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Effects of Winter Cereals (*Triticum aestivum* L., *Hordeum vulgare* L., *Triticosecale* Wittmack) and Winter Pea (*Pisum sativum* L.) Intercropping on Weed Cover in South-Eastern and Central Hungary

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Abstract: Growing two or more crops together in the same area at the same time, called intercropping, is a well-known agroecological method of weed suppression. Cereal-legume intercropping systems are of great importance in increasing biodiversity in arable lands. In cereal-legume mixtures, cereals provide physical support to legumes and enhance weed suppression. Cereals have a stronger weed suppression ability than peas. The aim of our research was to determine the weed composition and weed cover of pure winter wheat, pure barley, pure triticale and pure winter pea, as well as associated wheat-pea, barley-pea, and triticale-pea crops in two locations (Szeged and Fülöpszállás) and in two growing seasons (2020/2021 and 2021/2022). In Fülöpszállás, the average weed cover was significantly higher than in Szeged. When comparing the years and crop production methods, significant differences were observed in weed cover in the pure legume plots. More weed species appeared in Szeged and Fülöpszállás in the second year than in the first year. Cereal-pea intercropping reduces the need for herbicides; we can achieve more sustainable and effective weed management without herbicide treatment.

Keywords: weed cover; weed suppression; cereal-pea intercropping; plant association; winter pea; winter wheat; triticale; barley

1. Introduction

Growing two or more crops together in the same area at the same time, called intercropping, is a well-known agroecological method of weed suppression [1–3]. Cereal-legume intercropping systems are of great importance in increasing biodiversity in arable lands [4,5]. This cropping practice is based on a multispecies system that exploits synergistic effects between plants [3,4]. The main aim of this cultivation method is to make the best possible use of light, nutrients and the area [6,7]. The crops used in intercropping are morphologically diverse, so they adapt to climatic conditions better than individually grown plants [8]. Cereal-legume intercropping systems allow lower inputs which reduce the environmental impact of agriculture [7,9]. Intercropping systems provide many ecosystem services, including the control of soil erosion, carbon sequestration, the regulation of water infiltration, a reduction in nutrient leaching, the improvement of nutrient availability, the degradation of agrochemicals, an increase in biodiversity, the attraction of pollinators and a reduction in pests and weeds [10–13].

Weed control is an important factor in plant associations [14–19]. It is very difficult for farmers to grow peas in pure stands because their competitiveness of field peas against weeds is poor [20]. In fields where only peas grow, yield losses caused by weeds can reach 40–70% [17,21]. Intercropping systems have improved competitive ability against weeds [14–16]. In cereal-legume mixtures, cereals provide physical support to legumes and increase weed suppression [18]. Cereals have a larger seed size than weeds; therefore, they have an advantage over weeds in their initial growth [22–24]. Cereals can slow down and dominate the development of competing plants, thus modifying the weed community [22,25]. In plant associations in which monocotyledonous crops are mixed with dicotyledonous crops, weed suppression has crucial importance [14,26,27]. Cereals have a stronger ability to weed suppression than peas [24].

Chemical weed management sustainability can be a challenge. Herbicides change weed communities; therefore, only the most persistent of weed species can survive [28,29]. Worldwide, the number of herbicide-resistant weed species is almost 300 [1,30,31]. Weeds have resistance to 21 of the 31 known herbicide action sites and to 165 different herbicides [31]. Herbicides account for more than 40% of the annual average of 179.798 tons of pesticides used in the EU [32,33]. Evolving modern agriculture prioritizes low herbicide uses and ecologically based weed control [34]. Intercropping systems reduce weed cover, weed density and growth more effectively than single-crop systems [35]. Mixtures of cereals and forage legumes can be useful in suppressing perennial weeds [36,37]. Crop diversification has changed the number and composition of weeds [28,38]. A reduction in the number of weeds has been observed in wheat grown with legumes (peas, beans, chickpeas) [39–41] and in barley-pea intercropping systems [41,42].

In Hungary, the cropping structure is basically dominated by cereals. However, cereal-legume intercropping systems can increase the sowing area of protein crops. In the long term, these principles of sustainability should be implemented in arable crop production. This article primarily focuses on a reduction in weed pressure in plots of winter pea stands, which are practically impossible to grow without chemical herbicides. This is one of the key reasons why legumes are very difficult to grow in organic farming systems. Our research aimed to determine the weed composition and weed cover of plots of pure winter wheat, pure barley, pure triticale and pure winter pea, as well as associated wheat-pea, barley-pea and triticale-pea crops.

2. Materials and Methods

2.1. Experimental Sites, Soil and Climate

Our investigations on the cereal-legume intercrop system were carried out at research stations of the Hungarian University of Agriculture and Life Sciences in Szeged (46°17′29.6′′ N 20°05′17.3′′ E) and Fülöpszállás (46°50′16.4′′ N 19°15′03.3′′ E) in 2020/2021 and 2021/2022. The research station in Szeged was located in the southeast of Hungary, near Szeged. Fülöpszállás was located between Kecskemét and Dunaföldvár in the central part of the country (Figure 1).

The experimental soil was chernozem meadow soil in Szeged with an organic matter content of 2.50–2.82% and a slightly alkaline reaction (pH = 7.17–7.50). Nitrogen content was 19.40–35.20 mg/kg, phosphorus content was 235.1–385.0 mg/kg and potassium content was 237.1–387.0 mg/kg. The soil in Fülöpszállás was calcareous meadow soil, with an organic matter of 2.39–2.80% and pH = 7.72–7.90. Nitrogen content was 17.4–27.5 mg/kg, phosphorus content was 188.0–266.4 mg/kg and potassium content was 572.0–624.8 mg/kg. The USDA classification and World Reference Base for Soil Resources database were used to determine the soil type and classes of textures [43,44] (Table 1).

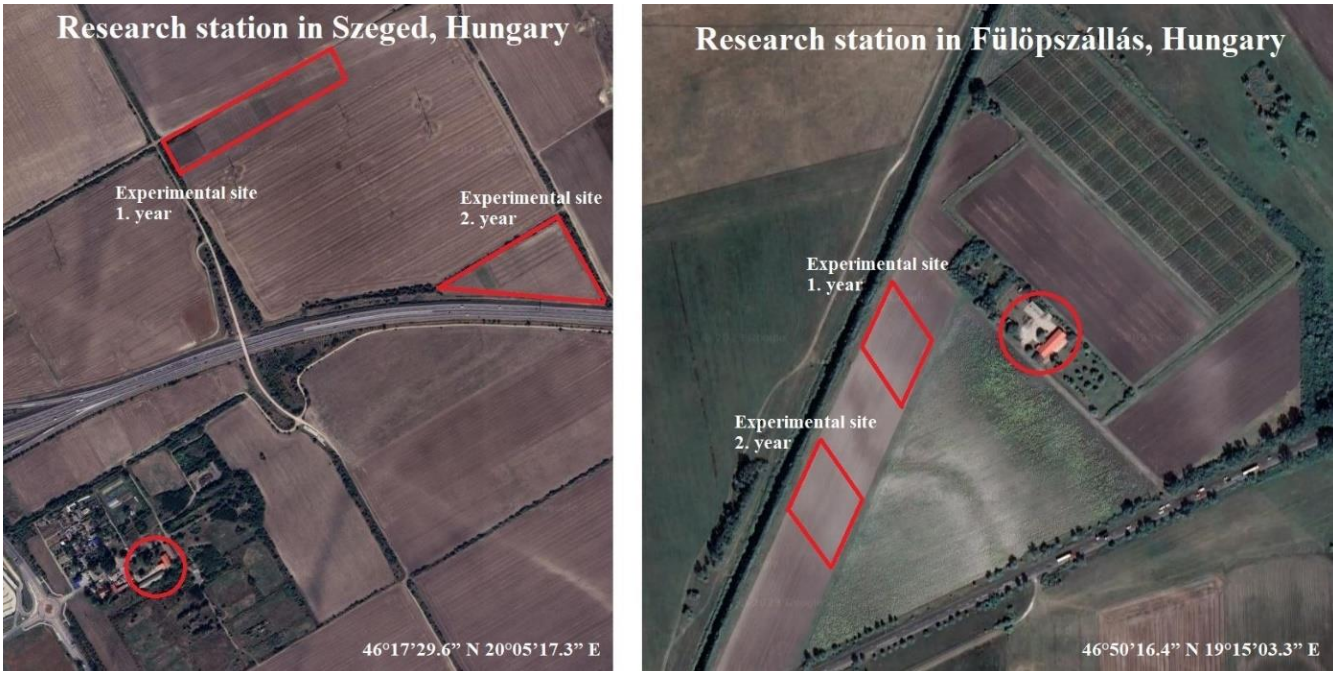

Figure 1. Location of research stations and experimental sites in Szeged and Fülöpszállás.

Table 1. Soil information at the two locations (Szeged, Fülöpszállás).

Parameters	Units of Measure	Szeged		Fülöpszállás	
		2020/2021	2021/2022	2020/2021	2021/2022
pH (KCl)	pH	7.5	7.17	7.9	7.72
K_A	K_A unit	41	41	50	49
All salt	m/m %	0.03	0.09	0.02	0.02
Organic matter	m/m %	2.5	2.82	2.8	2.39
$CaCO_3$	m/m %	1.7	0.76	18	21.1
P_2O_5	mg/kg	235.1	385	266.4	188
K_2O	mg/kg	237.1	387	624.8	572
NO_3^--N + NO_2^--N	mg/kg	35.2	19.4	27.5	17.4
SO_4^{2-}-S	mg/kg	10.9	22.4	6	19.4
Na	mg/kg	60.4	119	249.3	163
Mg	mg/kg	195.1	288	429.4	357
Cu	mg/kg	1.4	4.17	2.3	1.62
Zn	mg/kg	5.8	4.82	1.9	0.73
Mn	mg/kg	11.9	291	23.5	26.7
Soil type		Chernozem meadow soil		Calcareous meadow soil	
Textural class		clay loam		clay	

According to the solar climate division, Hungary is located between north latitudes of 45°45′ and 48°35′, in the temperate zone. This climate is very changeable; the main reason for this is that the climate is influenced by oceanic air masses with a high moisture content and dry continental air masses with extreme temperatures and mild air masses of high humidity coming from the Mediterranean Sea. In the summer, 60–70% of the air mass comes from the sea. In cold winters, dry land air masses can be observed in the country. As a result, several climate zones have emerged in Hungary. Szeged and Fülöpszállás can be classified in the warm-dry climate zone.

The average precipitation per month and air temperatures (maximum, minimum) in Szeged can be seen in Figure 2. In 2020, winter precipitation was above average. The precipitation in 2021 (January, February, March, April) was below 50 mm. May was wetter than previous months in each year, but the months of June in 2021 and 2022 were drier than average. June (33.9 °C), July (34.5 °C) and August (35.1 °C) were the hottest summer months, with temperatures higher than 30 degrees centigrade. The maximum air temperatures were above freezing every month. Regarding the minimum air temperatures, the coldest month was January (−7.2 °C). Furthermore, the minimum air temperatures were below freezing in the months of November (−1.0 °C), December (−3.2 °C), February (−5.5 °C), and in the spring months of March (−4.1 °C) and April (−1.8 °C) (Figure 2).

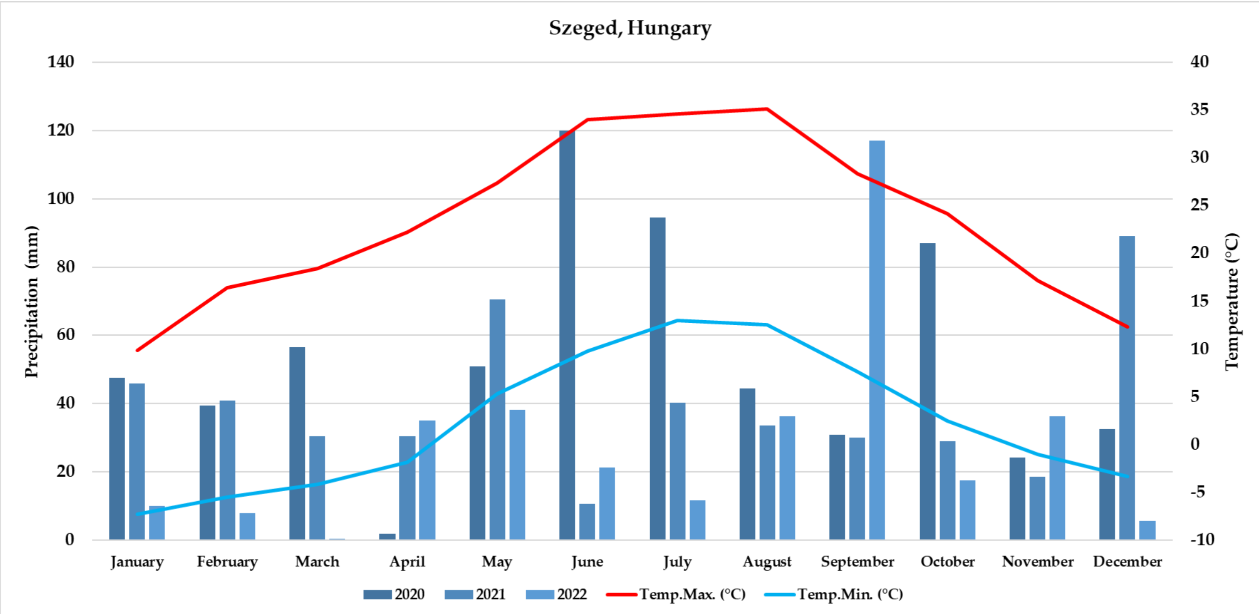

Figure 2. The average precipitation and air temperatures (maximum and minimum) in Szeged (2020–2022).

Figure 3 represents the average precipitation and air temperatures (maximum, minimum) in Fülöpszállás. In the summer and in the pre-sowing period of 2020, soils were saturated with above-average amounts of precipitation (June, July, August, September and October). Precipitation in March and June 2021 was below average. In 2022, after sowing, there was almost no significant rainfall from October to April. The maximum air temperatures in Fülöpszállás were below 35 degrees centigrade in the summer months (June 33.6 °C, July 34.2 °C, August 34.4 °C). The air temperature maximums were above 10 degrees centigrade each month. Winter (November −2.8 °C and December −4.8 °C) and early spring months (March −5.5 °C and April −2.5 °C) were colder in Fülöpszállás than in Szeged. The coldest month was also January (−7.9 °C).

2.2. Agronomic Management

After the harvest in August, stubble cultivation was carried out at a soil depth of 15 cm. Before sowing, on the 2nd of October, NPP complex (15:15:15) fertilization was applied. On the 10th of October, the fields were plowed at a soil depth of 30 cm. On the 20th of October, the seedbed was prepared with a combinator at a soil depth of 10 cm. In Szeged, sowing took place at the end of October, and we sowed in Fülöpszállás at the beginning of November. Because of the dominance of cereals in Hungary, winter wheat (*Triticum aestivum* L.) is the first crop to be sown in the fields every year. In both years, the plots were sown with a parcel grain machine (Wintersteiger Plotman). The row width was 12.5 cm, and the sowing depth was approximately 4–5 cm. The winter wheat variety was GK Csillag, the winter barley variety was GK Aréna, and the triticale variety was GK Maros. For the legume crop, the winter pea variety Aviron was chosen. At the beginning of March, a nitrogen fertilizer (34% ammonium-nitrate) was applied with an initial dose of 30 kg/ha. At the end of March, the plots were treated with fungicide (azoxystrobin) at a dose of 0.7 l/ha. In the middle of April, the plots were treated with insecticide (alpha-cypermethrin) in a dose of 0.1 l/ha. At the end of April, the second nitrogen fertilization (34% ammonium-nitrate) was carried out at a dose of 30 kg/ha. In the middle of May, plots were treated with insecticide (gamma-cyhalotrin) at a dose of 0.08 l/ha. In Szeged, the harvest took place at the beginning of July, and in Fülöpszállás, a week later. Pre-emergence or post-emergence herbicides and irrigation were not used in the experiment.

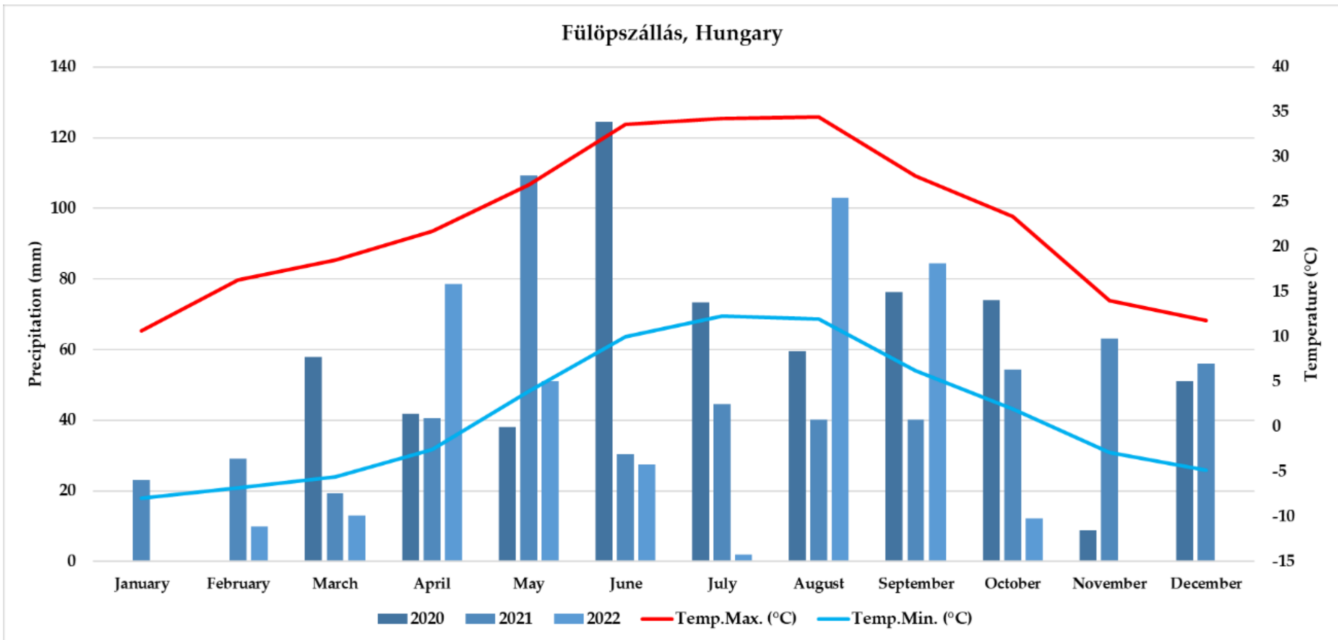

Figure 3. The average precipitation and air temperatures (maximum and minimum) in Fülöpszállás (2020–2022).

For plant associations, 50% of seed mixtures were prepared. Thus, for cereals, 2.5 million germinable seeds/ha were used instead of the recommended 5 million germinable seeds/ha, and for winter peas, 500.000 germinable seeds/ha were used instead of the recommended 1 million germinable seeds/ha. These components were mixed and then sown simultaneously (Table 2). Cereal-legume intercrops, pure cereals and pure pea plots were examined in four repetitions on random block plots of 10 m^2.

2.3. Assessment

The survey method was based on the weed coverage of the experimental site (percentage value), where the method of Németh-Sárfalvi [45] was used. To record weed species and weed cover, a sample frame of 1 m^2 was prepared, and this method was used to estimate weed cover in quadrants (expressed as %) and record the weed species. In fieldwork, four data recording dates per year were determined on the two experimental sites. The dates of data collection were designed by phenological phases. The first data recording was carried out in the phase of the cereals' tillering phase, the second in the cereals' stem elongation phase, the third when the peas were flowering, and the fourth before harvest. The dates of data collection were as follows (Table 3).

Table 2. Plant density of pure crops and mixtures.

Cereal	Seed Numbers (million/ha)	Pea	Seed Numbers (million/ha)	Cropping System
GK Csillag (wheat)	2.5	Aviron	0.5	wheat-pea
GK Aréna (barley)	2.5	Aviron	0.5	barley-pea
GK Maros (triticale)	2.5	Aviron	0.5	triticale-pea
GK Csillag (wheat)	2.5	Aviron	0	pure wheat
GK Aréna (barley)	2.5	Aviron	0	pure barley
GK Maros (triticale)	2.5	Aviron	0	pure triticale
Wheat Barley Triticale	0	Aviron	0.5	pure pea

Table 3. Dates of data collection in the two experimental years in Szeged and Fülöpszállás.

Data Collection Dates	
Szeged	
1. year (2020/2021)	2. year (2021/2022)
7 April 2021	21 April 2022
5 May 2021	20 May 2022
3 June 2021	7 June 2022
28 June/2021	16 June 2022
Fülöpszállás	
1. year (2020/2021)	2. year (2021/2022)
12 April 2021	7 April 2022
5 May 2021	25 May 2022
7 June 2021	14 June 2022
23 June 2021	30 June 2022

The sample frame was randomly placed twice in 51 plots in Szeged and in 25 plots in Fülöpszállás. Thus, on one data collection date, data were collected from 152 quadrants. A total of 608 sample areas of 1 m^2 were examined in two years and in two experimental sites.

2.4. Statistical Analysis

Data were statistically processed and analyzed with the statistical software SPSS v.27 [46], using three-way random block design repeated measures analysis of variance (ANOVA). The three fixed factors were the experimental site (Szeged, Fülöpszállás), the crop production method (pure cereal, cereal-pea intercrop), and the plant species (wheat, barley, triticale, pea), while the plots were the blocks. The repeated-measure within-group effects were considered along with the inspection events (4 times in each year and at each site, Table 3). To ensure that normal distribution, 1/sqrt(x + 0.1) transformation was applied, and the normality of the model residuals was accepted as the absolute values of their skewness and kurtosis were all below 1. The homogeneity of variances was violated (Leneve's test, $p > 0.05$); therefore, robust correction was performed. The sphericity was accepted by Greenhouse–Geisser ε as it was above 0.6. Having obtained a significant overall result, we performed a follow-up univariate three-way random block design ANOVA with Bonferroni's correction. Finally, pairwise comparisons were made to test the factor effects individually. In the case of species comparison, we used Games–Howell's post-hos test to avoid the biasing effect of violated homoscedasticity. The within-factor (time) effect was compared pair wisely based on the marginal means and using Sidak's method.

3. Results

3.1. Weed Cover and Weed Species

Tables 4 and 5 show the average weed cover (%) found on two experimental sites on sixteen collection dates and with different crop production methods.

In Szeged, four weeds (*Convolvulus arvensis* L., *Sinapis arvensis* L., *Ambrosia artemisiifolia* L., *Hibiscus trionum* L.) were found in the first year (2020/2021). In plots of pure winter peas, the largest area (35%) was covered by field bindweed (*Convolvulus arvensis* L.). Before the harvest, nearly 40% of weed cover was found in plots of pure winter pea. In the first year, the average weed cover was less than 0.5% in plots of cereal-legume intercrops and pure cereals. In the second year (2021/2022), six weed species were found in Szeged, but three weed species (*Veronica hederifolia* L., *Chenopodium album* L., *Chenopodium hybridium* L.) were not present in the first year. In early June of 2021/2022, Charlock mustard was the dominant weed, with a coverage of 80% in the plots of pure peas. On four data-collecting dates, plots of pure peas had the highest average level of weed cover (11 to 81%) in Szeged, which gradually increased until harvest. However, in cereal-legume intercropping systems, the average weed cover in the first sampling fell from 4.65% to 0.09 before harvest. The average weed cover in plots of pure cereals decreased from 5.47% to 0.26% before harvest (Table 4).

In Fülöpszállás, four weeds (*Cirsium arvense* (L.) Scop., *Veronica hederifolia* L., *Convolvulus arvensis* L., *Capsella bursa-pastoris* L.) were found in the first year (2020/2021). Of these weed species, Creeping thistle (*Cirsium arvense* (L.) Scop.) was the most dominant, with the highest average weed cover (62.5%) in plots of pure peas. The creeping thistle had the highest weed cover (5–62.5%) in Fülöpszállás. Before harvest, the average weed cover was the highest (64.5%) in plots of pure peas. The average weed cover was 13% in cereal-legume intercrops and 8% in pure cereals before harvest. Weed cover was higher (13–47%) in cereal-legume intercrops than in pure cereals (8–36.7%) in Fülöpszállás. In the second year (2021/2022), seven weed species (*Cirsium arvense* (L.) Scop., *Convolvulus arvensis* L., *Ambrosia artemisiifolia* L., *Chenopodium album* L., *Polygonum aviculare* L., *xTriticosecale* sp., *Veronica hederifolia* L.) were found in Fülöpszállás. The creeping thistle showed the highest weed cover (30–65%) in the plots. On four sampling dates, the average weed cover (5.5–68.25%) was the highest in the plots of pure peas. The average weed cover was lower in cereal-legume intercropped plots (0.8–17%) compared to the plots of pure cereals (2–17.5%) on all data-collecting dates (Table 5).

The overall within-subject time effect and its two-way and three–way interactions with species and site were all highly significant (the unexplained variance rates expressed by Wilk's λ were below 0.4 in all cases with $p < 0.001$), while any–way interactions of time and the production method was significant ($p > 0.20$).

The between-subject effects of the species and site, together with their interaction, were also significant (species: $F(1;109) = 4.34$, $p < 0.01$; site: $F(1;109) = 39.74$, $p < 0.001$; interaction: $F(1;109) = 13.75$, $p < 0.001$). Meanwhile, the production method effect was not significant ($F(1;109) = 0.78$, $p = 0.38$). The pairwise comparison results regarding the between-subject effects of 'sites' and 'species' as well as the within-subject effects of 'time' can be found in Table 6.

Table 4. Average weed cover (%) and weed species richness of cereal-legume intercrops, pure cereal, pure legume in Szeged during two experimental years.

	English Name	**Latin Name**	**1. Year (2020/2021)**											
			Weed Cover (%)											
			7 April 2021			**5 May 2021**			**3 June 2021**			**28 June 2021**		
			Cereal-Legume Intercrops	**Pure Cereal**	**Pure Legume**	**Cereal-Legume Intercrops**	**Pure Cereal**	**Pure Legume**	**Cereal-Legume Intercrops**	**Pure Cereal**	**Pure Legume**	**Cereal-Legume Intercrops**	**Pure Cereal**	**Pure Legume**
1.	Field bindweed	*Convolvulus arvensis* L.	0.00	0.00	0.00	0.12	0.12	0.00	0.37	0.31	7.50	0.12	0.03	35.00
2.	Charlock mustard	*Sinapis arvensis* L.	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	4.00	0.00	0.00	4.00
3.	Common ragweed	*Ambrosia artemisiifolia* L.	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.75	0.00	0.00	0.00
4.	Flower of an hour	*Hibiscus trionum* L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.50
	Total		0.00	0.00	0.00	0.12	0.12	0.50	0.38	0.31	12.35	0.12	0.03	39.50
			2. year (2021/2022)											
			21 April 2022			20 May 2022			7 June 2022			16 June 2022		
1.	Charlock mustard	*Sinapis arvensis* L.	1.77	1.65	10.00	0.77	1.65	47.50	0.65	0.43	80.00	0.08	0.23	75.00
2.	Ivy-leaved speedwell	*Veronica hederifolia* L.	2.88	3.82	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.	Fat hen	*Chenopodium album* L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	6.00
4.	Maple-leaved goosefoot	*Chenopodium hybridium* L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00
5.	Common ragweed	*Ambrosia artemisiifolia* L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00
6.	Field bindweed	*Convolvulus arvensis* L.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00
	Total		4.65	5.47	11.00	0.77	1.65	47.50	0.65	0.43	81.75	0.09	0.26	81.00

Table 5. Average weed cover (%) and weed species richness of cereal-legume intercrops, pure cereal, pure legume in Fülöpszállás during two experimental years.

	English Name	Latin Name	1. Year (2020/2021)											
			Weed Cover (%)											
			12 April 2021			5 May 2021			7 June 2021			23 June 2021		
			Cereal-Legume Intercrops	Pure Cereal	Pure Legume	Cereal-Legume Intercrops	Pure Cereal	Pure Legume	Cereal-Legume Intercrops	Pure Cereal	Pure Legume	Cereal-Legume Intercrops	Pure Cereal	Pure Legume
1.	Creeping thistle	*Cirsium arvense* (L.) Scop.	11.81	5.88	16.50	7.75	4.90	15.00	5.54	5.03	27.50	11.19	5.18	62.50
2.	Ivy-leaved speedwell	*Veronica hederifolia* L.	35.13	28.40	10.50	31.63	28.85	21.50	0.00	0.00	0.00	0.00	0.00	0.00
3.	Field bindweed	*Convolvulus arvensis* L.	0.00	0.00	0.00	0.11	0.37	0.25	1.50	0.96	6.00	1.84	2.93	2.00
4.	Shepherd's purse	*Capsella bursa-pastoris* L.	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total		46.94	34.28	27.00	39.48	34.13	36.75	7.04	5.99	33.50	13.03	8.10	64.50
			2. year (2021/2022)											
			7 April 2022			25 May 2022			14 June 2022			30 June 2022		
1.	Creeping thistle	*Cirsium arvense* (L.) Scop.	0.00	0.00	0.00	6.19	12.20	30.00	13.25	12.00	60.00	6.63	10.05	65.00
2.	Field bindweed	*Convolvulus arvensis* L.	0.53	1.53	4.00	0.72	2.38	5.00	2.75	3.35	5.00	1.31	2.55	1.00
3.	Common ragweed	*Ambrosia artemisiifolia* L.	0.00	0.00	0.00	0.29	0.71	1.00	0.94	1.13	1.00	0.73	1.23	0.50
4.	Fat hen	*Chenopodium album* L.	0.00	0.00	0.00	0.04	0.15	0.25	0.03	0.45	2.50	0.38	1.08	1.50
5.	Common knotgrass	*Polygonum aviculare* L.	0.00	0.00	0.00	0.00	0.03	0.50	0.13	0.63	3.50	0.28	0.30	0.25
6.	Triticale	*xTriticosecale* sp.	0.00	0.00	0.00	0.11	0.24	1.50	0.00	0.00	0.50	0.00	0.00	0.00
7.	Ivy-leaved speedwell	*Veronica hederifolia* L.	0.26	0.46	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total		0.79	1.98	5.50	7.34	15.70	38.25	17.09	17.55	72.50	9.33	15.20	68.25

Table 6. Weed cover (%, mean ± standard deviation) measured at two experiment sites in plots of pure cereal, cereal-pea intercropping and pure pea.

			Inspection Time			
Sites	**Crop Production Methods**	**Species**	12 April 2021	5 May 2021	7 June 2021	23 June 2021
Fülöpszállás	Pure Cereals	Barley	**9.50 ± 0.71 a**	**23.00 ± 7.07 a**	**11.25 ± 13.08 b**	**4.00 ± 2.83 a**
		Wheat	**31.00 ± 31.22 b**	**26.61 ± 26.7 a**	**3.41 ± 4.15 a**	**9.28 ± 13.12 b**
		Triticale	**56.00 ± 5.66 c**	**26.75 ± 15.91 a**	**11.00 ± 0.00 b**	**7.50 ± 0.71 b**
	Pure Pea		**27.00 ± 19.80 b**	**36.75 ± 21.57 b**	33.5 ± 4.95 c	64.50 ± 3.54 c
	Cereal-Pea Intercropping	Barley	**18.75 ± 6.84 b**	**17.18 ± 9.35 a**	**7.18 ± 3.92 b**	**11.75 ± 10.69 b**
		Wheat	**14.04 ± 22.25 Ba**	**15.40 ± 23.23 Ba**	0.92 ± 2.29 Aa	**0.92 ± 1.44 Aa**
		Triticale	**39.33 ± 12.82 c**	**34.95 ± 7.34 b**	**9.10 ± 5.32 b**	**11.58 ± 5.41 b**
			Inspection time			
			7 April 2021	5 May 2021	3 June 2021	28 June 2021
Szeged	Pure Cereals	Barley		0.00 ± 0.00 a	0.05 ± 0.07 b	0.00 ± 0.00 a
		Wheat		0.15 ± 0.14 Aab	0.45 ± 0.36 Bb	0.14 ± 0.25 Ab
		Triticale		0.00 ± 0.00 a	0.00 ± 0.00 a	0.00 ± 0.00 a
	Pure Pea			0.5 ± 0.71 Ab	12.35 ± 5.44 Bc	39.5 ± 21.92 Cc
	Cereal-Pea Intercropping	Barley		0.03 ± 0.05 a	0.00 ± 0.00 a	0.00 ± 0.00 a
		Wheat		0.18 ± 0.14 Bb	0.41 ± 0.33 Bb	0.04 ± 0.05 Ab
		Triticale		0.00 ± 0.00 a	0.18 ± 0.25 ab	0.00 ± 0.00 a
			Inspection time			
			7 April 2022	25 May 2022	14 June 2022	30 June 2022
Fülöpszállás	Pure Cereals	Barley	**2.25 ± 1.06 b**	**9.25 ± 2.47 b**	**21.75 ± 5.30 b**	**11.75 ± 0.35 b**
		Wheat	0.33 ± 0.43 Aa	4.08 ± 4.76 Ba	9.75 ± 8.97 Ca	**5.24 ± 5.79 Ba**
		Triticale	0.80 ± 0.57 ab	**8.75 ± 2.47 b**	**17.5 ± 2.83 b**	**10.50 ± 2.12 b**
	Pure Pea		5.50 ± 0.71 b	38.25 ± 5.3 c	72.5 ± 20.51 c	68.25 ± 8.84 c
	Cereal-Pea Intercropping	*Barley*	1.28 ± 1.54 Aa	**6.13 ± 2.47 Ba**	**18.58 ± 6.22 Cb**	**16.00 ± 7.36 Cb**
		Wheat	0.15 ± 0.40 a	6.50 ± 12.26 a	4.90 ± 7.71 a	4.90 ± 7.72 a
		Triticale	**2.08 ± 1.86 a**	**20.20 ± 5.77 b**	**20.33 ± 7.76 b**	**15.08 ± 7.42 b**
			Inspection time			
			21 April 2022	20 May 2022	7 June 2022	16 June 2022
Szeged	Pure Cereals	Barley	0.00 ± 0.00 a	0.00 ± 0.00 a	0.00 ± 0.00 a	0.00 ± 0.00 a
		Wheat	**5.56 ± 5.08 Cb**	0.86 ± 1.10 Bb	0.73 ± 0.87 Bb	0.08 ± 0.15 Ab
		Triticale	0.25 ± 0.35 ab	0.50 ± 0.28 ab	0.50 ± 0.71 b	0.25 ± 0.35 b
	Pure Pea		11.00 ± 5.66 b	47.50 ± 31.82 b	81.75 ± 6.72 c	81.00 ± 8.49 c
	Cereal-Pea Intercropping	Barley	0.03 ± 0.05 a	0.00 ± 0.00 a	0.00 ± 0.00 a	0.00 ± 0.00 a
		Wheat	5.45 ± 6.25 Bb	2.46 ± 2.87 Bb	0.63 ± 0.92 Ab	0.39 ± 0.38 Ab
		Triticale	0.03 ± 0.05 a	0.03 ± 0.05 a	0.05 ± 0.08 a	0.00 ± 0.00 a

Different letters are for significantly different values. Lower case letters are for the comparison of species within sites, inspection time and crop production method (Games–Howell, $p < 0.05$, read vertically). Upper case letters are for comparison of time effect within site, crop production method, species, and year (Sidak, $p < 0.05$, read vertically in rows where the species name is in italic). Values in bold are significantly higher in comparison to the sites within species, inspection time and crop production method ($p < 0.05$).

The fourth figure illustrates the average weed cover of the two experimental sites and different cropping systems. Different letters indicate significantly different groups at $p < 0.05$ significance level. Comparing the experimental sites, significant differences could be observed between Szeged and Fülöpszállás in plots of pure cereals and cereal-pea intercropping plots. In Fülöpszállás, the average weed cover was significantly higher than in Szeged ($p < 0.01$). In Szeged, the average weed cover was less than 1% in pure cereal and intercropped plots, while in Fülöpszállás, the average weed cover was between 16% and 18%. No significant difference in the average weed cover in plots of pure peas was found between Szeged and Fülöpszállás. The average weed cover in plots of pure peas was 37.1% in Szeged and 47.7% in Fülöpszállás, which is 10.6% higher than in Szeged. Comparing the crop production methods, no significant difference was found in the plots of pure cereals and intercropped plots. However, a significant difference ($p < 0.05$) was observed between the plots of pure peas (Figure 4).

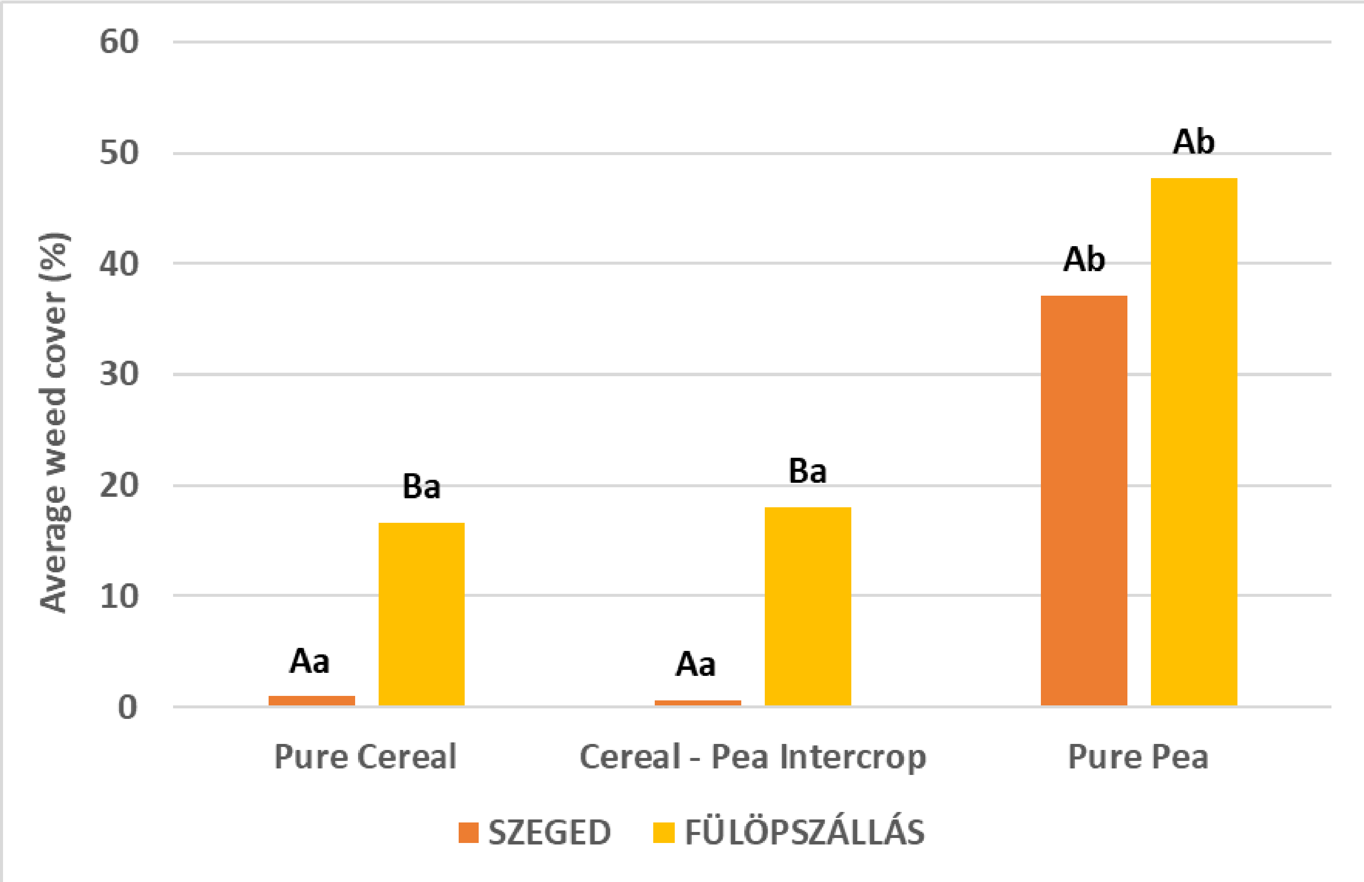

Figure 4. Average weed cover (%) measured at two experiment sites in plots of pure cereal, cereal-pea intercropping and pure pea. Capital letters: comparison of experiment sites (Szeged, Fülöpszállás). Small letters: comparison of crop production methods (pure cereal, cereal-pea intercrop, pure pea). Different letters are for significantly different groups (Games–Howell, $p < 0.05$).

The fifth figure represents the average weed cover subjected to different crop production methods in the first year (2020/2021) and the second year (2021/2022). In comparing the years, in the second year, the average weed cover decreased in the intercropped and pure cereal plots. However, no significant difference was found between the first year (10.3%) and the second year (7.2%) in the plots of pure cereals. In addition, there was no significant difference in plant associations between the first year (13.3%) and the second year (5.1%). In the plots of pure peas, a significant difference was found ($p < 0.05$) when comparing the years and crop production methods. The average weed cover was more than double in the second year (58.2%) compared to the first year (26.7%) (Figure 5).

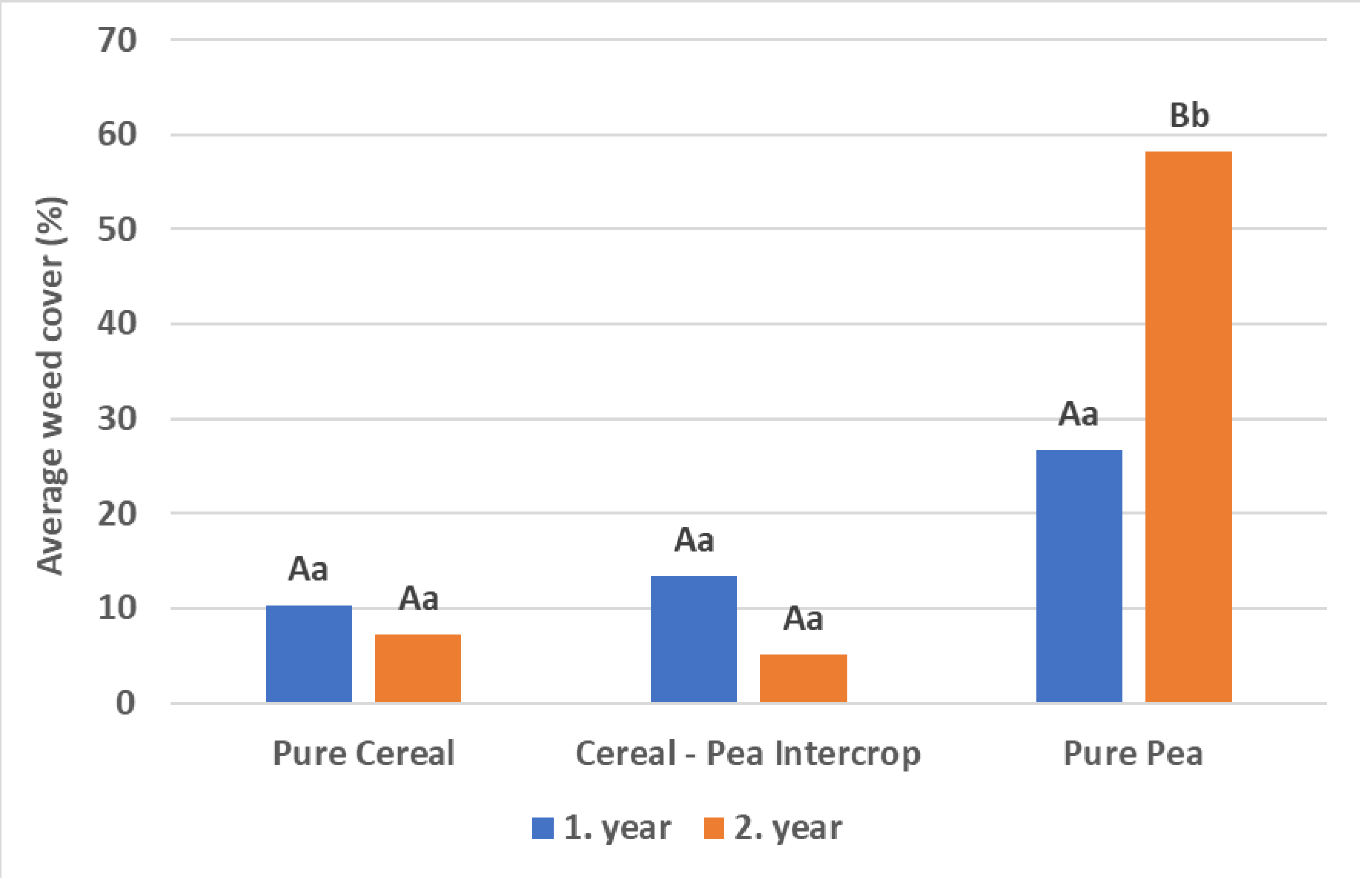

Figure 5. Average weed cover (%) measured in the two-growing season in plots of pure cereals, intercropping and pure peas. Capital letters: comparison of experiment years (first year: 2020/2021, second year: 2021/2022). Small letters: comparison of crop production methods (pure cereal, cereal-pea intercrop, pure pea). Different letters are for significantly different groups (Games-Howell, $p < 0.05$).

The sixth figure illustrates the average values of weed cover in different cropping systems with different species. Three cropping methods (pure cereals, cereal-pea intercropping, pure legume) were compared, and it was observed that significant differences were found only in the plots of pure legume ($p < 0.001$). In plots of pure legume, the average weed cover was 38.7%, while the average weed cover was less than 10%, both in the plots of pure cereals at 6–9.7% and in cereal-pea intercrops at 5.8–9.8%. When the crop species were compared, the lowest percentage of weeds was found in barley (6%), followed by triticale (9.6%) and winter wheat (9.7%) in the plots of pure cereals. The same trend was observed in cereal-pea intercropping systems, with the lowest average weed cover in barley-winter pea intercrops (5.8%), followed by the triticale-winter pea (8.7%) and winter wheat-winter peas (9.8%). No significant difference was found between the pure cereal and cereal-pea intercropping systems (Figure 6).

3.2. Yield Losses in Different Cropping Systems

In the pure pea stand, the yields in plots without chemical weed management were 56.24% compared to the yields in plots with herbicide treatment. In plots of wheat-pea intercropping without herbicide treatment, the yields decreased by 28.19% for peas and 10.15% for wheat. In the plots of triticale-pea associations, yield loss was 60% for the peas and 9.95% for the triticale. The yield of the plots of barley-pea intercropping was the lowest, with a decrease of 16.32% for peas and 3.59% for barley. The yield loss in pure cereal stands was the lowest in the plots of pure barley (7.68%); it was 2.5 times higher in plots of pure triticale (19.34%) and the highest in the plots of pure wheat at 21.13% (Figure 7.)

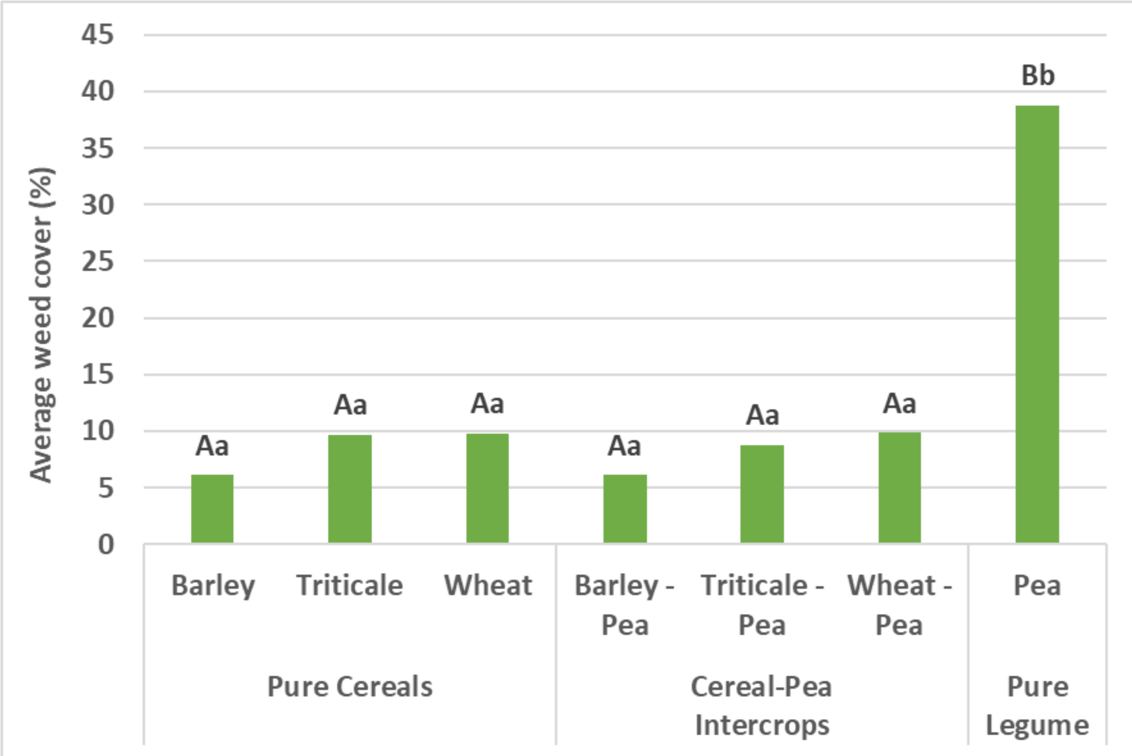

Figure 6. Average weed cover (%) in different cropping systems with different species. Capital letters: comparison of cropping methods (pure cereals, cereal-pea intercropping, pure legume). Small letters: comparison of species (barley, triticale, wheat, barley-pea, triticale-pea, wheat-pea, pea). Different letters are for significantly different groups (Games-Howell, $p < 0.05$).

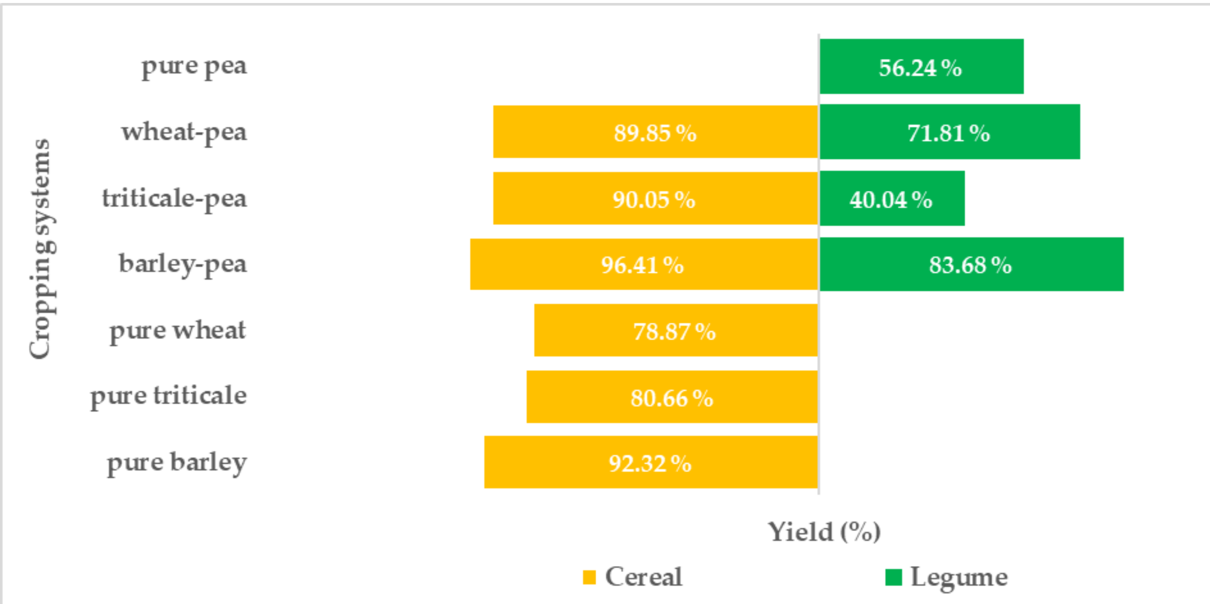

Figure 7. The yield of plots with chemical weed management compared to plots without herbicide treatment, in Szeged.

In pure pea stands, the yield of plots without chemical weed management was 76.35% compared to the plots treated with an herbicide. In plots of wheat-pea intercropping without herbicide treatment, the yield of peas decreased by 47.90%, and the yield of wheat decreased by 42.14% compared to the plots treated with herbicides. In plots of triticale-peas, the yield loss of the peas was 33.78%, and the yield loss of triticale was 1.25%. For peas, the lowest yield loss recorded was 15.41%, whereas the yields of barley decreased by 16.82% in the plots of barley-pea intercropping. In the case of cereals, the yield loss in pure wheat stands was 20.11%; this was highest (24.51%) in pure triticale and lowest in pure barley at 4.51% (Figure 8).

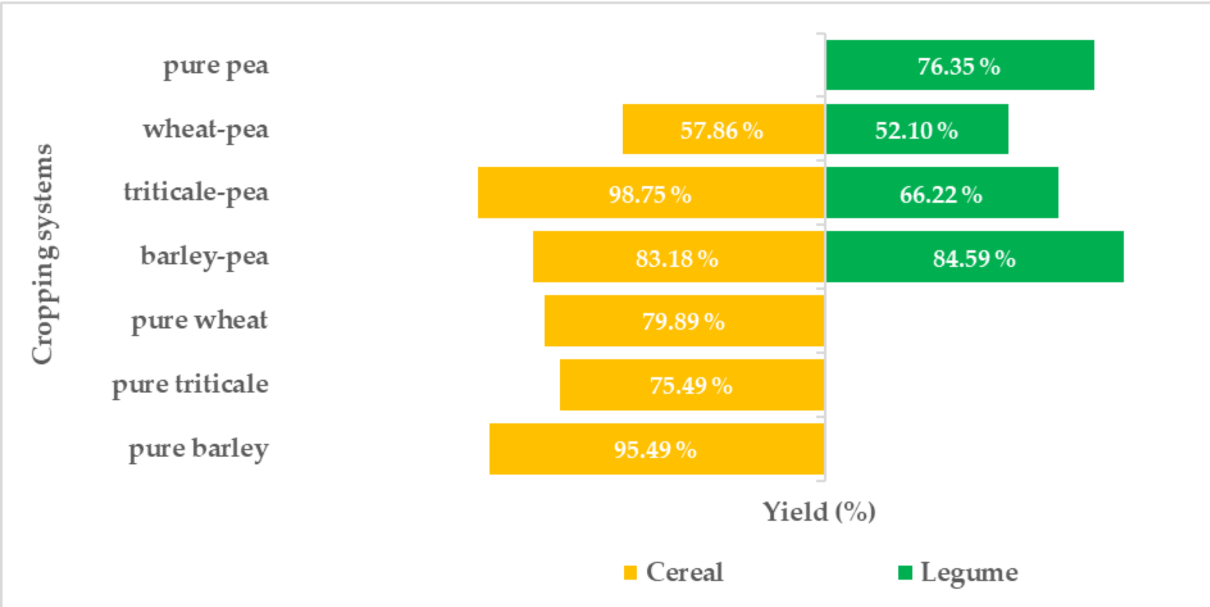

Figure 8. The yield of plots with chemical weed management compared to plots without herbicide treatment, in Fülöpszállás.

4. Discussion

In Hungary, five main crops (winter wheat, barley, maize, sunflower, rape) dominate arable lands, with cereals accounting for almost three-quarters of the area [14,47]. One-sided cereal crop production has agronomic and economic benefits, together with the simplification of technical conditions, but in the long run, may pose problems in terms of plant protection, soil management and sustainable environment management [48]. With the effects of climate change in mind, these crop production methods leave the country economically vulnerable [49]. In Hungary, it is necessary to diversify the rotation of predominant cereal crops by increasing the size of areas inhabited by legumes. For farmers, crop rotation with larger sowing areas of legumes could be successful if legume crops are compatible with the conditions in farm fields and the local climate. There are many species of legume crops. As an alternative source of protein plants, winter peas should be considered because they have the second highest yields of any legume crop in the world [14,50].

Cereal-legume intercropping is a crop production method that increases the sowing area of protein crops. Intercropping systems could improve the crop rotation structure by increasing the sowing area of legumes, on condition that the sowing areas of cereals are not reduced. Cereal-pea intercropping is a method that increases the biodiversity of arable land, controlling weeds more effectively by associating cereals, reducing the risk of environmental pollution, and solving weed suppression naturally. This study dealt with the examination of the weed cover of plots of pure cereals, pure peas and cereal-pea plant associations without weed management in two different experimental sites in Hungary.

More weed species were found in Szeged and Fülöpszállás in the second year than in the first year. However, the most diverse composition of weed species was found in the plots of pure peas. Our research provides evidence that plant diversification changes weed composition and the number of weed species [28,38]. Cereal-pea intercrops reduce the number of weed species and their weed cover.

We can also agree with the hypothesis that growing peas in pure stands have a low weed suppression capacity [9]. In both experimental years, a much higher weed cover in pure stand peas than in plots of pure cereals and cereal-pea intercrops was found. This is supported by the fact that monocotyledonous cereals have a stronger weed suppression ability than dicotyledonous peas [24]. Therefore, when they were used in mixtures, this property of cereals compensated for the weak weed suppression ability of peas in the plots of intercropping. The cereals created a balance in plots of cereal-pea intercrops at the expense of the spread of weeds.

We designed our experiments with three varieties of cereals; thus, we could examine the weed suppression abilities of wheat, barley and triticale. Barley has been found to have a better weed suppression ability in pure stands and cereal-pea intercropping [51–53]. Our results support the conclusions of other researchers [41], i.e., the amount of weed biomass was higher in wheat than in barley due to the fact that barley has a higher early growth rate than wheat [54].

In Szeged, the lowest losses in the yield of cereals were in barley-pea plots. Furthermore, the decrease in the pea yield was lower in wheat-pea and barley-pea intercropping systems than in pure pea stands. In Fülöpszállás, the lowest losses of cereals were in the triticale-pea plots. However, the lowest pea yield loss was in the barley-pea plots, less than in pure pea stands. From our results, we can conclude that when peas are associated with barley, the yield loss of peas can be maintained at a low level.

The results of two years of intercropping experiments in central and south-eastern Hungary suggest that, without herbicides, peas can be grown more effectively in plots of cereal-pea intercrops, which is due to the fact that weed cover is lower in plots of cereal-pea intercrops. The growth of herbicide-resistant weeds can be reduced this way. Cereal-pea intercropping reduces the number of herbicides, without herbicide treatment so that sustainable and effective weed management can be successful.

5. Conclusions

Based on our research results, the following conclusions were drawn:

- Organic and low-input farmers can benefit from the use of cereal-legume intercropping.
- By using these systems, biodiversity could be increased, and farmers could increase their rate of legume crops in crop rotation.
- Without the use of herbicides, winter peas can be grown more effectively in cereal-legume intercropping systems.
- By growing two plants together, farmers could benefit from the positive effects that these plants have on each other (weed suppression, N fixation, etc.) and grow them with less environmental pollution (herbicides, fertilizers, etc.).
- The cereal-pea crop production method is a much more natural way to increase the protein content of the forage.

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Conflicts of Interest: The authors declare no conflict of interest.

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