Chapter 6

Mixtures of Legumes with Cereals as a Source of Feed for Animals

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Additional information is available at the end of the chapter

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1. Introduction

Mixtures of spring cereals with legumes are considered good agricultural practice in many European countries, especially in organic and low-input farming system [1, 2]. Cultivation of mixtures contributes to the complementary use of habitat resources and compensatory growth of individual plant species, causing an increased productivity and greater stability of yield [3, 4]. Moreover, the risk of lodging of legumes is significantly reduced. Mixtures limited the negative effects of excessive share of cereals in crop rotation and they are a good forecrop for the succeeding crops. They have a positive effect on the soil fertility, enriching it with nitrogen through a symbiosis of legumes with nodule bacteria and in organic matter due to the huge amount of crop residue left behind [5]. Legume-cereal mixtures are treated with lower doses of nitrogen fertilizer in comparison with the sole cereal, which is advantageous from an economic point of view. The increase in nitrogen dose usually leads to an increase in the yield of cereal component, while the share of legumes seeds in the yield decreases. Mixed crops can be cultivated on soils poorer by one valuation class than individual species cultivated as sole crops. Yielding of mixtures and crop quality largely depends on the selection of components and their participation. Yield of mixture seeds decrease with increasing percentage of legumes at sowing. Cultivation of mixed crops increases protein content in the seeds of cereal component increases the yield of crude protein in the biomass and increases the content of this component in the yield of the seeds mixture. Such crops are also an effective method of weed infestation control and reduce the spread of diseases and pests, which is very important in organic production system [6, 7, 8].

2. Material and methods

Paper was established on the base of the authors' results and literature. The authors' field experiments were conducted according to organic agriculture rules in Agriculture Experimental Stations of Institute of Soil Science and Plant Cultivation – State Research Institute and individual organic farms in different parts of Poland. The results of research were statistically elaborated. The impact of the examined factors experiments on the determined characteristics were assessed using analysis of variance, the half-intervals of confidence being determined by Tukey's test at the significance level of $\alpha = 0.05$.

2.1. The importance of legume-cereal mixtures and benefits from the cultivation

Mixtures of legumes with cereals may be used in different ways. If they are grown for seeds, they can be used for the production of fodder for monogastric animals (pigs and poultry), because of the increased protein content compared to the grains of sole cereals. In turn, if they are cultivated for green forage, they provide valuable roughage for ruminants. They can also be used for plowing, as green manure.

Mixtures make a better utilization of habitat resources than sole crops. Differentiation in the size and depth of the root systems of cereals and legumes allows them to utilization water and nutrients from different soil layers, the result of which is a compensatory growth and development of plants. The research on comparison of mixtures root systems of wheat and barley with peas sown together in alternate and intersecting rows showed that sowing in alternate rows was the least favorable [9]. Competition between the components of the mixtures can involve the access to light. A higher cereal component often results in limiting growth conditions for the accompanying legume by shading, especially under conditions of increased nitrogen. In legumes, photosynthesis is then limited and nitrogen uptake is reduced [10].

Studies on mixtures of yellow lupine with triticale and oats have shown that a competitive potential of a single legume is larger than a single cereal plant, but because of the larger number of cereals in the mixture, their total pressure on legumes is stronger than the pressure of legumes on cereals [11]. The strength of interspecific competition depends on the severity of intraspecific competition, which is largely related to the participation of the individual components. Mixtures of legumes with cereals create the conditions for the formation of allelopathic interactions that have a significant influence on the subsequent development of stand structure and the share of each component in the creation of seeds yield. Secondary metabolites of root exudates may affect rhisospheric organisms, as well as the neighboring plants [12]. Studies [13] have shown that water solutions of root exudates of seedlings of wheat, triticale and barley (an effect of 5 cereal seedlings on 1 seed of legume), after 4 days, strongly reduced the germination of seeds of pea, vetch, blue and yellow lupine, and after 8 days, exudates of barley and wheat caused the loss of germination of pea seeds (Table 1).

An additional benefit of growing legume-cereal mixtures is their effect on soil fertility and its phytosanitary status. Mixtures mitigate the negative effects associated with consecutive sowing of cereals as they become an element which interrupts the continuity of the crops.

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Specifications	Germination after 4 days				Germination after 8 days			
	pea	vetch	yellow lupine	blue lupine	pea	vetch	yellow lupine	blue lupine
Control	96.7 a*	93.7 a	97.7 a	85.7 a	96.7 a	95.7 a	98.5 a	86.5 a
Wheat	58.0 b	57.5 b	48.2 b	48.2 b	Rotted	74.5 b	51.0 b	48.2 b
Triticale	59.5 b	77.0 c	68.7 c	67.5 c	62.5 b	90.5 a	80.2 c	70.0 c
Oat	95.5 a	92.2 a	95.0 a	77.5 a	96.0 a	95.5 a	98.0 a	79.2 ac
Barley	46.0 b	78.5 c	62.0 c	50.5 b	Mildewed	88.0 c	65.2 b	52.2 b

* Number within columns followed by the same letters do not differ significantly

Table 1. Influence of cereal root excretions on germination of legume seeds [own study]

Mixtures provide biodiversity resulting from the different morphological characteristics, physiological and sensitivity of individual components to consecutive sowing, and in the case of cereals, this method allows to avoid the negative consequences of their too frequent sowing in the same field and thus reduce the spread of diseases and pests [14].

In recent times, a lot of attention has been paid to the possibility of nitrate leaching from the soil in the positions of winter crops sown after legumes. Significantly lower losses of nitrogen occur after crops of legume-cereal mixtures. The studies have shown that pea grown as sole crop used nitrogen derived from biological fixation in 70%, while in mixed cultivation with cereals-in 99%, contributing indirectly to potentially smaller losses of this component [15]. Also, lysimetric studies have shown that the level of nitrogen leaching in crops of mixture of peas with barley was reduced compared with the treatments where these plants were grown in sole crop. Therefore, in the areas of protection of drinking water, it is recommended to sow legumes in mixtures with cereals [16, 17].

Pre-crop	Seedsyield		Variability of yields in years (%)
	$t{\cdot}ha^{-1}$	%	
Yellow lupine	5.28	100	3.5
Pea + lupine	5.17	98	3.8
Oat + lupine	4.98	94	1.8
Oat + peas	4.94	94	3.6
Oat	4.79	91	4.5
Oat + barley	3.63	69	13.6
Oat + triticale	3.23	61	17.4
Triticale + barley	3.17	60	15.6

Table 2. Yields of winter wheat grown as affected by different pre-crops [21]

Legume-cereal mixtures are a good forecrop for root crops, but especially for cereals. They enrich the soil with organic matter and nutrients. For example, crop residues of mixtures of lupine with triticale (straw, stubble and roots) provide 32 kg of nitrogen and 55 kg of potassium

[18]. The value of the leftover position depends on the selection of components, their participation in the stand, the level of yield and soil conditions. Studies have shown that the yields of winter wheat cultivated after the mixture of pea with spring cereals (wheat, barley) were higher from 5 to 27% than after spring barley, while after a mixture of yellow lupine with triticale-by 31% compared to the yields following the triticale [19, 20]. Cereal species significantly affected the forecrop quality of the mixtures. Mixtures of legumes with wheat, barley and triticale were definitely better forecrops for winter wheat than the same cereals cultivated in sole crop, while a mixture with oats influenced on a small increase in the yield of successive crops compared with sole oats [21, 22]. This is due to the characteristic of oats, which has phytosanitary features and is considered as one of good forecrops for winter cereals. However, cereal mixtures were a worse forecrop (Table 2). The share of components seeds in the mixture also affects the catch crop value of the stand. A larger proportion of legumes in the mixture positively affected the yield of the following plants (winter wheat). This reaction was higher on good soils compared to the poorer ones [22, 23].

2.2. Biological nitrogen fixation

Biological process of atmospheric nitrogen fixation by the bacteria of *Rhizobium* and *Bradyrhizobium* that live in symbiosis with legumes has great significance for agriculture. In the symbiosis process, legumes provide the bacteria with carbohydrates, and in return they receive nitrogen assimilated by them, which they use to produce high-value protein. Nitrogen is used by plants in almost 100%, while in the case of mineral fertilizers, the plants generally use not more than 50% of this element. Cereals growing in the vicinity of legumes use the nitrogen assimilated by nodule bacteria, as it is transferred to the soil in the form of aspartic acid or β-alanine. This phenomenon is particularly important in low-input farming systems, especially in organic agriculture, where the biological fixation is the most important source of nitrogen [24, 25, 26].

The amount of nitrogen fixed by the nodule bacteria in the process of symbiosis depends primarily on the species of legume as a component, its share in the mixture and the level of nitrogen fertilization. The lysimetric studies with using ^{15}N have shown that in vetch sown with oats, 90% of the total nitrogen uptake (about 53 kg ha-1) comes from symbiosis, while oat uses about 28 kg of mineral N, which is one third of the nitrogen taken together by plants in the mixture [27]. The studies under mixed sowings of maize with soybean and oat with vetch have shown that exudates of active root nodules of legumes include NO^{3-}ions, which affect the increase of biomass and nitrogen content of non-legume components of these mixtures. The permeation of nitrate ions took place at night-from late evening to early morning [28]. The complementarity in the use of nitrogen by the mixture components was confirmed by a higher uptake of nitrogen with the yield of mixture seeds of oat with pea compared to sole crops of this species (Table 3). Almost twice as high nitrogen uptake with the yield of mixtures seeds compared to seeds yield of barley was significantly associated with a large proportion of the legume seeds in the sown mixture (70%). The research carried out in different European countries (Denmark, Germany, Great Britain, France and Italy) has shown that the overall N resources were used 30-40% more efficiently by pea-barley intercrops compared to the respective sole crops showing a high degree of complementarity between pea and barley across intercrop designs and very different growing conditions in Europe. As a mean of all site around 20% more efficient soil mineral N uptake was achieved by the intercrops than the sole crops. Soil N uptake by barley in intercrops was associated with an increased reliance of pea on N_2-fixation, rising the percent of total N derived from N_2-fixation [29]. The authors indicate the independent of climatic growing conditions, including biotic and abiotic stresses, across European organic farming systems pea-barley intercropping is a relevant cropping strategy to adapt when trying to optimize N use and thereby N_2-fixation inputs to the cropping system.

Treatment	Dose of nitrogen fertilization (kg·ha^{-1})			Mean
	0	30	60	
Barley	44 a*	55 a	75 a	58 a
Pea	78 b	86 b	93 b	86 b
Barley+pea	96 c	108 c	103 c	102 c

* Number within columns followed by the same letters do not differ significantly

Table 3. Nitrogen uptake with grain yield [own study based on 30]

The dose of mineral nitrogen had a significant impact on the amount of biological fixation of nitrogen by legumes. Increasing dose of mineral nitrogen caused a decrease in the fixation of atmospheric nitrogen, as it is a well-known tendency that if a plant has the possibility to use soil or fertilizer nitrogen, the assimilation of N_2 decreases. The research carried out in Poland has shown that increasing the level of fertilization of legume-cereal mixtures by mineral nitrogen from 0 to 90 kg ha^{-1} resulted in a significant reduction of atmospheric nitrogen fixation by legumes. Each 10 kg of the nitrogen applied in a dose of 30 and 60 kg ha^{-1} in a mixture of pea with wheat or pea with barley caused a reduction in the fixation of this element by about 7-8 kg, while at a dose of 90 kg, the reduction was higher by about 9 kg [31, 32]. Biological nitrogen fixation also depends on the soil conditions (nitrogen content, moisture content, pH) and the severity of disease and pests [33]. A large impact on the amount of symbiotic nitrogen fixation has also soil temperature. The optimal temperature range which allows for the maximum nitrogen fixation is (^{o}C): for big-leaved lupine-25, common vetch-20, faba bean-20, field pea-25, blue lupine-20-30, and for soybean-20-25 [34].

2.3. The selected factors of production

2.3.1. Species and varieties

Yielding of legume-cereal mixtures largely depend on the proper selection of species. Spring barley can be a good component for the mixtures with peas, due to similar habitat requirements, similar length of growing season and high nutritional value of seeds of such mixture, but also spring triticale and spring wheat, especially on the better soils. Naked oats, however, is a weaker component due to its low yield of grain which is also variable in years [35, 36]. Husked cultivars of oats and barley, however, are more useful to mixture with peas compared to the naked forms of these cereals (Table 4). Vetch yields best in a mixture with wheat, but triticale is also a good component for this legume crop (Figure 1). Other studies show, however, that spring barley is a better component for self-finishing cultivar of vetch compared to oats [37]. Lupines yield good in the mixtures with spring triticale and spring wheat, but poorly in the sowings with oats. In the mixture with oats, the yields of lupine seeds are low and variable in years, and their share in the yield of mixtures usually does not exceed 10%. In addition, yellow lupine proves to be more useful for mixtures with spring cereals than blue lupine [38, 39, 40].

Mixtures composition (sowing: seeds number per m²)	Seeds yield ($t \cdot ha^{-1}$)		
	mixture	cereal	pea
Barley naked (240) + pea (28)	6.35	5.70	0.65
Barley naked (205) + pea (35)	6.46	5.75	0.71
Barley husked (240) + pea (28)	7.20	6.49	0.71
Barley husked (205) + pea (35)	7.51	6.66	0.85
Oat naked (390) + pea (28)	4.20	3.61	0.59
Oat naked (335) + pea (35)	4.19	3.54	0.65
Oat husked (390) + pea (28)	6.19	5.53	0.66
Oat husked (335) + pea (35)	5.97	5.31	0.67

Table 4. Seeds yield and its components of mixtures of husked and naked spring cereals with pea [41]

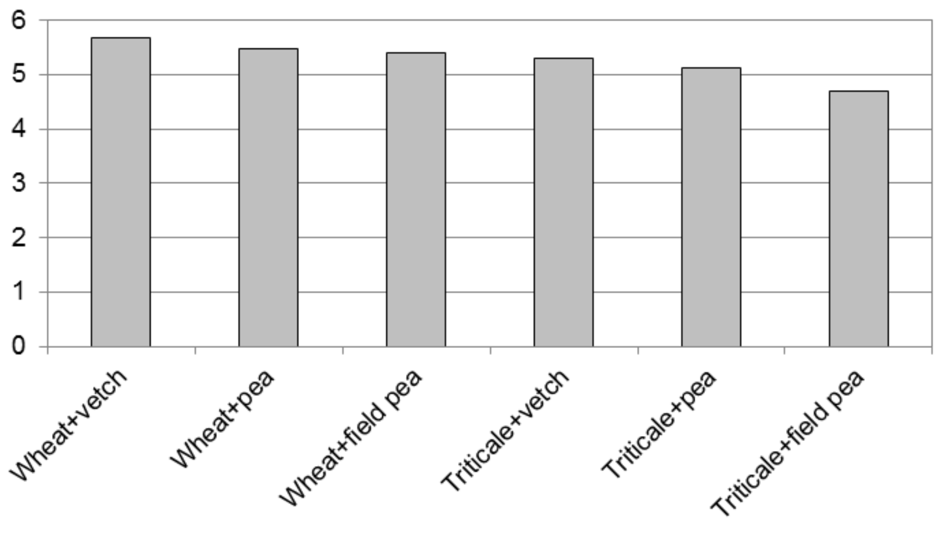

Figure 1. Yields of dry matter depending on the components of mixtures [own study].

On better soils, the choice of cereal species for the mixtures with peas is less important than the choice of legume variety for the cultivation effects [43]. Pea varieties differ considerably in term of the stems length, leaf arrangement, susceptibility to lodging and length of the growing season. They also differ in term of their complementarity in relation to cereals. It is important to choose the cultivars which yield best under given habitat conditions. The height of the components in the mixtures and their diverse habitus determine the canopy architecture. Large differences in the height of plants lead to layered structure of the stand, which creates less favorable light conditions for the species with shorter stems. Particularly unfavorable conditions occur when legumes dominate over cereals, because it leads to the lodging of plants and, consequently, to the yield reduction [44, 45]. High yielding potential was recorded for tendril-leaf cultivars of pea, which are particularly useful for mixtures with spring cereals grown for seeds. Due to the large amount of tendrils, they have a lower coefficient of transpiration and are less susceptible to lodging. Self-finishing cultivars of faba bean are very useful for legume-cereal mixtures, which under favorable soil and moisture conditions yield better in the mixtures with cereals compared to their sole crops [36].

One of the most important factors determining appropriate yielding of mixtures is the share of components seeds at sowing. Cereal sown with legumes gives greater yielding stability of the mixture, but it is also a strong competitor to the legume which causes that the share of legume seeds in the mixture yield is often variable and low. The studies on sowing density and the share of mixture components show that the percentage of legumes seeds should range from 30 to 50%. At tendency to higher lodging, of for example peas, a lower share of about 30% is more favorable [16, 46, 47]. The yields of mixtures primarily depends on the yield of cereal component, while only to a small degree on legume species. Increasing the share of legume seeds in the sowing norm increases their share in the yield, but the yield of grain cereals and the total yield of mixtures generally decrease (Tables 5, 6). This relationship has been confirmed for the mixtures of spring cereals with peas, yellow and blue lupine [39, 40, 42, 45, 47, 48, 49]. The yield and stability of the mixtures are therefore determined by the yield of cereals, and to a lower extent – by legumes. When determining the quantitative composition of the mixtures components of spring cereals with legumes, the following factors should be taken into account: the degree of lodging of the components, plant height, time of maturity and desirable share of legume seeds in the mixture yield, which should range between 20 to 40%.

Lupine share (%)	Cereal species in mixture					
	barley	wheat	triticale	barley	wheat	triticale
	yield of mixture seeds ($t \cdot ha^{-1}$)			share of lupine seeds (%)		
40	4.03 c*	4.00 c	4.23 b	5.2	7.3	8.0
60	3.74 b	3.80 b	4.17 b	9.4	10.3	10.8
80	3.41 a	3.34 a	3.51 a	14.8	15.4	15.0

* Number within columns followed by the same letters do not differ significantly

Table 5. Yield of seeds mixtures and share of blue lupine seeds in mixtures depending on cereal species and share of blue lupine in sowing [own study].

Mixture components		Sowing rate (number per m^2)	Yield					
oat (number per m^2)	pea variety		oat seeds		pea seeds		Sum - mixtures	
			t·ha^{-1}	% mean	t·ha^{-1}	% mean	t·ha^{-1}	% mean
412	Dawo	30	3.57	118	0.68	73	4.25	108
		45	3.08	102	1.06	115	4.14	105
		60	2.59	86	1.27	137	3.85	98
	Ramrod	30	3.64	121	0.46	49	4.10	104
		45	3.26	108	0.72	77	3.98	101
		60	2.93	97	1.06	115	3.99	101
	Turkan	30	3.46	115	0.63	68	4.09	104
		45	2.94	98	0.95	103	3.90	99
		60	2.20	73	1.26	136	3.47	88
275	Dawo	30	3.38	112	0.81	88	4.19	106
		45	2.90	96	1.07	116	3.97	101
		60	2.43	81	1.52	164	3.95	100
	Ramrod	30	3.48	116	0.60	65	4.08	104
		45	3.24	108	0.69	75	3.93	100
		60	3.00	100	0.97	105	3.98	101
	Turkan	30	3.30	110	0.63	68	3.93	100
		45	2.74	91	0.95	103	3.69	94
		60	2.06	68	1.34	144	3.39	86

Table 6. Yield of mixtures and their components depending on sowing rate [35]

2.3.2. Soil

The yields of legume-cereal mixtures largely depend on the soil type. On good soils, almost all plant species can be grown and yield very well, because there are no significant restrictions in terms of the selection of individual species. Mixtures may, however, be successfully grown on the worse soils by one quality class than their components grown in sole crops. As a result of differentiated plant growth and development rhythms of individual components, the plants better use of habitat conditions in less favorable soil conditions, as well as in the fields with differentiated soil, deficient water conditions, different forecrops or levels of soil culture [50]. Mixtures of peas with wheat and barley yielded best on Gleyic Phaeozem, Fluvic Cambisol and Haplic Luviosol. The poorest soils are based on sand [51]. On lighter soils (good rye complex), the most efficient mixture was spring triticale with yellow lupine, while slightly worse-triticale with pea and triticale with vetch. Mixtures of oats with yellow lupine and oats with pea also yielded well in such soil conditions [45, 52]. On good soil (good wheat complex), there is no need to cultivate spring cereals with lupines (white, yellow or blue), because the level of their yield has been found not significantly higher than on poorer soils. They are a valuable component, for cultivation on medium and light soils.

An important factor influencing the yield of mixtures is the availability of water in the ground. In the conditions of lower soil moisture, legume-cereal mixtures yielded better than sole crops [53]. Studies have shown that the use of irrigation allows for a cultivation of mixtures for the green matter even on very poor soils, guaranteeing a high level of yield [54].

2.3.3. Fertilization

Nitrogen fertilization is an agrotechnological factor which significantly affects the yield and quality of cereal and legume crops. Legume-cereal mixtures are feeding with lower doses of nitrogen compared to sole cereals. The reason of it is that at lower fertilization, the assimilation of atmospheric nitrogen by legumes increases, and also there crops are less susceptible to the lodging. There is also a smaller competition of cereals in relation to legumes. Increasing nitrogen fertilization results in the dominance of cereal plants, which adversely affects the morphological features and yields of legumes. The reaction of mixtures to the level of nitrogen fertilization also depends on the type of soil and the share of components. A stronger positive effect of fertilization on yield mixtures was observed on lighter soils and at the higher share of cereals [55].

In organic farming, it is necessary to completely resign from mineral nitrogen fertilization, which at the appropriate share of mixture components, good soil and moisture conditions and proper agricultural techniques, does not cause a significant decrease in the yield of mixture seeds. Natural or organic fertilization may be also used, but in a limited extent. Our study showed that in the lack of fertilization, the mixture of barley with peas was the most efficient, but mixtures of oats with peas and oats with vetch provided good yields as well. The significantly weakest was mixture of barley with vetch. In the case of the treatments fertilized with composted manure (at a dose of 30 t ha^{-1}), the mixtures which included peas were more efficient (Table 7). The facts that intercropping of legumes and cereals has produced higher yields than sole cereals without nitrogen fertilization was noticed by several reserchers [56, 57, 58].

Mixture composition	Without fertilization		Fertilization of compost	
	green matter yield (t·ha^{-1})	dry matter yield (t·ha^{-1})	green matter yield (t·ha^{-1})	dry matter yield (t·ha^{-1})
Oat+pea	40.7 b*	9.1 b	39.2 c	8.8 b
Oat+vetch	39.0 b	8.4 b	35.8 b	8.2 b
Barley+pea	41.2 b	10.2 c	38.4 c	8.6 b
Barley+vetch	32.6 a	7.0 a	32.1 a	7.0 a

* Number within columns followed by the same letters do not differ significantly

Table 7. Green and dry matter yields of mixtures cropped on silage [own study]

3. Nutritional value of legume-cereal mixtures (whole-crop silage and grain)

The seeds of legumes are significantly different from the grains of cereals. They contain large amounts of total protein (20 to 40%) and crude fibre and considerably higher amount of minerals compared to the cereals (mainly P), and small amounts of Ca and vitamins. Legume protein is deficient in methionine, a very important amino acid affecting its biological value, but on the other hand, it contains more lysine compared to the cereals. Legume seeds also contain anti-nutritional substances which cause bitter taste of feed and reduce its digestibility and the nutrient availability, so their share in the feed ration should be properly adjusted. It should be noted, however, that as a result of breeding progress there are legume varieties which do not contain or contain only insignificant amounts of anti-nutritional substances, such as alkaloids in lupines or tannins in faba beans and fodder peas, which would limit their feeding.

Cereal species in mixture	Lupine share (%)	Total protein ($g \cdot kg^{-1}$)	Crude fibre ($g \cdot kg^{-1}$)	Crude fat ($g \cdot kg^{-1}$)	Crude ash ($g \cdot kg^{-1}$)	P ($g \cdot kg^{-1}$)	K ($g \cdot kg^{-1}$)
Barley	40	114	26.2	22.2	20.9	3.5	4.4
	60	131	49.3	25.8	24.8	3.8	5.8
	80	139	51.2	27.0	24.6	4.2	5.7
Wheat	40	152	33.0	23.0	22.7	3.9	5.8
	60	177	34.8	26.8	22.4	4.3	5.9
	80	172	40.0	29.4	24.8	4.0	6.4
Triticale	40	139	30.6	22.0	24.5	4.2	6.1
	60	148	39.0	25.1	24.7	4.0	6.2
	80	158	46.0	26.2	27.2	4.6	7.3

Table 8. Content of nutrient components and macroelements in mixture seeds depending on spring cereal species and share of blue lupine [own study]

Growing legume-cereal mixtures significantly enriched feed, especially in protein. High efficiency of protein was recorded in the mixtures of peas with oats, but in terms of the feed quality, mixtures of pea with barley or triticale were favorable as well [59, 60, 61]. The results of the studies on mixtures of peas with barley, oats and wheat have shown that together with the increase of the share of legume, there was also an increase the concentration of protein in cereal grains and its share in the mixture yield [62]. The highest yield of protein was obtained when the share of peas in mixtures with barley and wheat was 75%, and with oats-50%. Our results confirmed these relationships. Increasing the share of blue lupine in two-species mixtures with barley, wheat and triticale resulted in an increase in the total protein content in the yield of mixtures seeds, but the concentration of crude fibre and crude fat has been increased (Table 8). The highest fat and protein content were found in the mixture of lupine with wheat, while the mixture with barley had the lowest amount of these components [40]. In the case of mixtures of peas with barley, there was also an increase in the content of total protein and crude fat in seed yield together with increasing share of legumes at sowing, while the amount of crude fibre decreased (Table 9). The share of pea in the yield had an only insignificant effect on the contents of P, K and Mg [60].

Pea share (%)	Total protein ($g \cdot kg^{-1}$)	Crude fibre ($g \cdot kg^{-1}$)	Crude fat ($g \cdot kg^{-1}$)	Crude ash ($g \cdot kg^{-1}$)	P ($g \cdot kg^{-1}$)	K ($g \cdot kg^{-1}$)	Ca ($g \cdot kg^{-1}$)	Mg ($g \cdot kg^{-1}$)
40	183.4	41.0	30.2	25.2	4.4	6.8	0.91	1.3
60	200.6	37.8	31.9	25.6	4.6	8.1	0.92	1.2
80	210.0	35.6	33.7	26.0	4.6	8.6	0.99	1.2

Table 9. Content of nutrient components and macroelements in mixture seeds of pea-barley depending on share of pea [own study]

Legume-cereal mixtures can be grown for green matter and used as a raw material for the production of silage for ruminants or they can be grown for seeds and be used as a component of concentrated feed for monogastric animals. Due to high yields and digestibility of dry matter, the phase of milk-dough stage of cereal is the appropriate term to harvest the mixture for green matter. Silage made from such a mixture may be administered to animals as the only roughage. The results of experiments have shown that silage from the whole-plant legume-cereal mixtures allows to achieve large weight gains of bulls, and the nutrients of that feed are well utilized [63]. It was also found that the energy value of the silage from whole plant of legume-cereal mixtures is similar to maize silage harvested for green matter at milk-dough stage of grain maturity [64]. Dairy cows fed of peas mixed with barley, were characterized a higher milk production compared to the animals fed only with barley. In addition, live weight of cows increased together with the increase in the share of pea in the silage [65]. Better milk production results in cows were obtained when they were fed with silage from the mixtures of pea with barley compared with the mixture of pea with triticale. Higher content of protein and lower content of neutral digestibility fibre (NDF) clearly indicated a more favorable cultivation of such mixture [66]. Protein and energy value of silage from legume-cereal mixtures depends on their composition and the share of individual components. Our study showed that mixtures of pea and vetch with oats had the highest protein and energy value compared to the mixture with barley (Table 10). Taking into account the share of components, it was found that increasing the share of legume seeds at sowing increases digestibility and improves the protein value of the feed made of the mixtures [49].

The nutritional value of legume-cereal mixtures grown for grains mainly depends on the composition of the mixture and the share of components. One of the most important criteria for grain quality evaluation is concenration of crude protein. Analysis of grain quality showed that crude protein concentration in the total intercrops grain yields was significantly higher compared with the sole wheat, but was lower than in sole grain legumes (Table 11). The highest

Mixture composition	PDIF* (g·kg DM)	PDIN (g·kg DM)	PDIE (g·kg DM)	UFL (g·kg DM)	UFV (g·kg DM)	Digestibility of DM (%)
Oat+pea	35.0	98.5	86.8	0.75	0.71	66.2
Oat+vetch	34.7	100.7	87.0	0.76	0.70	66.0
Barley+pea	28.6	86.8	82.7	0.73	0.68	66.2
Barley+vetch	28.8	87.2	83.2	0.74	0.69	66.4

*PDIF – protein digested in the small intestine

PDIN – protein digested in the small intestine supplied by rumen-undegraded dietary protein plus protein digested in the small intestine supplied by microbial protein from rumen-degraded protein

PDIE – protein digested in the small intestine supplied by rumen-undegraded dietary protein plus protein digested in the small intestine supplied by microbial protein from rumen-fermented organic matter

UFL – feed unit for lactation

UFV – feed unit for maintenance and meat production

Table 10. Energy and protein value and digestibility of dry matter of legume-cereal mixtures (50% cereals + 50%legumes) [own study]

crude protein concentration was determined in wheat and vetch intercrop grain yield. The same relationships have been found in the studies on mixtures of wheat and spring barley with peas. In addition, it has been shown that these mixtures contained more methionine, and barley also contained more threonine than cereals grown in sole crops [67].

Treatment	Grain yield ($t \cdot ha^{-1}$)	Crude protein ($g \cdot kg^{-1}$ of DM)	Crude protein ($kg \cdot ha^{-1}$ of grain yield)
Wheat	3.15	113	354
Pea	2.37	230	538
Lupine	1.51	259	383
Bean	1.99	287	571
Vetch	1.88	314	593
Wheat+pea	2.93	130	393
Wheat+lupine	2.77	121	356
Wheat+bean	2.84	135	396
Wheat+vetch	3.34	159	553

Table 11. The grain and crude protein yield of spring wheat and legume grown as sole and dual intercrops [58]

The nutritional value of seeds and grains of legume-cereal mixtures is also analyzed by testing the nutritional value of the protein expressed by the ratio of essential egzogenic amino acids-

EAAI (Essential Amino Acid Index) of Oser's and a rate of limiting amino acid-CS (Chemical Score) of Block and Mitchell's. The results showed that mixtures of winter triticale with vetch had higher EAAI rates than mixtures of winter rye with vetch, and isoleucine was the amino acid which limited nutritional value of the protein. On the other hand, the mixture of spring triticale with field pea characterized by higher rate of protein nutrition value EAAI and high content of lysine, isoleucine and threonine in comparison with a mixture of triticale with pea [68, 69].

4. Weed infestation of legume-cereal mixtures

Control of weed infestation in organic farming involves the use of direct methods, involving interventions into the stand and indirect methods of preventive character, such as proper crop rotation, choice of varieties with greater competitiveness against weeds, proper agronomical practices and the use of undersown crops and mixed sowings [70, 71, 72]. Mixed sowings of legumes with cereals strongly compete with weeds than sole crops, but it is also dependent on the composition of the mixture, the share of components, as well as weather and habitat conditions [58]. Our findings showed that among four mixtures of: oats with peas, oats with vetch, barley with peas and barley with vetch, with 50% share of the components at sowing, the mixture of barley with peas was the most weedy, as evidenced by the largest matter and number of weeds (Table 12). This mixture was also characterized by the largest species diversity of weeds, estimated by Shannon index. The most competitive to weeds was the mixture of oats with vetch. The mixture of barley with vetch had the smallest species diversity of weeds, as was estimated by Simpson's index which indicated a clear dominance of one weed species (Figure 2) [73]. Other studies indicate that among the four mixtures of spring wheat with legumes, such as peas, lupine, vetch and faba bean, the mixture of wheat with vetch limited weed infestation the most, while the least competitive was the mixture with lupine. The highest weed infestation was recorded in the sole lupine and pea [58]. Increasing the share of legume in the mixture caused an increase in weed infestation, which indicates higher competitiveness of cereals than legumes in relation to weeds [73, 74, 75]. Weather conditions have also the significant impact on weed infestation of mixtures. The favorable effect of mixtures on reducing of weed infestation discloses more in the wet years, which favor the development of mixtures and weeds [73, 75].

Mixture composition	Fresh matter of weeds ($g \cdot m^{-2}$)	Dry matter of weeds ($g \cdot m^{-2}$)	Number of weeds ($plants \cdot m^{-2}$)	Number of weeds species
Oat + pea	83.1	17.4	20.7	11
Oat + vetch	53.8	11.9	19.9	10
Barley + pea	355.2	37.8	46.1	16
Barley + vetch	183.7	23.0	42.1	11

Table 12. Weeds mass and number in mixtures depending on share of components [own study]

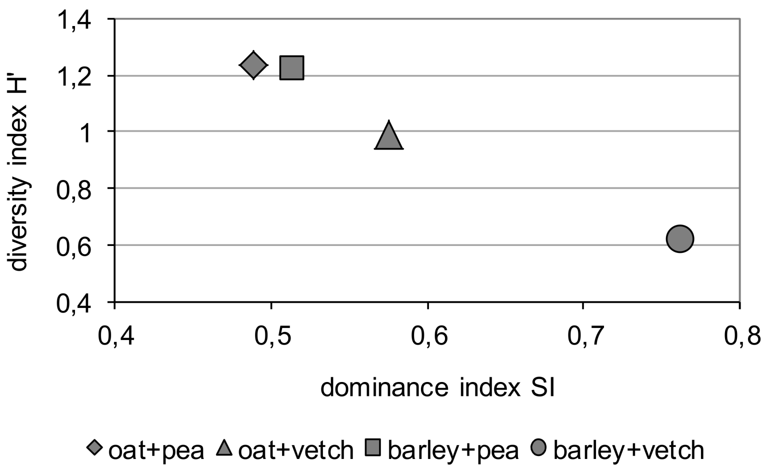

Figure 2. Shannon's diversity index (H') and Simpson's dominance index (SI) for weed flora in mixtures [own study]

5. Undersown crop of serradella in cereals

Intercrop cultivation is one of the agrotechnological ways to reduce adverse changes in agro-ecosystems, which are the result of a large share of cereals in cropping pattern. Their biomass is a significant source of organic matter, and it also has a positive effect on the physical, chemical and biological properties of the soil [76]. Serradella is a species of legume which yields well on poor, slightly acidic soils. Its cultivation provides a number of benefits for animals; provides a valuable, easily digestible feed, positively affects the milk yield of dairy cows, does not contain harmful compounds and it is willingly fed by animals [77]. Undersown into cereal as a support plant, it is more reliable in yielding, less prone to lodging and does not cause trouble during combine harvest. Growing mixed crops also creates more competition for weeds, which allows reducing, and in organic farming, to completely resign from herbicides [72, 78, 79, 80, 81].

Cultivation of serradella has also an ecological importance. The crop residue of this plant contains about 50 kg ha^{-1} of nitrogen, which is largely derived from a biological fixation. Serradella also plays phytosanitary role, reducing the spread of diseases and pests, regenerates the soil and improves balance of organic matter and soil fertility [82, 83]. A limitation in the cultivation of serradella is moisture. The deficiency of water in the initial stages of growth negatively affects the yield of this species [84].

Serradella can be undersown into spring and winter cereals grown for green matter or grains. Our findings showed that undersown serradella positively affected on dry matter yield of spring and winter cereals harvested at the milk-dough stage (for green matter). The highest increase of cereal yield was achieved in the cultivation of serradella with spring barley (Table 13). In the cultivation of cereals for grains (full maturity stage), undersown serradella did not significantly affect the yield of spelt wheat and oats, but limited the yield of spring barley and winter rye compared with the sole crops. The yield of serradella green matter undersown into cereals harvested for green matter was almost two-times higher compared to those harvested in full maturity stage. Regardless of the time of harvesting of the cover crop, the highest yields of serradella green matter were obtained at undersowing into spelt wheat [85, 86].

Specification	Harvest for green matter		Harvest for grain	
	yield of cereal DM ($t \cdot ha^{-1}$)	green matter of serradella ($t \cdot ha^{-1}$)	yield of cereal grain ($t \cdot ha^{-1}$)	green matter of serradella ($t \cdot ha^{-1}$)
Spelt wheat	4.54		2.61	
Spelt wheat+serradella	5.32	9.26	2.69	5.02
Winter rye	4.97		2.33	
Winter rye+serradella	5.59	7.42	2.06	4.67
Oat	8.36		4.08	
Oat+serradella	8.21	7.34	3.99	4.15
Spring barley	6.27		3.26	
Spring barley+serradella	8.46	8.13	2.54	4.67

Table 13. Yield of cereals in sole crop and intercropped with serradella depending on the harvest time of cover crop [own study]

Serradella undersown into cereals increases the content of total nitrogen and organic carbon in the soil as compared to the contents before sowing of serradella. Furthermore, the amount of nitrogen at harvesting cereals for seeds is higher than at harvesting for green matter. A longer growing period of legumes grown for seeds contributes to a more efficient fixation of atmospheric nitrogen. The process of mineralization of aging roots, nodules as well as leaves, flowers and pods which fell from the lower layers of legumes is started, and nitrogen and other components are released into the soil [86, 87].

6. Conclusions

The cultivation of mixtures of legumes and cereals offers a number of potential agronomic benefits. Coming from two different plant families, legumes and cereals complement each other in the capture of resources. Cereal crops growing in the vicinity of legumes benefit from nitrogen assimilated by legume root nodule bacteria. Increasing the supply of nitrogen by applying fertilizer caused in a substantial reduction of fixation of atmospheric nitrogen by legume crops. Mixtures are particularly relevant to the exploitation of poorer soils which are unsuitable for the production of either component grown as a sole crop. Yielding of the mixtures is highly dependent on the species and proportion of component. The share of legumes in the seed mixture in terms of seed number is recommended to range from 30 to 50%. Total seed yield of mixtures decreases with increasing share of legume seeds in sowing. Increasing the dose of nitrogen for the cultivation of mixtures usually leads to increase in the yield of cereal component, but reduces the proportion of legume seeds in the crop. Legume-cereal mixtures can be grown for green matter and used as a raw material for the production of silage for ruminants or they can be grown for seeds and be used as a component of concentrated feed for monogastric animals. Increasing the share of legume seeds at sowing increases the protein concentration, digestibility and improves the protein value of the feed made of the mixtures.

Legume-cereal mixtures are a good forecrop for cereals. They reduce the negative effects associated with sowing of cereals one after another. Mixtures enrich the soil with organic matter and nutrients, but the value of their post-crop area depends on the choice of components, their share in the stand, the level of yields and soil conditions. Cultivation of cereals after legume-cereal mixtures is characterized by higher yield stability. An ecological importance has also cultivation of serradella as undersown, which plays additionally phytosanitary role, reducing the spread of diseases and pests and regenerates the soil. The benefits of mixed sowings of legumes with cereals are associated with a significant reduction of weed infestation, especially in organic farming. Intercrops are already largely adopted in organic farming, but additional efforts in research are needed for their adoption in more number of farms.

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