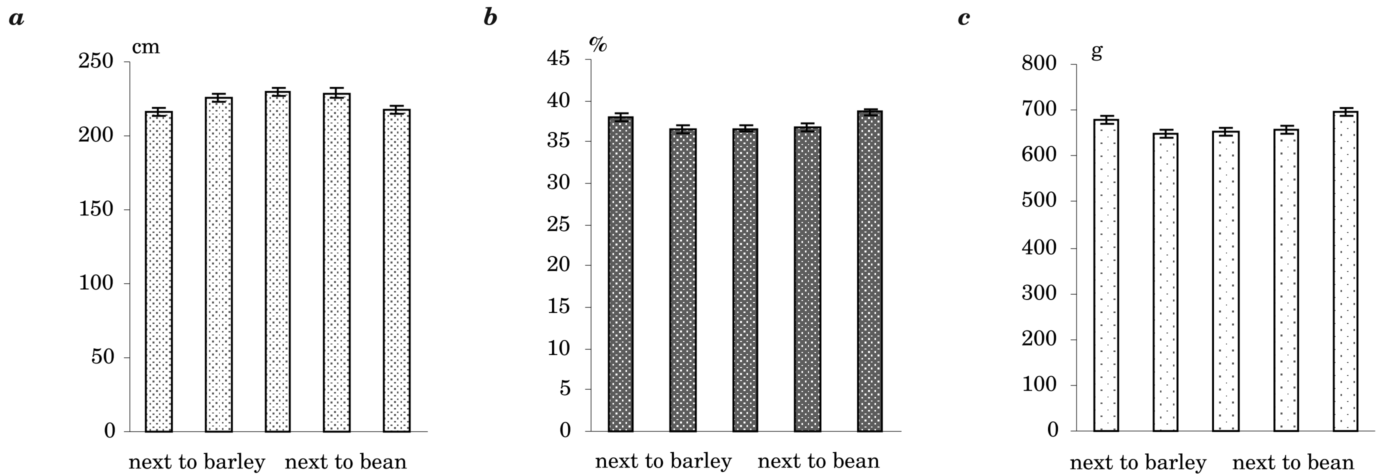

Fig. 4. The influence of row position in the strip on some elements of maize yield structure (average for weed control method): *a* – plant height, *b* – percentage of ears, *c* – weight of one plant; note: bars represent the standard errors

weed control (GŁOWACKA 2013). Mechanical method is often insufficiently effective because the weeds in the maize rows are not completely destroyed (ABDIN et al. 2000). Differences in weed infestation, significantly affected the yield and yield structure of the maize. The lowest maize biomass, with the smallest percentage of ears, was produced in conditions of mechanical weed control. The use of chemical treatments increased yield by 17.8% and the percentage of ears by 3.4%. Statistical analysis did not confirm an interaction between the cropping systems and weed control method.

Maize in strip cropping is often accompanied by soy. As a taller plant, maize can significantly reduce the access of soy to light and compete with it for water and minerals, and as a result significantly reduce soybean yield (EGLI and YU 1991, LESOING and FRANCIS 1999). For this reason, small grain plants such as wheat and oats are included in the strip cropping to minimize the negative impact of the maize on the other plant (IRAGAVARAPU and RANDALL 1996). In this study, common bean was introduced in the strip cropping because it is a leguminous plant often grown for dry seeds, especially in south-eastern Poland (ŁABUDA 2010). In a previous study by GŁOWACKA (2011), trade yield of bean increased in spring wheat/maize/common bean strip cropping, and a positive effect of strip cropping was evident in conditions of mechanical weed control. In the present study as well the seed yield was on average 13% higher in the strip cropping than in the sole cropping (Table 2). Strip cropping also significantly increased the number of pods and seeds per plant, seed weight per plant, and 1,000 seed weight. The beneficial effect of strip cropping was pronounced on plots where mechanical weed control was used (Table 2 and Table 4). This was probably due to the observed and discussed in other paper, lower weed infestation in the beans grown in strips and weeded mechanically (GŁOWACKA 2013). At these site, strip cropping reduced the number of weeds by 32% and their above-ground dry weight by 42% compared to sole cropping, while at the sites with chemical weed control the differences were only 14% and 13% for the number and biomass of weeds, respectively. Previous studies conducted in Poland have determined that strip cropping of maize, common bean and spring weed reduced both the number and dry weight of weeds in common bean and spring wheat in comparison with sole cropping (GŁOWACKA 2010). LIEBMAN and DYCK (1993) also suggest that weed infestation of crops can be reduced by the introduction of strip cropping. In addition, the adjacent strip of maize was a barrier protecting the bean plants from the wind, which may have improved water use and the temperature in the bean crop, thus favourably influencing the number of pods per plant (Table 4). Contrary, in the study by COLL et al. (2012) biomass and grain production of soybean decreased by 71–80% and by 64–77% when it was intercropped with maize and sunflower respectively. Intercrops arrangement in the cited study consisted of two rows of soybean and one row of maize or sunflower. In our experiment strip cropping consisted of 7 rows of common bean, 22 rows of barley and 5 rows of maize. Thus the negative impact of the maize on the neighbouring plant of common bean was smallest.

Table 4

Chosen yield components of common bean (mean from 2008–2010)

I. Cropping method (CM)	II. Weed control (WC)	Number [piece]			Weight [g]			Plant densities [per 1 m²]
		pods per plant	seeds per		seeds per		1,000 seeds	
			pod	plant	pod	plant		
Sole cropping (1)	*A* *B*	11.4 16.9	2.9 3.2	35.1 60.5	1.62 1.99	19.4 32.1	540.5 570.7	43.2 46.5
Strip cropping (2)	*A* *B*	14.0 18.3	3.1 3.3	40.0 65.8	1.85 2.10	25.6 36.4	585.0 610.0	44.8 47.8
$LSD_{0.05}$ for CM · WC		n.s.	n.s.	n.s.	n.s.	2.0	3.7	n.s.
Average for factors								
Averages CM	sole cropping strip cropping	14.2 16.1	3.0 3.2	47.8 52.9	1.80 1.97	25.8 31.0	565.6 597.7	44.8 46.3
$LSD_{0.05}$ for CM		1.0	n.s.	1.8	0.6	1.8	3.4	n.s.
Averages WC	*A* *B*	12.8 17.6	3.0 3.3	37.5 63.2	1.73 2.04	22.5 34.3	562.8 600.6	44.0 47.1
$LSD_{0.05}$ for WC		0.7	0.2	1.9	0.3	1.4	2.6	2.9
Years	2008 2009 2010	17.1 14.0 14.5	3.2 3.0 3.0	57.4 45.8 47.2	2.10 1.70 1.80	32.0 26.2 27.0	598.0 570.0 577.0	47.0 43.0 46.0
$LSD_{0.05}$ for years		1.4	n.s.	2.4	0.3	1.8	4.6	3.5

Explanations as in Table 2

Both the seed yield and yield components varied depending on the row position in the beans strip. The fewest pods and seeds per plant were noted in the row adjacent to barley, and the most in the row next to maize. The highest seed weight per plant was observed in the row next to the barley (Figure 5). The yield of bean seeds was the lowest in the row bordering the maize strip. Differences between the rows in the strip were particularly evident under conditions of mechanical weed control (Figure 2). Although a negative impact of the maize was visible in the row directly adjacent to the maize, yield increased in successive rows and was highest in the row adjacent to the barley (Figure 2 and Figure 3). Changes in the number of pods and seeds per plant in rows of the bean strip showed that competition from maize was not as strong in the earlier stages of development (Figure 5). Maize and beans were sown at the same time, and maize is characterized by slow initial growth. During the

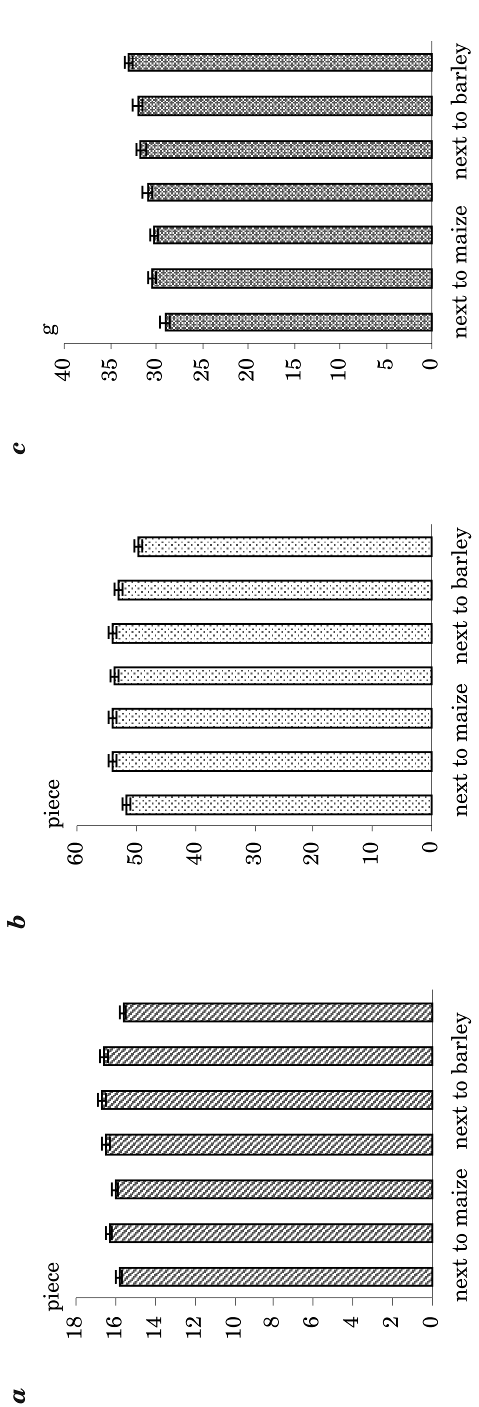

Fig. 5. The influence of row position in the strip on some elements of common beans yields structure (average for weed control method): *a* – pods per plant, *b* – seed number per plant, *c* – seed weight per plant; note: bars represent the standard errors

seed-filling period the competitiveness of the maize for the beans was greater, so that the seed weight per plant was higher in the row directly adjacent to the barley.

Beans plants are relatively small, which also increases their susceptibility to weed infestation, particularly in the initial period of growth (HEKMAT et al. 2007, SIKKEMA et al. 2008). An important element in the cultivation of common beans is to keep the plantation free from weeds during the first 3–5 weeks after sowing. Limiting weed control to mechanical treatments can significantly reduce the yield of beans (GŁOWACKA 2011). In this study, weed control limited to weeding of interrows twice decreased seed yield by an average of 38% compared to the use of herbicides (Table 2). Mechanical weed control also significantly reduced the some elements of yield structure (Table 4). This may be due to the fact that the use of herbicides significantly reduced the number and biomass of weeds compared to mechanical weed control (GŁOWACKA 2013).

The yield and yield structure of the barley was variable in different years of the study, and varied depending on the cropping system and weed control method (Table 2 and Table 5). In the first and second year, spring barley yield was significantly higher (+6.6%) in the strip cropping than in the sole cropping. In the third year of the study the impact of strip cropping was not significant. Average grain yield in the experiment was about 4.9% higher in strip cropping. Studies on strip cropping have generally found yield increases in small grains accompanying maize and soybeans (IRAGAVARAPU and RANDALL 1996, GHAFFARZADEH et al. 1998). The small grains in these experiments and the barley in the present study were sown 3–4 weeks earlier than other plants, so there was less competition in the border rows in the early stages of growth. Later, when the beans and maize can compete with the barley, it needs less water, nutrients, and light. Strip cropping significantly increasing the number of spikes per unit area, the weight and number of grain per spike and 1,000 seed weight. It did not affect the length of the culm. The higher yield in the strip cropping resulted from the reaction of barley to the edge effect, especially in the row adjacent to the common beans (Figure 2 and Figure 3). The yield advantage of the border row was mainly attributed to more solar energy, good ventilation, and less competition for nutrients, which resulted in more spikes or panicles, higher biomass production, and consequently higher grain yields (WANG et al. 2013). In a study by RUDNICKI and GAŁĘZEWSKI (2008) on the edge effect, the yield of oat grain in the first border row increased by 85%. In our study, barley yield in the first row of the bean strips was higher than in the middle rows by 27% and 16%, for the mechanical and chemical weed control. In the barley row adjacent to the maize grain yield also increased, but to a much lesser extent. Higher yield of border rows resulted from greater access to photosynthetically active light, better ventilation and less competition for nutrients and water (RUDNICKI and GAŁĘZEWSKI 2008, WANG et al. 2013). Spikes densities and the number of grains per spike were higher in the border rows of the barley strip, irrespective of the neighboring plant species. However, higher seed weight per spike was noted in the border rows adjacent to the bean strip (Figure 6). The number of spikes is determined mainly by tillering phase, which depends on natural factors such as temperature and water availability and agricultural practices, mainly of nitrogen availability for plants. The tillering phase of barley occurred at times, when the other accompanying crops had a reduced demand for resources. Avoiding the overlapping of critical periods improves complementarities in the use of resources between intercrop components with positive implications on resources use efficiency (COLL et al. 2012).

Table 5

Chosen yield components of spring barley (mean from 2008–2010)

I. Cropping method (CM)	II. Weed control (WC)	Number of spike [per 1 m^2]	Length of [cm]		Grain number in spike	Weight of [g]	
			culm	spike		grain from spike	1,000 grains
Sole cropping (1)	*A* *B*	476.0 518.0	79.6 75.7	7.1 7.0	18.5 18.7	0.96 1.02	50.7 53.0
Strip cropping (2)	*A* *B*	497.0 536.0	76.1 70.6	7.4 7.7	19.4 19.7	1.06 1.09	51.9 54.0
$LSD_{0.05}$ for CM · WC		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Average for factors							
Averages CM	sole cropping strip cropping	497.0 516.0	77.6 73.4	7.0 7.6	18.6 19.5	0.99 1.08	51.8 52.9
$LSD_{0.05}$ for CM		16.0	n.s.	0.3	0.4	0.03	0.6
Averages WC	*A* *B*	487.0 527.0	77.9 73.2	7.3 7.3	19.0 19.2	1.01 1.06	51.3 53.5
$LSD_{0.05}$ for WC		18.0	4.4	n.s.	n.s.	0.02	0.4
Years	2008 2009 2010	535.0 504.0 482.0	79.2 74.7 72.9	7.6 7.2 7.1	22.6 18.2 16.7	1.23 0.92 0.91	55.7 52.4 53.6
$LSD_{0.05}$ for years		28.0	6.3	0.4	0.9	0.08	0.7

Explanations as in Table 2

Land equivalent ratio (LER) is often used to compare the efficiency of intercropping with sole cropping (CONNOLLY et al. 2001). On average for the experiment, the LER was 1.13 and 1.09 for mechanical and chemical weed control. This means that maize/beans/spring barley strip cropping was 9–13% more efficient than the sole cropping of a single species.

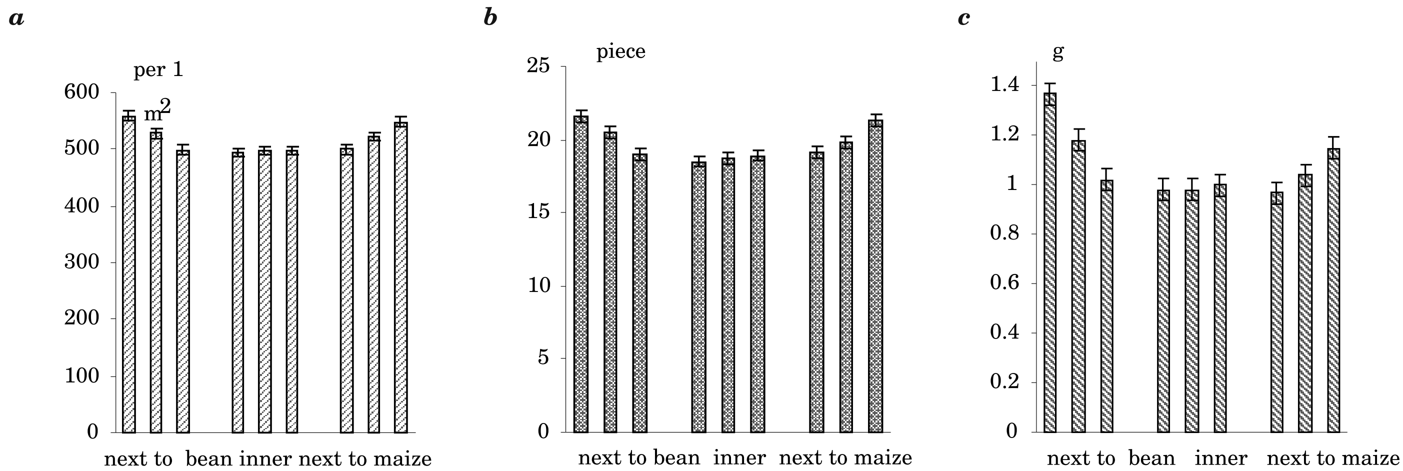

Fig. 6. The influence of row position in the strip on some elements of spring barley yield structure (average for weed control method): *a* – number of spikes, *b* – grain number per spike, *c* – grain weight per spike; note: bars represent the standard errors

Conclusion

1. Strip cropping significantly increased the yield of dent maize, as well as the percentage of ears in the total yield.

2. The beneficial effects of strip cropping on seed yield in common beans were significant only where mechanical weed control was used. Strip cropping also significantly increased the number of pods and seeds per plant, seed weight per plant, and 1,000 seed weight.

3. Spring barley yield was slightly higher in the strip cropping than in the sole cropping. Strip cropping also positively affected yield components, such as the weight and number of grain per spike and 1,000 seed weight.

4. Yields of dent maize, spring barley, and common bean were significantly higher for the chemical weed control method than for the mechanical method.

5. A significant interaction between the cropping system and weed control method was found only for beans, with strip cropping found to be more effective in combination with mechanical weed control.

6. Both yield and yield components varied depending on the row position of the strip. The extent of the changes depended not only on the trait tested and the crop species, but also on the neighbouring plant in the strip.

7. The land equivalent ratio indicates that strip cropping was comparable to or more efficient than sole cropping. This, in combination with environmental benefits, indicates that strip cropping can be an element of sustainable agriculture.

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