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Effects of Weed Control Treatments on Weed Composition and Yield Components of Winter Wheat (*Triticum aestivum* L.) and Winter Pea (*Pisum sativum* L.) Intercrops

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Abstract: Intercropping is an ancient and worldwide agricultural practice expected to become more prevalent in Hungary due to the accumulating impact of climate change. In this study, the plant association of pure winter wheat (*Triticum aestivum* L.) and pure winter pea (*Pisum sativum* L.) was analyzed without weed control and with applied herbicides at different intervals (pre-emergence, early and late post-emergence) and different active herbicide ingredients. Two growing seasons, 2018–2019 and 2019–2020 were examined to compare weed composition and weed cover to evaluate the effect of the applied herbicides at different timings. To determine weed control efficiency, weed surveys were conducted six times in each growing season. The effect of cultivation methods (pure and mixed plots) on the development of plants was also measured by yield production analysis. Findings from these investigations indicate that there were significantly more weed species and occurrences of weeds in pure wheat and pure pea plots compared to mixed plots. In addition to cultivation and weed control treatments, meteorological events significantly influenced the development of the plants, and thus the yield components.

Keywords: winter wheat; winter pea; intercrop; yield components; weed cover; weed control

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1. Introduction

Since the Second World War, chemical inputs and genetic selection have played a prominent role in agriculture in developed countries [1]. The spread of high-yielding varieties led to an oversimplification of the sowing structures and an important loss of biodiversity [2,3]. The appearance of partial monocultures is often associated with plant protection and tillage problems [4–7], while also leaving farmers vulnerable to market demands [8,9]. There is evidence that the excessive use of synthetic fertilizers disrupts the balance of the nitrogen cycle in soils, induces eutrophication, and has a role in global warming [10–14]. A growing interest in new cropping systems has been initiated by the increasing awareness of the environmental damage that comes from the use of artificial fertilizers and pesticides [15,16], and also the limited availability and significant monetary cost of fertilizers [17]. Therefore, the redesigning of cropping systems has come to the fore to achieve greater efficiency, reduce the use of chemical inputs, and thereby conserve resources [15,18].

There is a similar trend observed in Hungary as well, where currently two-thirds of the arable land is cultivated with cereals due to their higher economic competitiveness compared to protein plants [8,19,20]. Grain legumes, including field peas, are missing from the crop rotation, even though they are a valuable source of protein, with suitability for domestic cultivation [21–23]. In addition, they provide a renewable resource of nitrogen for agriculture, reduce overdependence on fertilizers [6,24,25], contribute to diversification, and break the crop effect in cereal-based rotations [26,27] in an environmentally friendly and sustainable way [27–29].

Intercropping is an ancient and worldwide cropping practice in many tropical parts of the world [16,30], but it is far less known in European countries [15,31,32]. It is defined as the growing of two or more crop species at the same time in one place during a growing season [33,34]. The interest in this valuable cropping system is more pronounced in low-input farming systems, especially in organic farming [18,31,35], where organic farmers do not apply chemical products against environmental fluctuations, but rely on varieties that are developed by traditional breeding programs. These varieties may not be able to simultaneously meet all the expectations regarding resistance against pests, fungus pathogens, weeds, and resource use efficiency [36]. In contrast, intercropping is based on plant interaction in order to maximize growth and productivity. The most common advantage of intercropping is the quantity and stability of yields by more efficiently using the available resources (light, water, and nutrients) compared to sole cultivation [16,37–39]. Other benefits of intercropping include improved weed competitive ability and lower incidence of insect pests and disease organisms [26,40]. Weed control is an important aspect of intercropping, as field peas appear to be a weak competitor against weeds compared to other species [41–43]. Yield loss caused by weeds can reach 40 to 70% in the case of pure pea sowing [41,44]. Under weedy conditions, integrated practices such as increased seeding rate, and the choice of the proper cultivar can improve the competitiveness of field peas, especially in organic production [45,46]. In that sense, intercropped cereal is a valuable component, providing not only physical support to minimize pea lodging, but concurrently improving its competitiveness against weeds [42]. Cereals have a relatively large seed size, which gives them an initial growth advantage over weeds in the early stage of the growing season [47–49]. Therefore, if cereals dominate and slow down the development of competing plants, it can modify the hierarchy of the weed community [47,50].

Weed suppression is one of the key elements in successful intercropping that is even more typical in intercrops where a dicotyledonous crop is matched with a monocotyledonous crop; therefore, the choice of herbicides is a real challenge [36,51]. Due to the few available active ingredients allowed in European agriculture, the limited number of herbicides may provide less protection [52], increase the risk of herbicide resistant weed development, as well as display marginal selectivity [53,54]. The selectivity of foliage-applied herbicides is based on differences in herbicide retention on crops and weeds [55]. In most cases, damage to the cultivated plants is determined by visual estimation using a scale of 0% (no injury) to 100% (total death) [56]. Pendimethalin is one of the most commonly used active ingredients in pea cultivation, and can be used even before the crop appears [46]. The application of this active ingredient had no negative effect on peas or lentils, but reduced biomass and grain yield of the subsequently planted wheat crop [57]. A similar observation was made in terms of green peas, where more harvestable pods were achieved than in the treatment without herbicide [58]. Bentazon is a suitable active ingredient for post-emergence application with appropriate weed development, temperature, and humidity [52]. The experiment proved that bentazon did not cause visually detectable crop damage in dry peas, while the most favorable yield was more dependent on the choice of the herbicide than the time and rate of application [59]. Furthermore, bentazon-treated peas have a higher protein content and total yield per plant, and contain a higher proportion of chlorophyll, carotenoids, total sugar, and vitamin C in pods at harvest [60]. 2-Methyl-4-chlorophenoxyacetic acid (MCPA) is widely used to control broad-leaved weeds in peas, although peas are occasionally injured by MCPA depending on the time of day of the herbicide application. Peas are more vulnerable to damage during early afternoon MCPA application as the carbohydrate content of peas is associated with the susceptibility to injury by MCPA [61]. The time of herbicide application is also important regarding the degree of exposure to light and high temperatures [55]. The split application resulted in lower crop damage, and therefore a higher yield, than a single application [62].

Only a few studies were published about the changes in weed community structure due to intercropping and the effect of pre-emergence and post-emergence herbicide application on weeds within intercrop systems. Therefore, our research aimed to (1) determine the weed composition and weed cover of pure wheat, pure pea, and associated wheat–pea crops; as well as (2) evaluate the effect of four herbicides applied at three different times on the development of associated plants.

2. Materials and Methods

2.1. Experimental Design

Field experiments were conducted for two consecutive years in the growing seasons of 2018–2019 and 2019–2020 at the Plant Production and Agrotechnical Research Station of the Hungarian University of Agriculture and Life Sciences in Szeged-Öthalom (46°17′29.5″ N 20°05′17.5″ E). Soil characteristics of the experiment comprise meadow chernozem soil with a humus content of 2.8–3.2% and a slightly alkaline reaction (pH = 7.9). Content of nitrogen was 24.0 mg/kg, phosphorus was 248 mg/kg, and potassium was 209 mg/kg. The average precipitation and temperature can be seen in Figure 1. In 2018/2019, the first half of the growing season turned out to be much drier than average. Subsequently, during April, May, and June, the amount of precipitation greatly exceeded the average. In addition, the temperature during November, December, and January was colder than usual, while the spring and early summer temperatures exceeded the 30-year average. During the sowing time in 2019/2020, there was scarce rainfall, which caused the plants to germinate protractedly. The subsequent precipitation did not compensate for this deficiency.

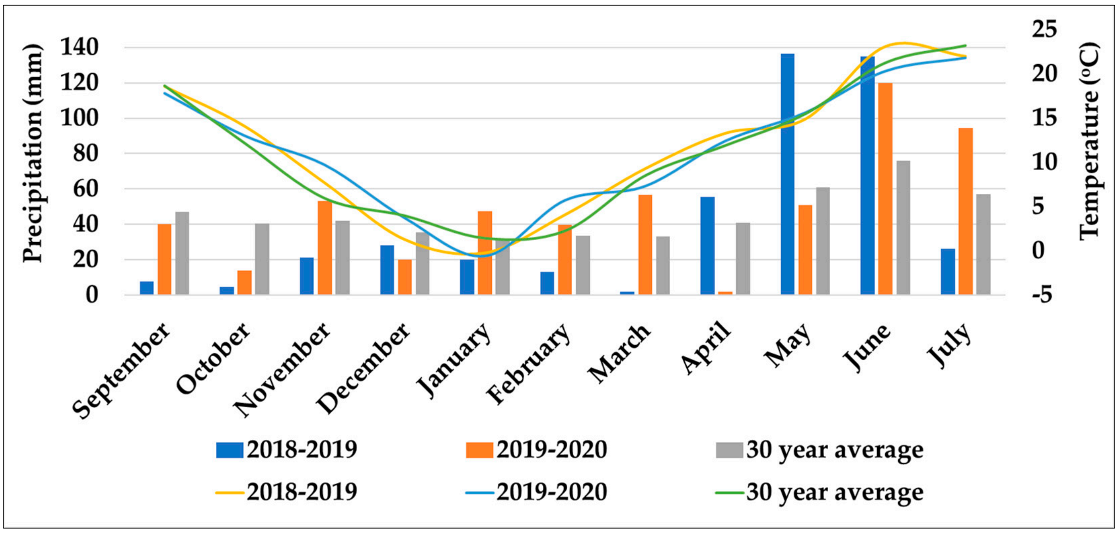

Figure 1. Average precipitation and temperature in the experimental years and in the last 30 years.

Concerning crop rotation, the preceding crop was winter wheat (*Triticum aestivum* L.) in both years. There was no organic fertilizer application at the experimental site in the last 5 years, however, autumn multinutrient fertilizer was applied at the rate of 200 kg ha^{-1} (Complex NPK (8:24:24)).

The experiment was carried out on a random block layout using 10 m^2 experimental plots with four repetitions, using the winter wheat (*Triticum aestivum* L.) variety GK Szilárd and winter pea (*Pisum sativum* L.) variety Aviron. The GK Szilárd is an awnless medium-maturity winter wheat variety with excellent lodging resistance, medium-to-wide and strongly curved leaves, large, fertile, long, and intermediate head type, with good tillering and high drought tolerance. The Aviron is a green seeded, mid-season maturing, highly winter-hardy variety of dry wrinkled pea for food and feed, with excellent drought resistance. Mixtures of the aforementioned wheat and pea were established with 300 (wheat) and 60 (pea) germinable seeds/m^2, respectively. Crops were sown on the 30 October 2018 and on the 18 October 2019 with a parcel grain machine (Wintersteiger Plotman). Grains of both varieties were sown simultaneously. Row width was 12.5 cm and sowing depth was approximately 4–5 cm. The treatments of the experiment are shown in Table 1. There was no weed control in pure wheat, pure pea, and their mixed parcels (treatments 1–3). Intercropped plots ranged from treatment 4 to 16. These plots included herbicide applications (pre-emergence and early post-emergence or late post-emergence) with different active ingredients (pendimethalin, bentazon, MCPA, MCPB). The first herbicide treatment was a pre-emergence treatment with pendimethalin (number 4). The next three treatments (number 5 to 7) are associated with early post-emergence herbicides (bentazon, MCPA, MCPB). During the next three treatments (number 8 to 10), pendimethalin with three late post-emergence herbicides (bentazon, MCPA, MCPB) were applied. In the last six treatments, no pre-emergence herbicide was used, but plant associations were applied with early or late post-emergence herbicides (numbers 11 to 16). Application conditions are shown in Table 2.

Table 1. Dates and doses of herbicide treatments applied at different growth stages in both experiment years, 2018 and 2019.

Number of Treatments	Date of Treatments in 2018	Date of Treatments in 2019	Growth Stages of Wheat	Growth Stages of Pea	Active Ingredient	Dose (g/ha)
1	pure winter wheat (*Triticum aestivum* L.), no weed control					
2	pure winter pea (*Pisum sativum* L.), no weed control					
3	winter wheat (*Triticum aestivum* L.) and winter pea (*Pisum sativum* L.) in intercropping system, no weed control					
4	30 October	18 October	germination	germination	pendimethalin	1600
5	30 October	18 October	germination	germination	pendimethalin	1600
	5 March	17 March	tillering	4–6 leaves stage	bentazon	960
6	30 October	18 October	germination	germination	pendimethalin	1600
	5 March	17 March	tillering	4–6 leaves stage	MCPA	750
7	30 October	18 October	germination	germination	pendimethalin	1600
	5 March	17 March	tillering	4–6 leaves stage	MCPB	1752
8	30 October	18 October	germination	germination	pendimethalin	1600
	26 April	23 April	stem elongation	beginning of flowering	bentazon	960
9	30 October	18 October	germination	germination	pendimethalin	1600
	26 April	23 April	stem elongation	beginning of flowering	MCPA	750
10	30 October	18 October	germination	germination	pendimethalin	1600
	26 April	23 April	stem elongation	beginning of flowering	MCPB	1752
11	5 March	17 March	tillering	4–6 leaves stage	bentazon	960
12	5 March	17 March	tillering	4–6 leaves stage	MCPA	750
13	5 March	17 March	tillering	4–6 leaves stage	MCPB	1752
14	26 April	23 April	stem elongation	beginning of flowering	bentazon	960
15	26 April	23 April	stem elongation	beginning of flowering	MCPA	750
16	26 April	23 April	stem elongation	beginning of flowering	MCPB	1752

Table 2. Conditions of herbicide treatments in both experiment years 2018/2019 and 2019/2020.

Parameters	2018–2019			2019–2020		
	30 October	5 March	26 April	18 October	17 March	23 April
Temperature (°C)	13.0	10.0	12.0	12.0	8.5	21.0
Relative humidity (%)	65.0	60.0	70.0	70.0	85.0	65.0
Wind speed (m/s)	2.0	3.0	5.0	3.0	3.0	4.0
Cloud cover (%)	30.0	20.0	50.0	50.0	30.0	40.0
Precipitation (mm) 2 weeks before treatment	4.7	0.0	15.0	24.0	39.5	2.0
Precipitation (mm) 2 weeks after treatment	6.0	12.0	28.4	18.0	11.0	19.0

2.2. Assessments

Weed density was measured on six occasions of each growing season on the day of the herbicide treatments, 2–3 weeks after, and before harvest (in the year 2018–2019: 15 November, 5 and 19 March, 26 April, 10 May, 10 July; in the year of 2019–2020: 8 November, 17 and 31 March, 23 April, 8 May, 8 July). The survey method was based on weed coverage of the experimental site (percentage value), where the method of Balázs–Ujvárosi was used [63]. The effectiveness of the different weed control treatments was determined as a percentage in relation to the number of weeds in the winter wheat (*Triticum aestivum* L.)-winter pea (*Pisum sativum* L.) mixed plot without weed control. The efficiency was characterized by the expressions in Table 3, based on standard methods of efficacy trials for authorization on herbicides in Hungary [64].

Table 3. Evaluation of weed control efficiency in nine categories.

Weed Control Efficiency	
98.1–100%	Excellent
95.1–98%	Very good
90.1–95%	Good
82.1–90%	Acceptable
70.1–82%	Uncertain
50.1–70%	Weak
30.1–50%	Extremely weak
0.1–30%	Bad
0%	Ineffective

The effect of the cultivation method (pure and mixed parcels) and weed control treatments on plant development were evaluated by plant samples from every parcel collected from a unit area of 1 m^2 before harvest. During the process of plant sampling, yield components were determined from 1 m^2: in the case of winter wheat (*Triticum aestivum* L.), these were the number of plants, shoots, ears, spikelets, grains, and grain weight; in the case of peas, these were the number of plants, shoots, pods, grains, and grain weight.

2.3. Statistical Analysis

The yield components were evaluated with an analysis of variance using the program SPSS 22. The development of the plants was evaluated with Sváb-type cumulative yield production analysis [65–67]. In classic yield production analysis, the components are related to another component, but independent from each other; therefore, they are interchangeable. A serious drawback of this yield production analysis is that they do not characterize the development of yield in chronological order. In contrast to cumulative yield production analysis by Sváb, with individual components concerned with an area unit, they follow the development stages of the plant, and in that sense, they are not interchangeable. Yield components are the final phase products of the development stages of the plant, which effectively characterize the present and previous development phases. Because of the irreplaceability of yield components with the use of cumulative yield production analysis, we can see a development process from which the direction and level of the effect of the agrotechnical or ecological element can be determined. In the case of winter wheat (*Triticum aestivum* L.), the following are considered yield components: A = number of plants/m^2, B = number of shoots/m^2, C = number of ears/m^2, D = number of spikelets/m^2, E = number of grains /m^2, F = grain weight/m^2. In the case of peas, we determined the number of plants (G), shoots (H), pods (I), grains (J), and grain weight in 1 m^2. The cumulative yield production analysis allows graphic representation of plant development, where the horizontal axis (x) shows yield components (end products of different development stages)/from a given area (m^2) in the order of development, and the vertical axis (y) shows the percent value of yield components compared to the base value, where we considered the number of plants. Despite the difference in the yield components on a large scale and in the unit of measure, the percent value representation of graphic yield analysis is advantageous in one common graph. Connecting the tested yield components with a line, we can determine the relative process of development of the analyzed plants compared to the 100% basis on the horizontal axis (x). The lines connecting each final phase product indicate the direction and intensity of development. The intensity of development is calculated from the proportion of yield components referring to 1 m^2.

3. Results

3.1. Weed Cover

The rate of weed cover is illustrated in Tables 4–6 for pure winter wheat, pure winter pea, and wheat–pea plant association without weed control in both tested years (2018–2019 and 2019–2020). Both years display similar results from the weed survey in November for pure winter wheat plots (Table 4), with minor proportions (0.1–0.2%) of Ivy-leaved speedwell (*Veronica hederifolia* L.), Common chickweed (*Stellaria media* (L.) Vill), Shepherd's purse (*Capsella bursa-pastoris* L.), and Cleavers (*Galium aparine* L.). The rate of weed cover of these weeds increased (0.3–2.5%) for the early spring weed survey, with the appearance of Charlock (*Sinapis arvensis* L.) (2–3%). It can be observed that more precipitation (Figure 1) in winter and early spring increased the cover of weeds; thus, we noticed greater weed cover in the second experiment year (2019/2020) than in the first year (2018–2019). At the end of March, Forking larkspur (*Consolida regalis* Gray) populated (0.2%) the plots of pure winter wheat. At the end of April, the Common poppy (*Papaver rhoeas* L.) (0.5–1%) and Fat hen (*Chenopodium album* L.) (0.1%) were noticed. During May, observations were made of summer weeds such as Schleicher's fumitory (*Fumaria schleicheri* Soy.-Will.) (0.3%), Black bindweed (*Fallopia convolvulus* L.) (0.4–0.5%), Wild radish (*Raphanus raphanistrum* L.) (0.2–0.3%), and Annual yellow woundwort (*Stachys annua* L.) (0.2%) in pure stands of winter wheat plots. However, Ivy-leaved speedwell and Cleavers no longer appeared in the weed population. At the same time as the winter wheat harvest, Common ragweed (*Ambrosia artemisiifolia* L.) (0.7–0.75%) and Johnsongrass (*Sorghum halepense* (L.) Pers.) (1%) were noticed. However, Common chickweed was missing from the sample area (Table 4).

Table 4. Weed cover (%) of pure winter wheat (*Triticum aestivum* L.) without weed management in control plots (2018/2019 and 2019/2020).

English Name	Latin Name	EPPO Code	Winter Wheat 2018–2019						Winter Wheat 2019–2020					
			15 November	5 March	19 March	26 April	10 May	10 July	8 November	17 March	31 March	23 April	8 May	8 July
Ivy-leaved speedwell	*Veronica hederifolia* L.	VERHE	0.10	1.00	3.00	4.00	0.00	0.00	0.10	2.50	5.00	7.00	3.00	0.00
Common chickweed	*Stellaria media* (L.) Vill.	STEME	0.10	1.00	1.75	1.00	0.80	0.00	0.20	2.50	4.00	1.00	0.20	0.00
Shepherd's purse	*Capsella bursa-pastoris* L.	CAPBP	0.10	0.50	1.00	1.50	0.50	0.10	0.15	0.50	1.00	1.50	0.50	0.10
Cleavers	*Galium aparine* L.	GALAP	0.10	0.40	0.60	0.50	0.00	0.00	0.10	0.30	0.70	0.60	0.00	0.00
Common poppy	*Papaver rhoeas* L.	PAPRH	0.00	0.00	0.00	1.00	2.00	1.50	0.00	0.00	0.00	0.50	1.75	1.50
Forking larkspur	*Consolida regalis* Gray	CNSRE	0.00	0.00	0.20	1.00	1.50	0.00	0.00	0.00	0.20	1.00	1.50	0.00
Schleicher's fumitory	*Fumaria schleicheri* Soy.-Will.	FUMSC	0.00	0.00	0.00	0.00	0.33	0.75	0.00	0.00	0.00	0.00	0.30	0.50
Wild radish	*Raphanus raphanistrum* L.	RAPRA	0.00	0.00	0.00	0.00	0.20	0.30	0.00	0.00	0.10	0.20	0.30	0.50
Charlock	*Sinapis arvensis* L.	SINAR	0.00	2.00	2.00	4.25	6.75	4.00	0.00	3.00	5.00	5.75	6.00	4.00
Black bindweed	*Fallopia convolvulus* L.	POLCO	0.00	0.00	0.00	0.00	0.40	0.50	0.00	0.00	0.00	0.00	0.50	0.70
Common ragweed	*Ambrosia artemisiifolia* L.	AMBEL	0.00	0.00	0.00	0.00	0.00	0.75	0.00	0.00	0.00	0.00	0.00	0.70
Annual yellow woundwort	*Stachys annua* L.	STAAN	0.00	0.00	0.00	0.00	0.20	0.30	0.00	0.00	0.00	0.00	0.20	0.30
Fat hen	*Chenopodium album* L.	CHEAL	0.00	0.00	0.00	0.00	0.30	0.50	0.00	0.00	0.00	0.10	0.50	0.75
Johnsongrass	*Sorghum halepense* (L.) Pers.	SORHA	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00
Field bindweed	*Convolvulus arvensis* L.	CONAR	0.00	0.00	0.00	0.20	0.70	1.00	0.00	0.00	0.00	0.20	0.70	3.00
	Total		0.40	4.90	8.55	13.45	13.68	10.70	0.55	8.80	16.00	17.85	15.45	13.05

Table 5. Weed cover (%) of pure winter pea (*Pisum sativum* L.) without weed management in control plots (2018/2019 and 2019/2020).

English Name	Latin Name	EPPO Code	Winter Pea 2018–2019						Winter Pea 2019–2020					
			15 November	5 March	19 March	26 April	10 May	10 July	8 November	17 March	31 March	23 April	8 May	8 July
Ivy-leaved speedwell	*Veronica hederifolia* L.	VERHE	0.10	0.50	2.00	1.00	0.00	0.00	0.15	0.50	2.50	2.00	0.00	0.00
Common chickweed	*Stellaria media* (L.) Vill.	STEME	0.10	1.00	2.00	1.50	0.30	0.00	0.15	1.00	3.00	2.00	0.50	0.00
Shepherd's purse	*Capsella bursa-pastoris* L.	CAPBP	0.10	0.50	1.00	1.50	0.50	0.10	0.15	0.50	1.00	1.50	0.50	0.10
Cleavers	*Galium aparine* L.	GALAP	0.00	0.30	0.86	0.50	0.00	0.00	0.10	0.30	0.86	0.50	0.00	0.00
Common poppy	*Papaver rhoeas* L.	PAPRH	0.10	0.30	0.50	1.00	2.75	2.00	0.10	0.50	0.80	1.50	3.00	2.00
Forking larkspur	*Consolida regalis* Gray	CNSRE	0.00	0.00	0.00	0.20	1.00	0.10	0.00	0.00	0.00	0.33	2.00	0.50
Schleicher's fumitory	*Fumaria schleicheri* Soy.-Will.	FUMSC	0.00	0.00	0.00	0.00	0.50	0.70	0.00	0.00	0.00	0.00	0.50	1.00

Table 5. *Cont.*

English Name	Latin Name	EPPO Code	Winter Pea 2018–2019						Winter Pea 2019–2020					
			15 November	5 March	19 March	26 April	10 May	10 July	8 November	17 March	31 March	23 April	8 May	8 July
Wild radish	*Raphanus raphanistrum* L.	RAPRA	0.00	0.00	0.00	0.00	0.35	0.50	0.00	0.00	0.00	0.00	0.45	1.00
Charlock	*Sinapis arvensis* L.	SINAR	0.00	3.00	3.86	7.00	10.00	5.00	0.00	3.00	3.86	8.75	11.00	4.00
Black bindweed	*Fallopia convolvulus* L.	POLCO	0.00	0.00	0.00	0.50	1.50	1.00	0.00	0.00	0.00	0.50	2.00	2.00
Common ragweed	*Ambrosia artemisiifolia* L.	AMBEL	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	3.00
Annual yellow woundwort	*Stachys annua* L.	STAAN	0.00	0.00	0.00	0.00	0.60	0.80	0.00	0.00	0.00	0.00	0.50	0.70
Fat hen	*Chenopodium album* L.	CHEAL	0.00	0.00	0.00	0.10	0.50	1.00	0.00	0.00	0.00	0.10	0.50	1.00
Johnsongrass	*Sorghum halepense* (L.) Pers.	SORHA	0.00	0.00	0.00	0.00	1.00	2.00	0.00	0.00	0.00	0.00	1.50	5.00
Field bindweed	*Convolvulus arvensis* L.	CONAR	0.00	0.00	0.00	0.50	1.00	2.00	0.00	0.00	0.00	0.50	2.00	3.00
	Total		0.40	5.60	10.22	13.80	20.00	16.20	0.65	5.80	12.02	17.68	24.45	23.30

Table 6. Weed cover (%) of winter wheat (*Triticum aestivum* L.)–winter pea (*Pisum sativum* L.) plant association without weed management in control plots (2018/2019 and 2019/2020).

English Name	Latin Name	EPPO Code	Wheat–Pea Association 2018/2019						Wheat–Pea Association 2019/2020					
			15 November	5 March	19 March	26 April	10 May	10 July	8 November	17 March	31 March	23 April	8 May	8 July
Ivy-leaved speedwell	*Veronica hederifolia* L.	VERHE	0.15	0.50	1.00	0.50	0.00	0.00	0.20	0.60	1.50	0.50	0.00	0.00
Common chickweed	*Stellaria media* (L.) Vill.	STEME	0.10	1.00	1.75	1.00	0.20	0.00	0.10	1.00	1.50	1.00	0.30	0.00
Shepherd's purse	*Capsella bursa-pastoris* L.	CAPBP	0.10	0.50	1.00	1.50	0.50	0.10	0.10	0.50	1.00	1.50	0.50	0.10
Cleavers	*Galium aparine* L.	GALAP	0.00	0.20	0.50	0.30	0.00	0.00	0.10	0.20	0.50	0.30	0.00	0.00
Common poppy	*Papaver rhoeas* L.	PAPRH	0.00	0.10	0.50	1.50	2.00	1.50	0.00	0.10	0.50	1.50	2.00	1.50
Forking larkspur	*Consolida regalis* Gray	CNSRE	0.00	0.00	0.10	0.70	1.00	1.00	0.00	0.00	0.10	0.70	1.75	1.00
Schleicher's fumitory	*Fumaria schleicheri* Soy.-Will.	FUMSC	0.00	0.00	0.00	0.10	0.40	0.50	0.00	0.00	0.00	0.10	0.40	0.50
Wild radish	*Raphanus raphanistrum* L.	RAPRA	0.00	0.00	0.00	0.00	0.25	0.40	0.00	0.00	0.00	0.00	0.25	0.50
Charlock	*Sinapis arvensis* L.	SINAR	0.00	1.33	2.33	5.25	6.25	4.00	0.00	1.33	2.33	5.25	8.00	4.00
Black bindweed	*Fallopia convolvulus* L.	POLCO	0.00	0.00	0.00	0.10	0.20	0.00	0.00	0.00	0.00	0.10	0.20	0.00
Common ragweed	*Ambrosia artemisiifolia* L.	AMBEL	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.50
Annual yellow woundwort	*Stachys annua* L.	STAAN	0.00	0.00	0.00	0.00	0.50	0.60	0.00	0.00	0.00	0.00	0.50	0.60
Fat hen	*Chenopodium album* L.	CHEAL	0.00	0.00	0.00	0.00	0.75	0.75	0.00	0.00	0.00	0.00	0.75	1.00
Johnsongrass	*Sorghum halepense* (L.) Pers.	SORHA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Field bindweed	*Convolvulus arvensis* L.	CONAR	0.00	0.00	0.00	0.50	1.00	1.00	0.00	0.00	0.00	0.50	0.50	1.00
	Total		0.35	3.63	7.18	11.45	13.05	10.35	0.50	3.73	7.43	11.45	15.15	10.70

Pure winter pea plots, during both years (Table 5), contained Ivy-leaved speedwell (0.10–0.15%), Common chickweed (0.10–0.15%), Shepherd's purse (0.10–0.15%), and Common poppy (0.10%) during the autumn weed survey. Moreover, Cleavers (0.10%), in the autumn of the second examination year (2019/2020), were seen. At the time of the early spring weed survey, Charlock covered the largest proportion (3%) of the sample area, and became more dominant by the end of March (3.86%). Forking larkspur (0.2–0.33%), Black bindweed (0.5%), Field bindweed (*Convolvulus arvensis* L.) (0.5%), and Fat hen (0.1%) appeared in April. Then, at the time of the weed survey in May, Schleicher's fumitory (0.5%), Wild radish (0.35–0.45%), Annual yellow woundwort (0.5–0.6%), and Johnsongrass (1–1.5%) appeared. By this time, among the annual weeds, Ivy-leaved speedwell and Cleavers had disappeared from the sample areas (Table 5). The rainy weather of the second experimental year (Figure 1) favored the weed flora. More weed cover, 0.25–7.10%, was registered in 2019–2020 than in 2018/2019. Comparing the weed cover of pure winter wheat and pure winter pea, winter pea had a higher weed cover rate in general than wheat, except for the first half of the growing season in 2019/2020 (Tables 4 and 5).

In winter wheat–pea association plots (Table 6), at the time of November in both years, Ivy-leaved speedwell (0.15–0.20%), Common chickweed (0.10%), and Shepherd's purse (0.10%) were detected, and in 2019/2020, Cleavers (0.10%) were also present. It can be stated that the weed cover of Ivy-leaved speedwell was slightly higher (0.10–0.15%) in the wheat–pea association plots than in pure stands (0.15–0.20%). At the beginning of March, Common poppy (0.10%) and Charlock (1.33%) were observed, while at the end of March, Forking larkspur (0.10%) was noticed in the mixed plots. Schleicher's fumitory (0.10%), Black bindweed (0.10%), and Field bindweed (0.50%) appeared in April. During the weed survey in May, Ivy-leaved speedwell and Cleavers were not detectable, but Annual yellow woundwort (0.5%) and Fat hen (0.75%) became visible. There was no Common chickweed or Black bindweed in July in the sample area, while Common ragweed (0.5%) appeared. In the associated plots, Johnsongrass was not detected in either year (Table 6).

It can be observed that fewer weed species were noticed in the wheat–pea association plots, and achieved lower weed cover, than in pure stands.

3.2. Weed Control Efficiency

The effectiveness of the herbicide treatments in the wheat–pea association plots can be seen in Tables 7 and 8. The most common weeds (EPPO code) are included in these tables in order of their cover.

Pendimethalin applied at pre-emergence in 2018–2019 had a "bad" weed control effect on Shepherd's purse (20.5–23.5%) and an "extremely weak" effect against Ivy-leaved speedwell (49.5–50.5%) and Common chickweed (45.75–46.25%) (Table 7). In the following year, pendimethalin also had a "bad" weed control effect (25.5–29%) against Shepherd's purse, a "weak" effect (63.75–65.5%) against Ivy-leaved speedwell, an "extremely weak" effect (49.5–52.75%) against Common chickweed, and an "uncertain–acceptable" effect (80.75–83.5%) against Common poppy (Table 8). In the second growing season, the precipitation after sowing slightly improved the efficiency of pendimethalin.

In the growing season of 2018–2019, the early application of bentazon showed a "weak" effect against Shepherd's purse (56%) and Common poppy (63–67%). This active ingredient was "acceptable" against Common chickweed (85–87%) and Ivy-leaved speedwell (90%), and it had a "good" weed control effect against Charlock (91–92%) (Table 7). In the next growing season, the early treatment with bentazon was proven to have a "weak" effect against Shepherd's purse (55–57.5%) and Common poppy (61%). However, it had an "acceptable" effect against Common chickweed (83–84%), and a "good" weed control effect against Charlock (91–92%) and Ivy-leaved speedwell (93–94%) (Table 8). The late application of bentazon in 2018/2019 resulted in a "weak" weed control effect on Field bindweed (50–52%), Shepherd's purse (52–61%), and Common poppy (62–65%). This active ingredient was "acceptable" against Common chickweed (83%) and had a "good" effect against Charlock (90%) (Table 7). In the next growing season, the late application of bentazon was proved to have a “weak” effect against Field bindweed (52–53%), Shepherd’s purse (58–58.75%), and Common poppy (63–64%). It had an “acceptable” effect against Common chickweed (82–85%), and a “good” effect against Charlock (90–92%) and Ivy-leaved speedwell (90–93%) (Table 8).

Table 7. Weed control efficiency of chemical treatments compared to weed cover of untreated control winter wheat (*Triticum aestivum* L.)–winter pea (*Pisum sativum* L.) plant association plots in 2018/2019.

Treatment Number	Year	EPPO Code					
	2018–2019	SINAR	PAPRH	VERHE	STEME	CAPBP	CONAR
4	15 November 10 July	- 0.00	- 0.00	50.25 -	46.00 -	21.00 60.00	- 0.00
5	15 November 19 March 10 July	- 91.00 100.00	- 63.00 95.00	50.00 90.00 -	46.50 87.00 -	22.50 56.00 87.00	- - 0.00
6	15 November 19 March 10 July	- 90.00 95.00	- 92.00 97.00	50.25 25.00 -	46.00 50.00 -	20.50 92.00 100.00	- - 0.00
7	15 November 19 March 10 July	- 91.00 100.00	- 90.00 100.00	49.75 95.00 -	45.75 84.00 -	20.75 86.00 90.00	- - 0.00
8	15 November 10 May 10 July	- 90.00 100.00	- 65.00 98.00	50.50 - -	46.00 83.00 -	21.00 52.00 82.00	- 52.00 45.00
9	15 November 10 May 10 July	- 95.00 100.00	- 91.00 100.00	49.50 - -	45.75 45.50 -	23.50 92.00 100.00	- 81.00 100.00
10	15 November 10 May 10 July	- 97.00 100.00	- 93.00 98.00	50.00 - -	46.25 85.00 -	22.75 87.00 92.00	- 81.00 78.00
11	19 March 10 July	92.00 100.00	67.00 100.00	90.00 -	85.00 -	56.00 91.00	- 0.00
12	19 March 10 July	90.00 100.00	92.00 98.00	26.50 -	50.00 -	91.00 100.00	- 0.00
13	19 March 10 July	95.00 100.00	94.00 100.00	95.00 -	87.00 -	83.00 85.00	- 0.00
14	10 May 10 July	90.00 100.00	62.00 90.00	- -	83.00 -	61.00 87.00	50.00 40.00
15	10 May 10 July	94.50 100.00	92.00 100.00	- -	46.00 -	93.00 100.00	87.00 100.00
16	10 May 10 July	96.00 100.00	93.00 100.00	- -	84.50 -	93.00 95.00	83.00 80.00

Regarding the early treatment with MCPA in the first growing season, the weed control efficiency was “bad” in the case of Ivy-leaved speedwell (25–26.5%), “extremely weak” for Common chickweed (50%), “acceptable” for Charlock (90%), and “good” for Shepherd’s purse (91–92%) and Common poppy (92%) (Table 7). Early application in the second growing season was observed to have a “bad” weed control effect against Ivy-leaved speedwell (27–30%), while it was “extremely weak” against Common chickweed (50%) and “good” against Common poppy (90–91%), Shepherd’s purse (90–92%), and Charlock (92%) (Table 8). Late treatment with MCPA was “extremely weak” in the first year for Common chickweed (45.5–46%), and “uncertain–acceptable” against Field bindweed (81–87%), while this active ingredient had a “good” weed control effect against Common poppy (91–92%) and Charlock (94.5–95%) (Table 7). In 2019–2020, the late treatment of MCPA was observed to have an "extremely weak" effect on Ivy-leaved speedwell (30–32.5%) and Common chickweed (45–48%). Against the Field bindweed it was "acceptable" (82.5–83%), and was "good" at treating Common poppy (91–92%) and Shepherd's purse (92–93%) weed cover. The treatment was "very good" against Charlock (95–96%) (Table 8).

Table 8. Weed control efficiency of chemical treatments compared to weed cover of untreated control winter wheat (*Triticum aestivum* L.)–winter pea (*Pisum sativum* L.) plant association plots in 2019/2020.

Treatment Number	Year	EPPO Code					
	2019–2020	SINAR	VERHE	STEME	PAPRH	CONAR	CAPBP
4	8 November 8 July	- 0.00	65.00 -	51.50 -	82.00 82.00	- 0.00	25.50 72.00
5	8 November 31 March 8 July	- 92.00 100.00	65.25 93.00 -	50.50 83.00 -	83.50 61.00 90.00	- - 0.00	28.75 55.00 86.00
6	8 November 31 March 8 July	- 92.00 95.00	64.75 30.00 -	52.00 50.00 -	80.75 91.00 100.00	- - 0.00	25.50 90.00 100.00
7	8 November 31 March 8 July	- 95.00 100.00	65.50 97.00 -	52.75 83.00 -	81.50 92.00 100.00	- - 0.00	28.50 94.00 97.00
8	8 November 8 May 8 July	- 90.00 100.00	63.75 93.00 -	50.50 82.00 -	81.00 64.00 94.00	- 53.00 43.00	25.75 58.00 70.00
9	8 November 8 May 8 July	- 95.00 100.00	65.00 32.50 -	49.50 45.00 -	83.00 92.00 100.00	- 82.50 100.00	28.75 93.00 100.00
10	8 November 8 May 8 July	- 96.50 100.00	65.50 95.00 -	50.50 87.00 -	83.00 93.00 100.00	- 84.00 85.00	29.00 93.00 98.00
11	31 March 8 July	91.00 100.00	94.00 -	84.00 -	61.00 95.00	- 0.00	57.50 80.00
12	31 March 8 July	92.00 100.00	27.00 -	50.00 -	90.00 97.00	- 0.00	92.00 98.00
13	31 March 8 July	93.75 100.00	96.00 -	84.00 -	95.00 100.00	- 0.00	95.00 99.00
14	8 May 8 July	92.00 100.00	90.00 -	85.00 -	63.00 92.00	52.00 40.00	58.75 93.00
15	8 May 8 July	96.00 100.00	30.00 -	48.00 -	91.00 100.00	83.00 80.00	92.00 97.00
16	8 May 8 July	92.25 100.00	96.00 -	84.75 -	93.00 100.00	86.00 90.00	93.00 97.00

In terms of MCPB, when applied early in 2018/2019, an "acceptable" effect was achieved on Shepherd's purse (83–86%) and Common chickweed (84–87%). "Good" weed control was observed against Common poppy (90–94%), Charlock (91–95%), and Ivy-leaved speedwell (95%) (Table 7). In 2019–2020, early MCPB treatment was "acceptable" against Common chickweed (83–84%), and had a "good" effect against Common poppy (92–95%), Charlock (93.75–95%), and Shepherd's purse (94–95%), while it had a "very good" effect against Ivy-leaved speedwell (96–97%) (Table 8). In 2018/2019, the late treatment with MCPB resulted in an "acceptable" weed control effect against Field bindweed (81–83%) and Common chickweed (84.5–85%), while performed an "acceptable–good" effect against Shepherd's purse (87–93%), a "good" effect against Common poppy (93%), and a "very good" effect against Charlock (96–97%) (Table 7).

In 2019/2020, MCPB showed an "acceptable" effect on Common chickweed (84.75–87%) and Field bindweed (84–86%), while it was considered "good" against Shepherd's purse (93%), and "good–very good" against Charlock (92.25–96.5%) and Ivy-leaved speedwell (95–96%) (Table 8).

In summary, the late post-emergence use of the active ingredients (bentazon, MCPA, MCPB) removed most of the weeds from the experimental plots with "very good–excellent" efficiency by the end of the growing season. Field bindweed remained in those plots where early herbicide treatments (pre-emergence or early post-emergence) were applied.

3.3. Yield Components

3.3.1. Variance Analysis of Yield Components

The two-factor analysis of variance (with mean square values) of the yield components of winter wheat can be seen in Table 9.

Table 9. Results of variance analysis of winter wheat (*Triticum aestivum* L.) yield components (MS).

	df	Plant Number	Shoot Number	Ear Number	Spikelet Number	Grain Number	Grain Weight
Repeat	3						
Corrected model	29	86.226 ***	26,119.047 ***	13,249.454 ***	3,330,609.868 ***	2,757,015.267 ***	5304.925 ***
Intercept	1	9,613,510.208 ***	44,999,152.13 ***	27,823,959.07 ***	5450058432 ***	1.599×10^{10} ***	27,789,704.31 ***
Treatment	14	141.815 ***	341.151 ***	5298.075 ***	1,133,855.754 ***	4,656,496.312 ***	8560.761 ***
Growing season	1	304.008 ***	746,709.633 ***	267,246.408 ***	73,788,515.01 ***	9,768,101.408 ***	17,374.689 ***
Treatment × Growing season	14	15.080 ns	426.187 ***	3058.194 ***	494,656.473 ***	356,742.355 ***	1186.963 **
Error	90	25.914	9.728	37.775	3181.408	33,207.281	511.186
Total	120						

*** Significant at the 0.001 probability level. Confidence intervals are 99.9%. ** Significant at the 0.01 probability level. Confidence intervals are 99%. * Significant at the 0.05 probability level. Confidence intervals are 95%. ns: Non-significant.

The effect of treatment was significant for a given area (m^2): the number of plants, shoots, ears, spikelets, grains, and grain weight of winter wheat at the significance level of 0.001. The growing season also significantly influenced the number of plants, shoots, ears, spikelets, grains, and grain weight in a given area (m^2) of winter wheat (significance level of 0.001). The treatment × growing season interaction was significant for the number of shoots, ears, spikelets, and grains in a given area (m^2) (significance level of 0.001), as well as for the number of plants and grain weight in a given area (m^2) (significance level of 0.01).

The two-factor analysis of variance (with mean square values) of the yield components of winter pea can be seen in Table 10.

Table 10. Results of variance analysis of winter pea (*Pisum sativum* L.) yield components (MS).

	df	Plant Number	Shoot Number	Pod Number	Seed Number	Seed Weight
Repeat	3					
Corrected model	29	8.727 ***	8.132 **	11,761.386 ***	276,874.232 ***	5825.458 ***
Intercept	1	246,522.675 ***	271,986.408 ***	12,523,356.30 ***	90,826,260.01 ***	1,109,922.976 ***
Treatment	14	13.979 ***	11.855 ***	516.407 ***	7993.776 ***	307.454 ***
Growing season	1	31.008 **	31.008 **	333,064.033 ***	7,851,525.208 ***	161,965.351 ***
Treatment × Growing season	14	1.883 ns	2.776 ns	56.176 ns	4708.190 ***	190.612 ***
Error	90	3.658	4.164	32.394	242.447	11.907
Total	120					

*** Significant at the 0.001 probability level. Confidence intervals are 99.9%. ** Significant at the 0.01 probability level. Confidence intervals are 99%. * Significant at the 0.05 probability level. Confidence intervals are 95%. ns: Non-significant.

The effect of treatment is proven statistically (significance level of 0.001) in terms of the number of plants, shoots, pods, grains, and grain weight in a given area (m^2) of winter pea. The growing season significantly influenced the number of pods, grains, and grain weight in a given area (m^2) of winter pea (significance level of 0.001), as well as the number of plants and shoots in a given area (m^2) (significance level of 0.01). In terms of winter pea treatment x growing season interaction, it was reliable at the 0.001 significance level for the number of grains and grain weight. In contrast, the treatment × growing season interaction was not significant in the number of plants, shoots, and pods measured in a given area (m^2).

3.3.2. Changes in Winter Wheat Yield Components

The changes in the yield components of winter wheat in each treatment can be seen in Table 11. Although there was a statistically proven difference between the treatments in the case of the plant number/m^2, the difference between the lowest (8th treatment: pre-emergence application of pendimethalin and late post-emergence application of bentazon) and the highest value (9th treatment: pre-emergence application of pendimethalin and late post-emergence application of MCPA) was less than 6%. The shoot number values/m^2 varied between 601.5 pieces (8th treatment) and 628.88 pieces (1st treatment: pure winter wheat, without weed control). In the case of the number of ears, spikelets, grain, and grain weights in a given area (m^2), the lowest values were in the associated wheat plots without weed control, while the highest values were in pure wheat plots without weed control. The herbicide treatments were located between these two values (Table 11).

Table 11. Changes in winter wheat (*Triticum aestivum* L.) yield components (A, B, C, D, E, F) in the different treatments.

	Average of Two Years					
Treatment Number	**Plant Number (A) (pcs/m^2)**	**Shoot Number (B) (pcs/m^2)**	**Ear Number (C) (pcs/m^2)**	**Spikelet Number (D) (pcs/m^2)**	**Grain Number (E) (pcs/m^2)**	**Grain Weight (F) (g/m^2)**
1	284.88 ^{bcde}	628.88 ^{i}	539.88 ^{j}	7934.38 ^{f}	13,600.00 ^{i}	577.75 ^{g}
3	282.75 ^{bcd}	611.00 ^{def}	443.13 ^{a}	6462.13 ^{a}	10,790.75 ^{a}	445.75 ^{a}
4	280.50 ^{b}	608.75 ^{cd}	449.50 ^{b}	6903.13 ^{e}	11,021.38 ^{bcd}	450.25 ^{ab}
5	279.88 ^{b}	610.50 ^{de}	495.00 ^{g}	6900.38 ^{e}	12,238.50 ^{h}	498.17 ^{ef}
6	285.88 ^{cde}	609.88 ^{de}	511.75 ^{i}	6887.25 ^{e}	12,141.38 ^{h}	512.09 ^{f}
7	285.88 ^{cde}	614.13 ^{g}	502.00 ^{h}	6912.75 ^{e}	12,201.00 ^{h}	490.72 ^{def}
8	272.75 ^{a}	601.50 ^{a}	482.75 ^{de}	6711.13 ^{d}	11,672.13 ^{fg}	479.28 ^{cde}
9	289.13 ^{e}	604.88 ^{b}	484.38 ^{de}	6701.50 ^{d}	11,785.13 ^{g}	489.56 ^{de}
10	282.25 ^{bc}	606.50 ^{bc}	489.13 ^{fg}	6684.00 ^{d}	11,591.75 ^{ef}	478.72 ^{cde}
11	287.63 ^{de}	621.25 ^{h}	481.00 ^{d}	6591.13 ^{c}	11,120.63 ^{de}	470.81 ^{bcd}
12	281.25 ^{bc}	613.75 ^{fg}	482.00 ^{d}	6529.75 ^{b}	11,091.13 ^{cd}	478.72 ^{cde}
13	288.88 ^{e}	613.75 ^{fg}	488.50 ^{ef}	6468.13 ^{a}	11,145.00 ^{de}	477.50 ^{cde}
14	280.88 ^{bc}	614.25 ^{g}	463.50 ^{c}	6438.38 ^{a}	10,860.88 ^{abc}	452.20 ^{ab}
15	280.75 ^{b}	613.63 ^{fg}	458.63 ^{c}	6541.38 ^{bc}	10,973.75 ^{bcd}	462.20 ^{abc}
16	282.38 ^{bc}	612.88 ^{efg}	451.75 ^{b}	6423.00 ^{a}	10,913.00 ^{abc}	454.70 ^{ab}

Within a column, values marked with different letters are significantly different at the $p = 0.05$ significance level.

Based on the data in Table 12, it can be concluded that the growing season significantly influenced the parameters of winter wheat yield components. It can be declared that the plant number, shoot number, ear number, spikelet number, grain number, and grain weight in a given area (m^2) showed significantly higher values (1–29%) in the second experiment year (2019–2020) than the first experiment year (2018–2019) (Table 12).

Table 12. Changes in winter wheat (*Triticum aestivum* L.) yield components (A, B, C, D, E, F) in the study years.

Year	Plant Number (A) (pcs/m^2)	Shoot Number (B) (pcs/m^2)	Ear Number (C) (pcs/m^2)	Spikelet Number (D) (pcs/m^2)	Grain Number (E) (pcs/m^2)	Grain Weight (F) (g/m^2)
2018/2019	281.45 ^{a}	533.48 ^{a}	434.33 ^{a}	5955.07 ^{a}	11257.78 ^{a}	469.20 ^{a}
2019/2020	284.63 ^{b}	691.25 ^{b}	528.72 ^{b}	7523.38 ^{b}	11828.40 ^{b}	493.26 ^{b}

Within a column, values marked with different letters are significantly different at the p = 0.05 significance level.

3.3.3. Changes in Winter Pea Yield Components

The yield components of winter peas in each treatment can be seen in Table 13. The significantly highest values of plants, shoots, pods, grains, and grain weights were measured in pure stands, without weed control. The lowest values of plants and shoots were measured in plots with pre-emergence treatment. The lowest values of pods, grains, and grain weights were observed in the wheat–pea association plots, without weed control (Table 13).

Table 13. Changes in winter pea (*Pisum sativum* L.) yield components (G, H, I, J, K) in the different treatments.

	Average of Two Years				
Treatment Number	Plant Number (G) (pcs/m^2)	Shoot Number (H) (pcs/m^2)	Pod Number (I) (pcs/m^2)	Grain Number (J) (pcs/m^2)	Grain Weight (K) (g/m^2)
2	49.88 ^{b}	51.50 ^{c}	343.75 ^{f}	938.88 ^{i}	113.91 ^{i}
3	45.25 ^{a}	47.50 ^{ab}	315.25 ^{a}	827.88 ^{a}	88.90 ^{a}
4	44.13 ^{a}	45.75 ^{a}	317.13 ^{ab}	843.38 ^{bc}	89.35 ^{a}
5	45.38 ^{a}	47.63 ^{ab}	333.25 ^{e}	905.75 ^{h}	101.95 ^{h}
6	45.13 ^{a}	47.63 ^{ab}	324.75 ^{d}	893.25 ^{fgh}	99.21 ^{h}
7	45.63 ^{a}	48.50 ^{b}	332.88 ^{e}	901.75 ^{gh}	99.38 ^{h}
8	45.13 ^{a}	46.88 ^{ab}	325.38 ^{d}	889.75 ^{fg}	96.26 ^{efgh}
9	45.38 ^{a}	47.38 ^{ab}	322.75 ^{bcd}	865.63 ^{e}	98.09 ^{gh}
10	45.00 ^{a}	47.50 ^{ab}	323.13 ^{cd}	867.00 ^{e}	96.81 ^{fgh}
11	44.38 ^{a}	47.13 ^{ab}	320.13 ^{abcd}	884.88 ^{f}	93.28 ^{cd}
12	44.75 ^{a}	47.63 ^{ab}	317.63 ^{a}	850.00 ^{cd}	94.65 ^{def}
13	45.00 ^{a}	47.25 ^{ab}	318.88 ^{abc}	862.25 ^{de}	94.87 ^{defg}
14	45.38 ^{a}	47.13 ^{ab}	317.25 ^{ab}	847.38 ^{cd}	92.26 ^{abcd}
15	44.63 ^{a}	47.50 ^{ab}	315.50 ^{a}	832.88 ^{ab}	92.81 ^{bcd}
16	44.88 ^{a}	47.25 ^{ab}	318.13 ^{abc}	839.25 ^{abc}	90.87 ^{abc}

Within a column, values marked with different letters are significantly different at the p = 0.05 significance level.

According to the data in Table 14, it can be concluded that the growing season significantly influenced the products of the development phase in the case of the winter pea. Significantly higher values (2–124%) in terms of the number of plants, shoots, pods, grains, and grain weights in a given area (m^2) were achieved in the first experiment year (2018–2019) compared to the second year (2019–2020) (Table 14).

Table 14. Changes in winter pea (*Pisum sativum* L.) yield components (G, H, I, J, K) in the study years.

Year	Plant Number (G) (pcs/m^2)	Shoot Number (H) (pcs/m^2)	Pod Number (I) (pcs/m^2)	Grain Number (J) (pcs/m^2)	Grain Weight (K) (g/m^2)
2018–2019	45.83 ^{b}	48.12 ^{b}	375.73 ^{b}	1125.78 ^{b}	132.91 ^{b}
2019–2020	44.82 ^{a}	47.10 ^{a}	270.37 ^{a}	614.20 ^{a}	59.44 ^{a}

Within a column, values marked with different letters are significantly different at the p = 0.05 significance level.

3.4. Development Lines of Winter Wheat and Winter Pea Depending on the Treatments

The graphic representation of the development lines of winter wheat and winter pea is based on Sváb's cumulative yield analysis. On the graphs of the cumulative yield analysis, the yield components per sample area (1 m^2) are marked with the capital letters ABC.

- A = Plant number (pcs/m^2) winter wheat
- B = Shoot number (pcs/m^2) winter wheat
- C = Ear number (pcs/m^2) winter wheat
- D = Spikelet number (pcs/m^2) winter wheat
- E = Grain number (pcs/m^2) winter wheat
- F = Grain weight (g/m^2) winter wheat
- G = Plant number (pcs/m^2) winter pea
- H = Shoot number (pcs/m^2) winter pea
- I = Pod number (pcs/m^2) winter pea
- J = Grain number (pcs/m^2) winter pea
- K = Grain weight (g/m^2) winter pea

The effect of plant association on the development of wheat and pea is shown in Figures 2 and 3. Figure 2 shows the development lines of pure wheat and the associated wheat without weed control, where the 100% level represents the values of the pure wheat's yield components. It can be seen that there is almost no difference in the number of plants (at harvest) between pure wheat and associated wheat. The number of winter wheat plants in association with the higher plant density, decreased by only 0.8%. The number of shoots in associated wheat decreased by only 3%. The tillering was negligibly less than in pure wheat. From the direction and slope of the line connecting points "B" and "C", it is clear that associated wheat shoots were less productive because a lower number of ears were recorded than in the pure wheat. In pure wheat, the number of spikelets (pcs/m^2) was 20% less than in associated wheat. However, the lines "C" and "D" run almost parallel to each other; it can thus be concluded that the value of the number of ears was not changed by the association. The number of grains and grain weights in a given area (m^2) in associated wheat was 81% less than in pure wheat. From the slope of the lines "D" and "E", it is proven that the number of grains had decreased, and the flowering period was negatively influenced by the association. In the direction of the "E" and "F" lines, it can be seen that the grain weight of the associated wheat is lower than the pure wheat. Thus, for the final product, grain weight (pcs/m^2), the yield is 23% less than in pure wheat (Figure 2).

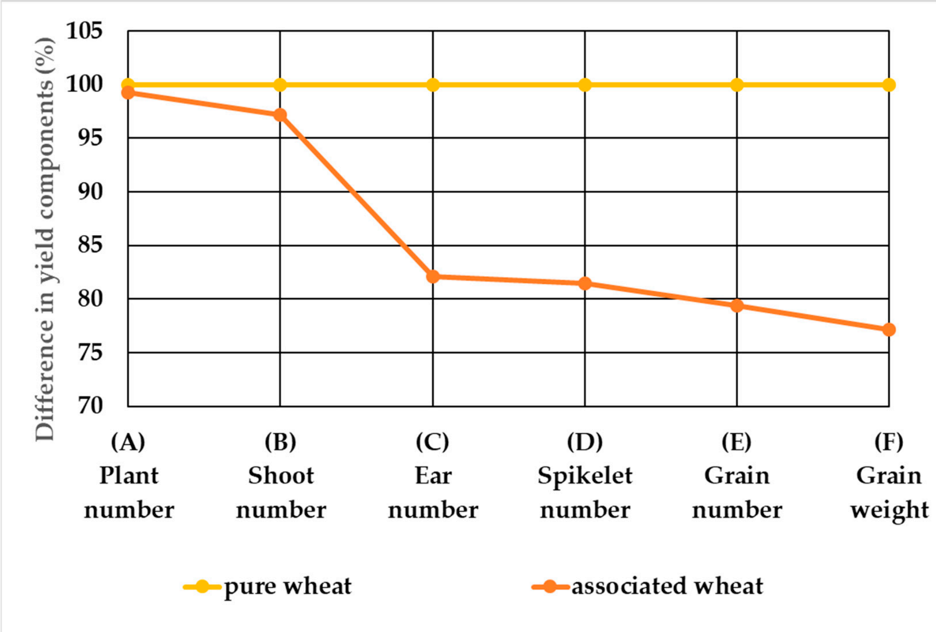

Figure 2. Development line of pure wheat (*Triticum aestivum* L.) and associated wheat over an average of 2 years.

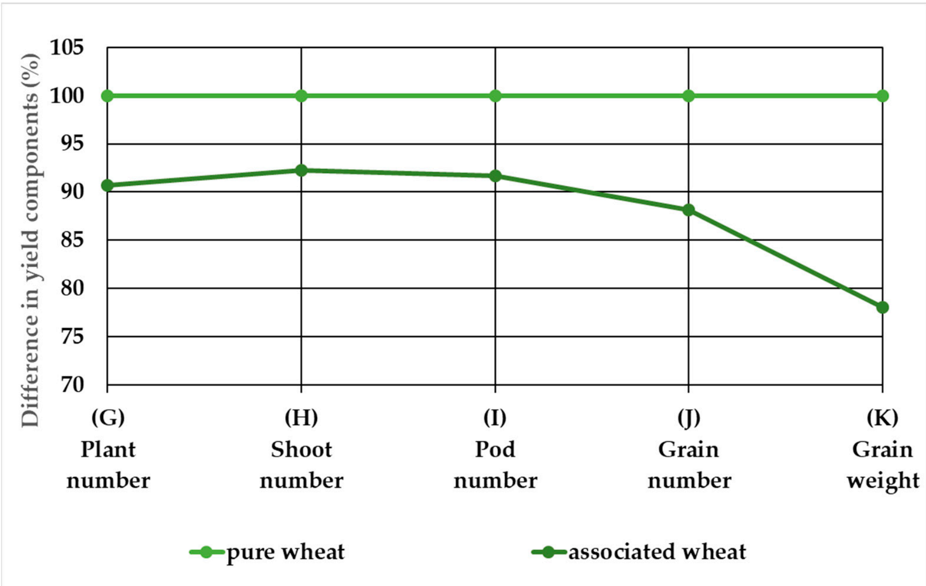

Figure 3. Development line of pure winter pea (*Pisum sativum* L.) and associated winter pea (*Pisum sativum* L.) over an average of 2 years.

The development line of pure pea and associated pea without weed management is presented in Figure 3, where the 100% level shows the values of the yield components in pure pea stands. It can be observed that the number of plants, shoots, and pods of the associated pea became 8–9% less at the time of harvest. However, the lines connecting points between "G" and "H" and between "H" and "I" are almost parallel to the sections of the pure pea. The values of shoots and the number of pods developing on one shoot were not affected by association. The number of grains "J" was reduced 12% by the association, and the number of grains per pod was also lower in the associated pea than in pure pea ("I" and "J" line slope). The grain weight of the associated pea was significantly lower than the pure pea ("J" and "K" line slope). Thus, the final product, grain weight (pcs/m^2), was 22% less than in pure pea (Figure 3).

The effects of herbicide treatments on the development of associated winter wheat and winter pea are illustrated in Figures 4–11. The effect of the pre-emergence treatment on the development of winter wheat is indicated in Figure 4. The 100% level represents the values of the yield components in the sample areas without pre-emergence treatment but with early post-emergence herbicide (treatments 11, 12, 13). The yield components of plots (treatments 5, 6, 7) with pre-emergence and early post-emergence weed control treatments were compared to treatments 11, 12, and 13. The number of plants (2–3%) and the number of shoots (1–2%) in the sample areas with pre-emergence treatment and without pre-emergence treatment did not differ largely. On the other hand, the pendimethalin treatments increased the number of ears (3–6%), the number of spikelets (5–7%), the number of grains (9–10%), and the total grain weight (2–7%) in the associated winter wheat (Figure 4).

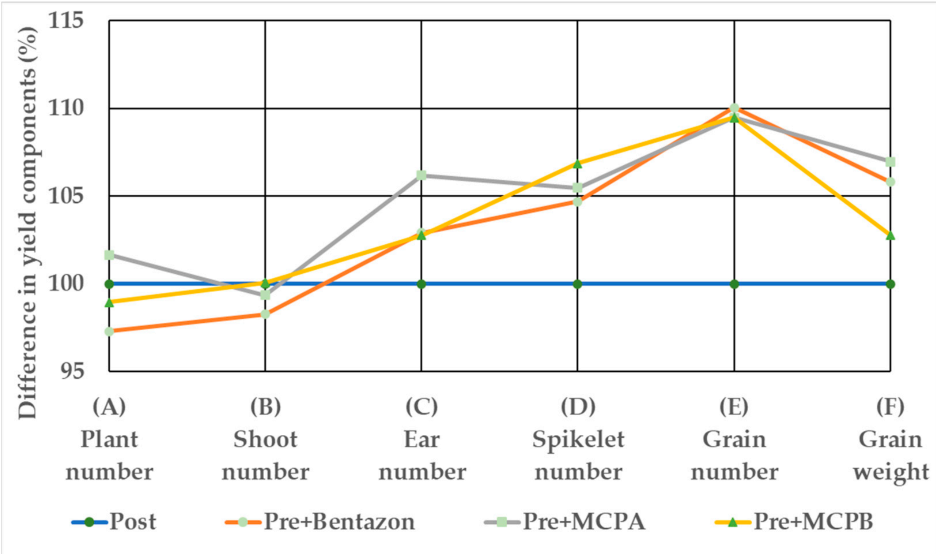

Figure 4. The effect of pre-emergence treatments on the development of winter wheat (*Triticum aestivum* L.) in post-emergence treatments at tillering, over an average of 2 years.

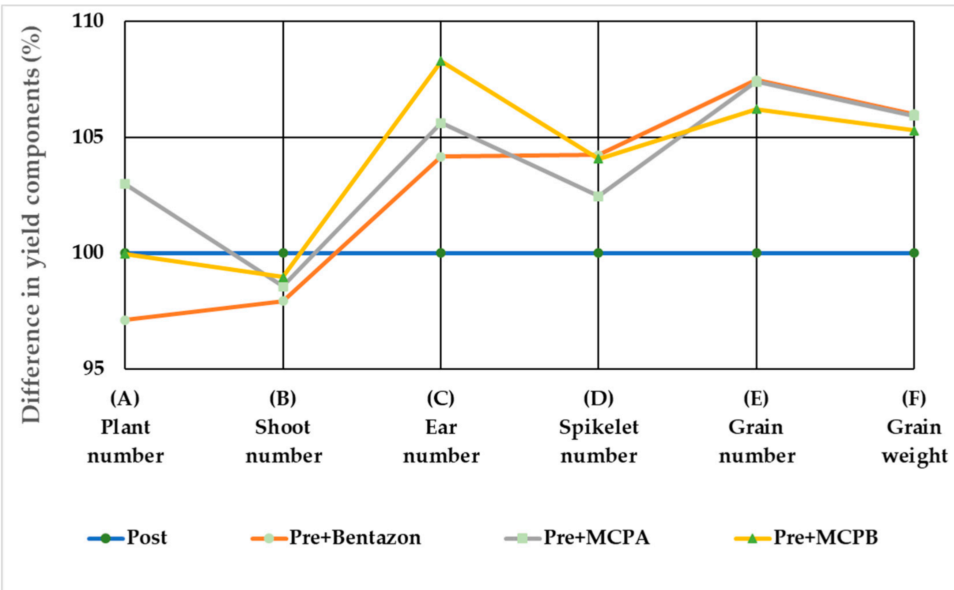

Figure 5. The effect of pre-emergence treatments on the development of winter wheat (*Triticum aestivum* L.) in post-emergence treatments at stem elongation, over an average of 2 years.

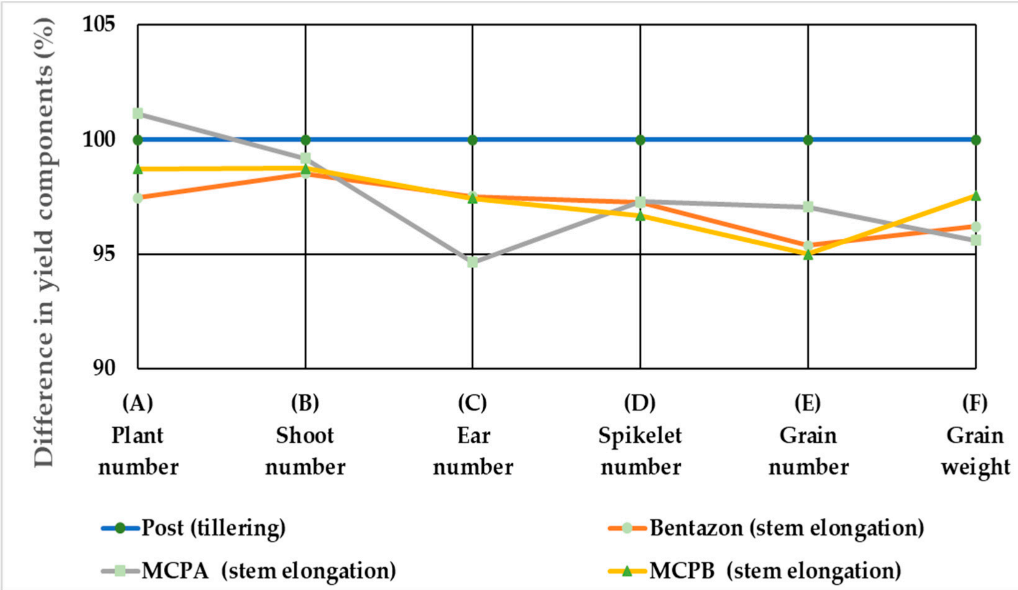

Figure 6. The effect of the timing of post-emergence treatments applied after pre-emergence treatments for the development of winter wheat (*Triticum aestivum* L.), over an average of 2 years.

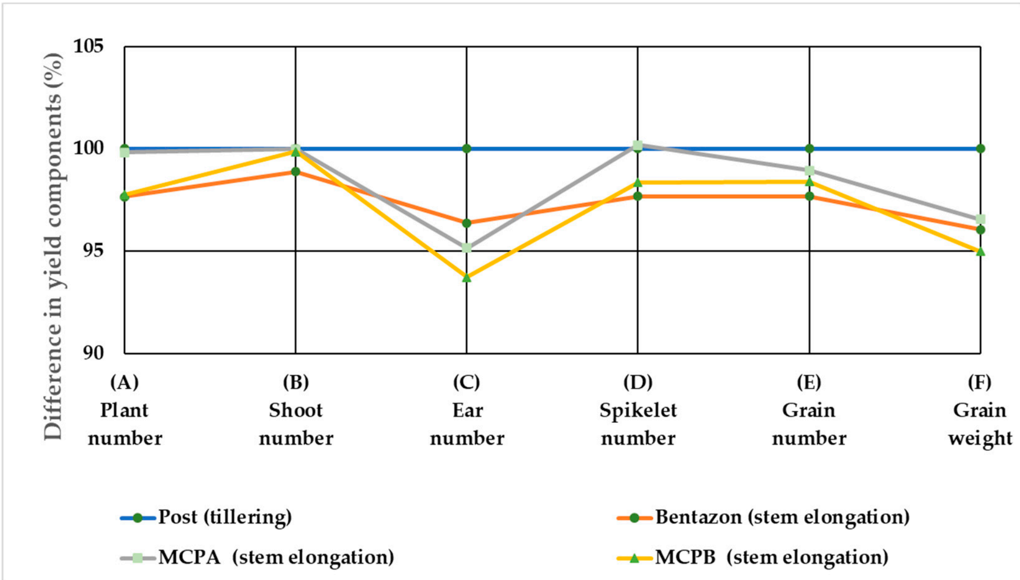

Figure 7. The effect of the timing of post-emergence weed management without pre-emergence treatment on the development of winter wheat (*Triticum aestivum* L.), over an average of 2 years.

The development lines of the associated winter wheat in the case of late post-emergence treatment can be seen in Figure 5. The 100% levels are represented by the yield components where late post-emergence treatments were applied (treatments 14, 15, 16) without pre-emergence treatments. Comparing these values to the yield components of pre-emergence and late post-emergence treatments (treatments 8, 9, 10), pendimethalin resulted in only a 3% difference in the number of plants, and a 1–2% difference in the number of shoots, which are both statistically insignificant. However, the use of pendimethalin increased the number of ears (4–8%), the number of spikelets (2–4%), the number of grains (6–7%), and the total grain weight/m^2 (6–5%) compared to treatments without pre-emergence herbicides (Figure 5).

The effect of the timing of post-emergence treatments on the development of winter wheat after the pre-emergence treatments can be observed in Figure 6. The 100% level is derived from the yield components that had no pre-emergence and early post-emergence (tillering) treatments (treatments 5, 6, 7). These values were compared to the final phase products of those parcels that were treated with pre-emergence and late post-emergence herbicides at stem elongation (treatments 8, 9, 10). The delay in post-emergence treatment decreased the number of plants and shoots (only 1–2%), the number of ears (2–5%), the number of spikelets (3%), the number of grains (3–5%), and the total grain weight (6–8%) (Figure 6).

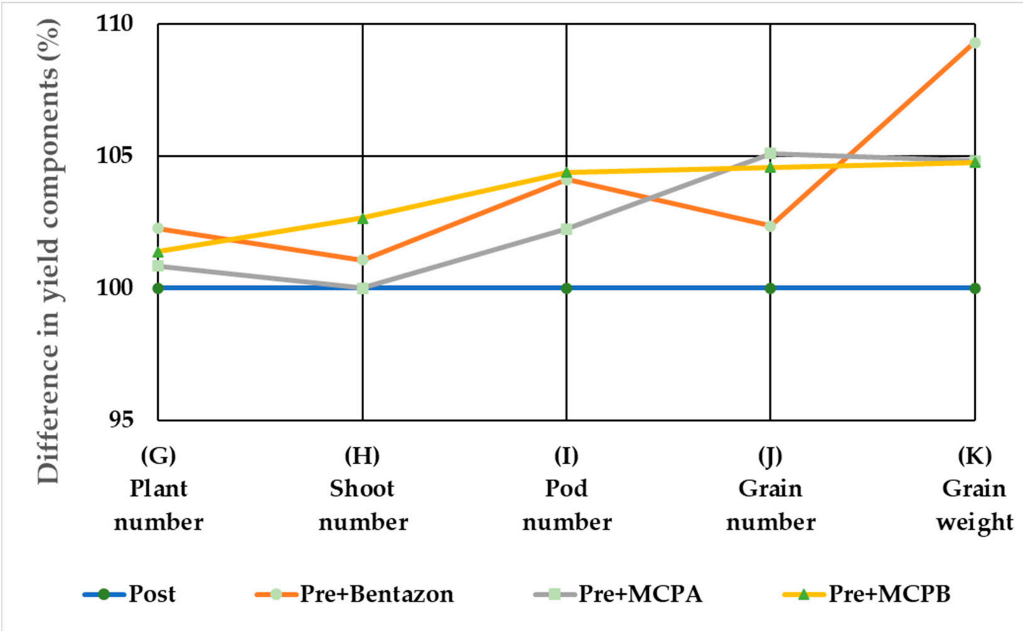

Figure 8. The effect of pre-emergence treatments on the development of winter pea (*Pisum sativum* L.) in post-emergence weed management at tillering, over an average of 2 years.

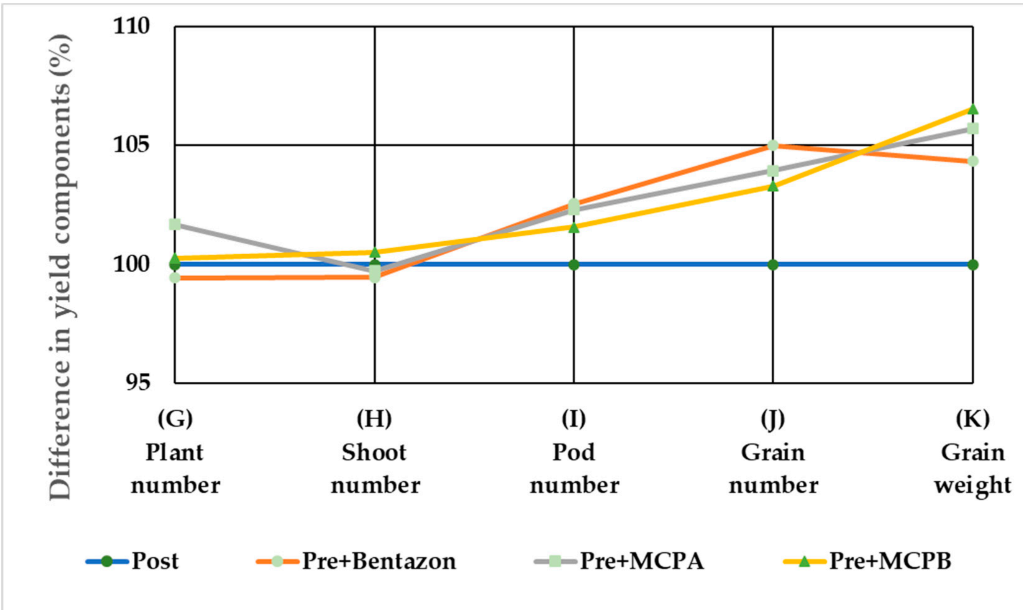

Figure 9. The effect of pre-emergence treatments on the development of winter pea (*Pisum sativum* L.) in post-emergence weed management at stem elongation, over an average of 2 years.

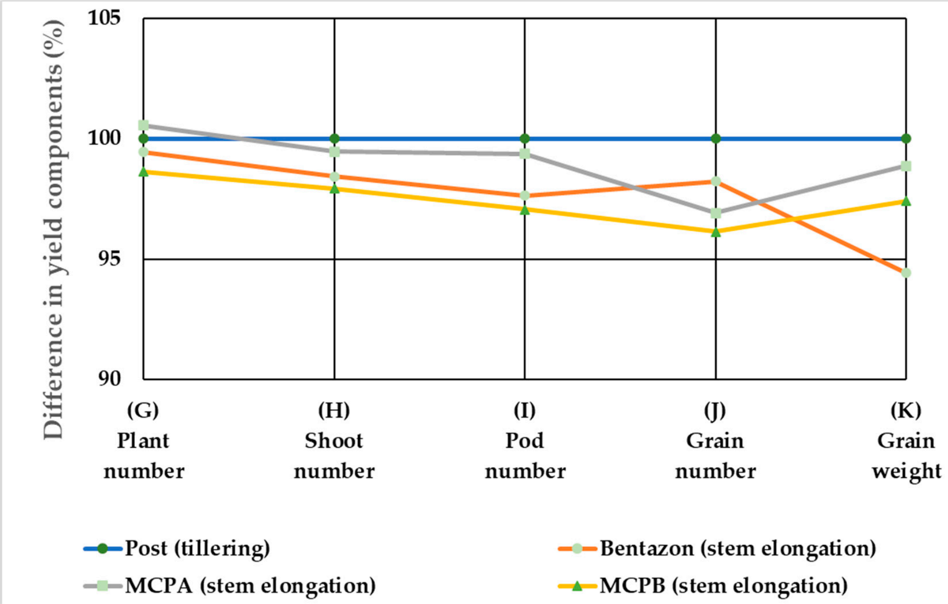

Figure 10. The effect of the timing of post-emergence treatments applied after pre-emergence treatment on the development of winter pea (*Pisum sativum* L.), over an average of 2 years.

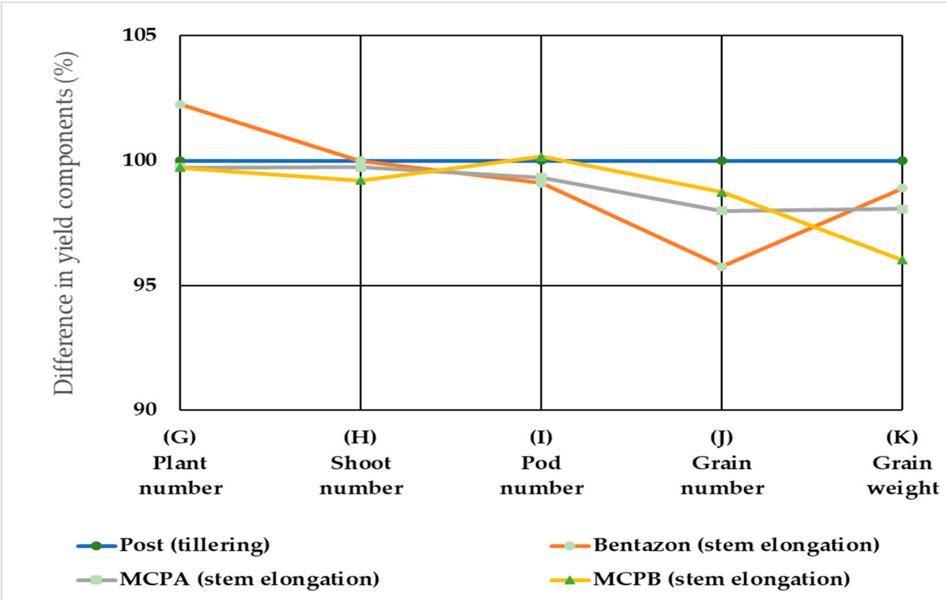

Figure 11. The effect of the timing of post-emergence treatments without pre-emergence treatment on the development of associated winter pea (*Pisum sativum* L.), over an average of 2 years.

In Figure 7, the effect of the timing of post-emergence treatment on the development of associated winter wheat without pre-emergence weed control is introduced. In this case, the 100% level means the values of the final phase products of post-emergence treated sample areas at the time of tillering (treatments 11, 12, 13). These values were compared with the yield components of the post-emergence treatment at stem elongation (treatments 14, 15, 16). If the post-emergence treatment was delayed, then a significant decrease was measured in the number of ears (4–5%) and the total grain weight (4–5%) (Figure 7).

Figure 8 shows the effect of pendimethalin on the development of winter peas. The levels of the yield components were considered to be 100% in plots where early post-emergence weed management without pre-emergence treatment was applied (treatments 11, 12, 13). These values to the yield components of the plots were compared (treatments

5, 6, 7) where pre-emergence and early post-emergence weed control were applied. The pre-emergence treatment increased the number of plants (1–2%), the number of shoots (0–3%), the number of pods (2–4%), the number of grains (2–5%), and the total grain weight (5–9%) (Figure 8).

Figure 9 illustrates the development lines of the associated winter pea parcels where late post-emergence treatment was applied in order to test the effect of pre-emergence treatment. The levels of the yield components were considered to be 100% in plots that received late post-emergence treatments without pre-emergence treatments (treatments 14, 15, 16). The former values were compared to the parcels that received pre-emergence and late post-emergence active ingredients (treatments 8, 9, 10). Pendimethalin caused a small difference in the number of plants and shoots. In addition, the pre-emergence active ingredient increased the number of pods (2–3%), the number of grains (3–5%), and the total grain weight (4–7%) (Figure 9).

In Figure 10, the effect of the timing of post-emergence treatments on final phase products of the winter pea can be seen, where the yield components of the pre-emergence and early post-emergence treatments (5, 6, 7) represent the level of 100%. The yield components of the pre-emergence and late post-emergence treatments (8, 9, 10) were compared to the previously mentioned treatments. It can be observed that if the post-emergence weed control is delayed, there is a decrease in the number of plants (0–1%), the number of shoots (1–2%), the number of pods (1–3%), the number of grains (2–4%), and the total grain weight (1–6%) (Figure 10).

The timing of post-emergence weed management had an effect on the development of the associated winter pea even without pre-emergence treatments. It can be seen in Figure 11, where the 100% value is determined by the yield components of post-emergence treatments at tillering (treatment 11,12,13). Compared with post-emergence treatments at stem elongation (treatments 14, 15, 16), it can be observed that the delay of the post-emergence treatment caused a significant decrease in the number of grains and the total grain weight by 1–4% (Figure 11).

3.5. Total Yield in Different Treatments

According to Figure 12, the yields of pure winter wheat and pure winter pea are much higher than the wheat or pea yields of the associated plots. However, the total yield of the associated plots almost reached the yield of pure wheat without weed control. The total yield of the wheat–pea plant association parcels treated via pre-emergence (pendimethalin) weed management with early (bentazon, MCPA, MCPB) and late (MCPB) post-emergence weed control exceeded the yield of pure wheat where there was no herbicide use (treatments 5, 6, 7, 9). It can be observed that the total yield of plant association plots with no herbicide treatments (treatment 3) was lower than the total yield of treatments 4–16 (Figure 12).

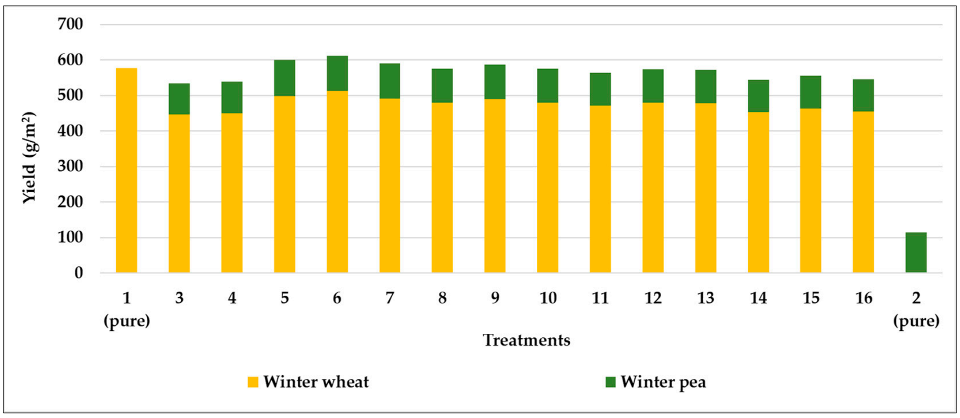

Figure 12. The total yield of winter wheat (*Triticum aestivum* L.) and winter pea (*Pisum sativum* L.) in different treatments.

4. Discussion

In Hungary, the sowing structure is dominated by cereals that limit the expansion of livestock due to their lack of protein and their uneconomical production. On one hand, the world market price of cereals determines the profitability of production, which causes a high degree of economic exposure not only for producers, but also for the country. On the other hand, monocrop production practices in farming can cause problems regarding nutrient supply, plant protection, and tillage in the long term. It is imperative from an economic, agronomic, and ecological point of view to diversify the current sowing structure gradually, increasing the sowing areas for protein plants, and applying diversified crop rotation.

The challenge is to improve the sowing structure and increase the land area of protein plants, while the content and quantitative values of cereals remain consistently high. Accordingly, plant association became the focus of attention in many countries, while it was forgotten in Hungary since the 1950s. The plant association of winter wheat and pea seems obvious since their sowing and harvesting times and mechanization requirements are similar. However, intercropping raises several issues (seed quantity, soil preparation, yield quantity); this examination deals with ceonology and weed control of the association of winter wheat and pea.

Based on the weed cover examination, it can be stated that in pure stands of winter wheat and pea, we found the same weed species (Ivy-leaved speedwell, Common chickweed, Shepherd's purse, Cleavers, Common poppy, Forking larkspur, Schleicher's fumitory, Wild radish, Charlock, Black bindweed, Common ragweed, Annual yellow woundwort, Fat hen, Johnsongrass, and Field bindweed. In contrast, Johnsongrass was not detected in the association of winter wheat and peas in any studied year. Pure pea plots without weed control were weedier to a greater extent than pure wheat without weed control. Our results strengthen the conclusions of other researchers [43,44], that special attention must be paid to weed control in pea cultivation. In the experimental plots of pure wheat with the sowing density of 300 seed/m^2 and pure pea with the sowing density of 60 seed/m^2, many more weed species were present, and with greater weed cover, than in the combination of winter wheat and pea. Our findings are similar to the results of other researchers [26,39], that plant association is very competitive against weeds. In our experiments, we increased the sowing density of the companion plants in the mixture compared to pure stands, similar to other trials where the appearance of weeds was also controlled by the increased sowing density in pure stands [41,45,46].

In a plant association, competition occurs between the cultivated plants for soil moisture, nutrients, space, and light. In our experiments, we found that the number of shoots, number of ears, number of spikelets, number of grains, and grain weight in a given area (m^2) of associated wheat significantly decreased compared to pure wheat. At the same time, the associated winter pea had significantly lower numbers of plants, shoots, pods, grains, and grain weight compared to the pure pea without weed control.

It was observed that meteorological events of the growing season have a remarkable impact on the development of the associated plants, and thus their yield components. For the associated winter wheat, the weather of the year 2019–2020 was more favorable; it reached a higher number of plants, shoots, ears, spikelets, grains, and grain weight compared to the first growing season. It was the opposite for peas; in the first year of the study, significantly higher numbers of plants, shoots, pods, grains, and grain weight in 1 m^2 were determined, compared to the year 2019–2020. In the growing season of 2018–2019, April, May, and June showed higher precipitation than the same period, approximately, of the following year. The rainy spring and rainy early summer helped the vegetative and generative development of winter pea and the growth of its yield components. Accordingly, it can be stated that one year favors one companion plant, another year the other, while growing season affects the expansion and dominance of the participating species of the plant association. Therefore, the total yield of the plant association is more balanced when more species are grown in the area.

In this way, plant associations can provide security for the producers. In order to achieve yield stability, plant associations are expected to play an increasingly important role in extreme-weather years because of climate change.

For effective weed control and economic plant production, it seems necessary to develop a chemical weed control protocol within integrated weed management in the case of winter wheat and pea association. Herbicide selection can cause problems when two different species are combined in a plant association [51]. In our experiment, we mixed the monocotyledonous winter wheat with a dicotyledonous leguminous winter pea; thus, the reaction of the cultivated plants to the active ingredients used for the companion plant was not predictable. During our investigations, the effects of the active ingredients of pendimethalin, bentazon, MCPA, and MCPB in winter wheat and pea intercrops was examined. The pre-emergence pendimethalin treatment did not cause phytotoxicity either in associated wheat or pea; its use increased the number of ears, spikelets, grains, and grain weight in a given area (m^2) in the case of winter wheat. Our research results support the opinion of other authors [57,58], that pendimethalin does not cause damage in peas; moreover, the number of pods, grains, and grain weight in a given area (m^2) also increased compared to the untreated plots. The effectiveness of pendimethalin against weeds is significantly influenced by the precipitation of each year; in the second growing season, the rainfall after sowing improved the efficacy of pendimethalin.

In plant associations, both early and late application of bentazon increased the number of ears, spikelets, grains, and grain weight in a given area (m^2) of winter wheat. Bentazon increased the number of pods, grains, and grain weight in $1/m^2$ in the case of winter pea compared to the zero weed control plots, which strongly reflects the results of other researchers [59,60]. However, it can be stated that delayed use of bentazon was less effective, thus the number of yield components that determined yield decreased. In contrast, the success of weed control in peas may depend more on the choice of herbicide than on the timing of weed control application [59].

In our study, MCPA did not cause phytotoxicity either in winter wheat or in winter pea. Compared to the zero weed control plots, the number of ears, spikelets, grains, and grain weight in a given area (m^2) of winter wheat, as well as the number of pods, grains, and grain weight of winter peas in 1 m^2, increased. MCPA should also be applied at the beginning of the development of the weeds, because the late post-emergence application was less effective than early post-emergence spraying.

In our investigation, MCPB did not cause phytotoxicity either in winter wheat or in winter pea. Compared to the plots, where there was no weed control, the number of grains and grain weight in a given area (m^2) in the case of winter wheat, and the number of pods, grains, and grain weight in a given area (m^2) in the case of peas, increased.

However, the active ingredients that were applied in the experiment were not efficient enough against Field bindweed. No other suitable agent is available in terms of the currently approved herbicides, the applied solution was the correct choice for the area. In this case, producers must know their land, and its weed flora, in order to decide on the establishment of a plant association with related weed control.

Our research investigation proves that the advantage of the plant association is not limited to the suppression of weeds, as the harvested yield from the mixed parcels was also remarkable in the two experimental years. Pure wheat with zero weed control produced only 7% more yield than the yield of winter wheat and pea association without weed control. Moreover, the experiment also shows that depending on the choice of the active ingredient of herbicide, a yield surplus of 1–14% can be achieved in winter wheat–pea association compared to the parcels with zero weed control. Environmentally friendly solutions may present challenges (reduced yield), but they should definitely be considered in order to achieve long-term goals, such as the incorporation of leguminous plants into the crop rotation or the stabilization of the income of farmers.

5. Conclusions

Sustainable cultivation methods that mitigate the negative effects of climate change are becoming more widespread in agriculture. Intercropping provides an environmentally friendly method of cultivation for farmers that reduces overdependence on artificial fertilizers and increases crop security and diversification. However, farmers are faced with weed control problems when using plant associations. With our study, we aimed to contribute towards a solution. Based on our research results, we can state the following:

- The high weed suppression ability is one of the beneficial properties of plant associations. Lower weed cover was observed and the number of weed species was lower in the associated winter wheat–winter pea parcels compared to pure stands.
- The herbicide selection is considered challenging when two different species are combined in a plant association due to probable phytotoxicity and effectiveness. Nevertheless, the active ingredients—pendimethalin, bentazon, MCPA, and MCPB—Did not cause visually detectable crop damage in associated wheat and pea, but resulted in better yield component values compared to unweeded stands. The main reason for this is that weeds did not compete for available resources (light, water, and nutrients) with cultivated plants; thus, after successful weed control, the development of the yield components was not impeded.
- The effectiveness of weed control in plant association depends not only on the selection of the active ingredient, but also on the application time. Accordingly, pre-emergence and early post-emergence treatments, or pre-emergence and late post-emergence treatments, proved to be more effective than a single early or late herbicide application. Pre-emergence treatment in drought years has "bad" and "extremely weak" weed control effects, which can be improved by rainfall or irrigation after the application.
- Due to the high plant density in intercropping, the yield and yield components of the companion plants decreased, but the total yield in a given area (m^2) was higher than in pure stands of the companion plants.
- The development of the associated plants, and thus the value of their yield components, largely depends on the growing season. Weather conditions influence the expansion and dominance of the participating species in intercropping. One year favors one companion plant, while another year favors the other companion plant. Thus, the application of plant association in crop rotation can provide yield stability for farmers, as total yield is more balanced.

The results of our two-year investigation encourage us to find the answers to further questions, based on which we intend to broaden our research. In the future, we plan to include more pea varieties in our experiments so that we can determine active ingredient sensitivity on a variety-specific basis. In addition, we aim to reveal the connection between active ingredient sensitivity and environmental conditions (soil quality, temperature, daily time of application) relative to plant association weed control.

Author Contributions: Conceptualization, I.K. and A.U.; methodology, I.K.; software, I.K.; validation, I.K., M.V.-N. and A.R.; formal analysis, A.R.; investigation, I.K.; resources, M.V.-N.; data curation, I.K.; writing—original draft preparation, I.K., M.V.-N., M.T., K.I., L.S. and A.R.; writing—review and editing, A.U., I.K., M.V.-N., M.T., K.I., L.S. and A.R.; visualization, A.R. and I.K.; supervision, A.U.; project administration, A.U.; funding acquisition, M.T. and A.U. All authors have read and agreed to the published version of the manuscript.

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