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Original Research

Pea and Spring Cereal Intercropping Systems: Advantages and Suppression of Broad-Leaved Weeds

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Abstract

Our experiments were designed to investigate yield formation of intercrops and their influence on broadleaved weeds under organic cropping conditions. Pea (*Pisum sativum* L. (Partim) and spring wheat (*Triticum aestivum* L. emend. Fiori et Paol.), spring barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.), and spring triticale (× *Triticosecale* Wittm.) were sown as intercrops (50:50 – a relative proportion of grain legume and spring cereal seeds) or as a sole crop. The results suggest that pea/wheat, pea/oat, and pea/triticale intercrops were superior to sole pea crop. However, intercrops and sole cereal crops exhibited similar weed suppression capabilities. According to the reduction of weed number and mass, the intercrops were ranked in the following order: pea/oat > pea/wheat; pea/triticale > pea/barley. Crop density significantly influenced the reduction of total weed numbers and air-dried mass. In crops with lower plant density, weed suppression depended on crop height.

Keywords: pea, cereal, intercropping, plant density and productivity indicators, weed suppression

Introduction

Agrophytocenosis is described as a community of agricultural crops and weeds characterized by interspecific and intra-species relationships, competition for light, soil nutrients, and moisture [1]. Human-controlled plant communities focused on agricultural crops, and technological tools to enhance their competitive ability and productivity [2]. Most weeds are destroyed by herbicides. Therefore, weed communities are constantly changing. Only the most persistent species survive and some of them develop herbicide resistance [3]. Weed control is a costly agronomic practice.

Weed management is a key issue in an organic farming system [4, 5], where weeds are controlled by direct destruction (manual or mechanical), preventive measures (appropriate crop rotation, soil tillage, and crop management) and by enhancing crop tolerance of weeds (choice of genotypes, sowing method, fertilization strategy) [4, 6]. Mechanical weed control, the major alternative to herbicide application, has some negative environmental impacts due to energy consumption and additional traffic on fields. There is a great need to develop alternative methods for weed management [5, 7]. More attention should be paid to the development of cropping systems in which crops themselves are better able to compete with weeds [8]. Crop diversification helps to stabilize in particular agricultural crops and weed

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Table 1. Main characteristics of the experimental soil to 0-25 cm depth.

Site	Dotnuva	Joniskelis
	Institute of Agriculture	Joniskelis Experimental Station
Location	55º24′ N, 23º51′ E	56º12′ N, 24º20′ E
Soil group	*Endocalcari-Epihypogleyic Cambisol (CMg-p-w-can)*	*Endocalcari-Endohypogleyic Cambisol (CMg-n-w-can)*
Soil surface texture	loam	clay loam
Texture composition (soil particles %)	19.3% clay, 28.9 % silt, 51.8 sand %	28.5% clay, 50.9% silt, 18.8% sand
Humus (%)	2.3	2.2
pH	7.5	6.4
N_{total} (g·kg^{-1} soil)	1.51-1.61	1.25-1.33
Available P_2O_5 (mg·kg^{-1} soil)	74-79	140-150
Available K_2O (mg·kg^{-1} soil)	135-140	205-225
Bulk density (mg·m^{-3})	1.4	1.5
Total porosity (%)	43-49	41-43

communities, and this changes the composition of the weed community, regulating their number [9]. Agricultural crops with different growth cycles (winter or spring crops) and agronomic requirements provide unfavourable conditions for weed growth. This prevents weed spread, germination, growth, and seed ripening [10, 11]. An important role is assigned to searching for alternative crop production technologies: catch crops, intercrops, bi-cropping [6, 12, 13], and crop potential usage for suppressing and tolerating weeds [10, 14].

Growing two or more crops together (intercropping) is a common practice in developing agricultural systems [5, 13, 15]. Cereal and legume intercropping is commonly practiced in many countries around the world [15, 17]. Intercropping demonstrates yield advantage in different climate environments, confirming the suitability of cereal and legume intercropping in North and Central Europe [18]. Its potential mechanisms and effects consist of competition (niche differentiation, resource use sharing, and weed control), diversity (pest and disease control), facilitation (physical support, excretion of N and allellochemicals) and associated diversity (habitats for natural predators, litter diversity enhancing soil microbial diversity) [17].

Agronomic studies into intercropping system may demonstrate weed control advantages over sole crops. Intercrops may be more effective than sole crops by occupying resources from weeds and suppressing weed growth. Strategies to improve weed management are still among the top research priorities, especially for low input farming and a future vision for the discipline should be directed to weed biology and an integrated approach to weed management [19, 20]. Therefore, before implementing specific intercropping systems, the following should be considered: spatial arrangement [16]; plant density [21, 22]; maturity dates of the crops being grown [15]; and plant architecture [23].

The aim of this study was to determine yield formation regularities of different cereal growth intercropped with pea, and their effect on the suppression of annual weeds under organic cropping conditions.

Materials and Methods

Site and Soil Description and Experimental Design

The experiments were carried out in four subsequent years during 2007-10 at the Institute of Agriculture (Dotnuva) and the Joniskelis Experimental Station (Joniskelis) of the Lithuanian Research Centre for Agriculture and Forestry. The site and soil characteristics are provided in Table 1. Two field experiments with 9 sowing treatments per site were established according to the same design. The experimental plots were laid out in a complete one-factor randomized block design. Wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.), and triticale (x *Triticosecale* Wittm.) were grown as sole crops and intercrops with field pea (*Pisum sativum* L.). The following crop cultivars were used: field pea (cv. Pinochio) – medium early (83 days), semi-leafless of medium height and productivity; spring wheat (cv. SW Estrad) – medium early (95 days) of medium height and productivity; spring barley (cv. Aura DS) – medium late (90 days) of medium height, productive; oat (cv. Migla) – medium early (94 days), tall, medium productivity; and spring triticale (cv. Nilex) – medium early (103 days), tall and productive.

The intercrop design was based on the proportional replacement principle, with mixed pea grain and spring cereal grains at the same depth in the same rows at relative

Table 2. Air temperature and rainfall at the experimental sites during the growing season.

Month	Air temperature (ºC)					Rainfall (mm)				
	2007	2008	2009	2010	Mean*	2007	2008	2009	2010	Mean*
Dotnuva										
April	6.9	8.8	8.8	7.3	6.0	15.8	38.7	13.1	44.2	37.0
May	13.5	12.2	12.7	13.7	12.3	98.2	13.2	26.7	94.2	52.3
June	17.6	16.1	14.6	16.2	15.6	61.5	49.2	168.6	72.4	62.5
July	17.2	18.2	18.1	21.7	17.7	118.1	47.6	90.0	142.0	74.2
August	18.7	18.0	16.8	19.8	16.7	50.8	90.8	67.1	71.1	73.7
Joniskelis										
April	6.2	7.3	8.4	6.8	6.2	12.8	54.6	18.2	23.2	37.4
May	13.5	10.8	12.9	13.6	12.3	49.0	12.9	17.2	69.3	45.6
June	17.1	14.8	14.4	15.6	15.6	67.7	36.2	80.9	54.4	59.4
July	17.4	17.3	18.1	22.1	17.2	107.0	66.1	107.6	74.4	69.2
August	19.2	17.4	16.2	19.8	17.1	56.8	116.5	49.8	57.6	67.9

*long-term mean based on climate data from 1924-2010

frequencies of half of the sole crop densities of each species (0.50:0.50). Actual plant densities were 120 field pea, 500 spring wheat, 450 spring barley, 500 oats, and 450 triticale plants m^{-2} in the sole cropping plots. The following crop sequence was used during the research period: intercrops and sole crops (according to experimental design), spring wheat, intercrops and sole crops (according to experimental design), winter wheat. The crops were cultivated according to organic management practices.

Weather Description

Dotnuva

In April-May 2007, the air temperature practically did not differ from the long-term mean. In May, the amount of rainfall was sufficient for plant growth (Table 2). June was slightly warmer, with heavy rainfall occurring at the end of the month. Rainy weather prevailed in July. Normally warm and humid weather dominated at the beginning of August. In April 2008 the weather was optimally wet. May was cool, windy, and dry, and reserves of productive moisture were reduced and conditions were close to critical for crop growth. In June, warm and very dry weather conditions persisted. After a prolonged dry period, the rainfall was very beneficial to plants. Warm and rainy weather prevailed in August, when rainy weather conditions delayed harvesting. Warm, sunny, and dry weather dominated during April 2009. Moisture shortage for spring cereals was felt already in the second half of May. June was cool and rainy. Rainfall amount was 2.7-fold higher than the norm during the month. Rainy weather conditions continued in July. In May-July 2010 the air temperature was 2ºC higher compared to the long-term mean; the amount of rainfall was about 60% higher than the long-term mean. In spring, moisture conditions delayed sowing. The germination and growing period was adverse for spring crops, because of which the experiment was rejected that year.

Joniskelis

In 2007 the daily air temperature in April and May differed little from the long-term mean. Heavier rainfall occurred only in May. The growing period of the main crops (May-July 2007) was slightly warmer (+1.0ºC) compared with the long-term mean. The amount of rainfall in July exceeded the long-term mean by 37.8 mm. In 2008 the weather conditions stood out even more markedly by wet spring and dry first half of the summer and excessively wet end of summer compared with the long-term data. Abundant precipitation in March and especially April delayed spring cereal sowing. May and June, a period of intensive plant growth, were cooler and drier. In July there was enough rainfall, and in August the amount of rainfall exceeded the long-term mean by 48.6 mm.

In 2009, April and May were drier, the amount of rainfall was by 19.2 and 29.3 mm lower and the weather was negligibly warmer compared with the long-term mean. High rainfall amounts in June and July (80.9 and 107.6 mm, respectively) partly offset the shortage of moisture. In 2010 during the growing season the weather conditions were close to normal, except for plant emergence period. Abundant amounts of rainfall in May (by 23.7 mm higher compared with the long-term mean) and recurring torrential rain aggravated plant emergence. The second half of summer was warm and wet.

Plant Analyses

The productive stems density was determined in the area of 0.25 m^2 in 4 places per plot before harvesting. At the same time, the height of 20 plants per plot was measured from the soil surface to the top of ear (or panicle) of cereal main stem, and of pea to the highest leaf on the main stem. Pre-harvest crop samples were uprooted from small plots of 0.25 m^2 in 2 places per plot. The aboveground biomass of intercrops was fractionated into species (cereals and peas) and weighed separately and presented as dry matter weight. Ten representative cereal stems and pea plants from each pre-harvest crop sample were threshed and grains were counted.

The crops were harvested at complete maturity stage. One kg grain samples were taken from each plot for the determination of dry matter, chemical composition, and 1,000-grain weight. The grain samples of intercrops were divided into fractions: cereals and pea. Nitrogen in cereal and pea grain was determined by Kjeldahl, phosphorus by spectrophotometric methods, and potassium by flame photometry.

Weed incidence in sole crops and intercrops was assessed twice during the growing period: number of weeds and species during cereal stem elongation stage (BBCH 32-34) and during grain filling stage (BBCH 73) of cereals, while the biomass of air-dry matter only during the grain filling stage. After separation into species, the weed fresh mass was weighed and dried in natural conditions and presented as air-dry mass. The air-dry mass, number, and species of weeds were determined in an area of 0.25 m^2 in 4 places per plot at cereal stem elongation (BBCH 32-34) and grain filling (BBCH 73) stages.

For the evaluation of statistically significant differences, the data of the number and air-dry mass of weeds were transformed according to the formula: Sqr(x+1). The experimental data were processed by Anova and Stat Eng [24] and evaluated according to Fisher criteria (F) and least significant differences (LSD_{05}). The LSD_{05} of crop productivity parameters (height, number of grain per plant (stem), 1000 grain weight) and nutrient (NPK) concentration in grain were estimated separately for pea and cereals and for intercrops.

Results

Regularities of Intercrop Formation

After germination in spring, pea sole crops and pea/cereal intercrops were observed in a lower density due to their higher nutrient area needed. Crop density was related to the number of seeds sown. In Dotnuva (in loamy soil), pea accounted for 27.2 and 29.7% of barley and wheat intercrop, respectively (data not shown). The greater part of pea was observed in intercrop with oat and triticale (35.2 and 34.7%, respectively). In Joniskelis (in clay loam soil), the number of pea plants varied from 20.3 to 24.6% in intercrops, (except for pea intercropped with triticale – 34.7%).

At cereal grain filling stage (BBCH 73), the productive stem number of cereals was higher than that of peas due to the ability of cereals to tiller, and pea stems density was impossible to increase by agrocultural implements [25]. Crop density of intercrops was lower compared to sole cereals. Pea density in the crop structure was similar: 12.0-18.4% (40-58 stems per m^2) in loamy soil, and 10.2-20.4% (28-43 stems per m^2) in clay loam soil (Table 3).

Comparison between the different intercrops showed that the highest stem density was in pea intercropped with spring wheat (346 stems per m^2), with barley (332 steams per m^2) in a loamy soil (Dotnuva), peas with oats (275 steams per m^2), and with wheat (268 steams per m^2) in a clay loam soil (Joniskelis). The more stable total densities of sole crops and intercrops were obtained in a loamy soil (Dotnuva) compared to a clay loam soil (Joniskelis). In Dotnuva, the growing conditions were more favourable for pea germination and establishment, at Joniskelis site it was for cereals. In different soils, the seed rate and growing conditions influenced optimal plant density and created the basis for competition between the components (pea, cereals, and weeds) during crop germination period. Hauggaard-Nielsen et al. (2008) have indicated that a relative proportion of pea intercrop around 40-50% is needed in order to achieve a level of intraspecific competition [17]. The height of cereals was predominantly dependent on plant morphological characteristics and ranked as follows: oat > triticale > wheat > barley > pea.

The height of pea in intercrops significantly decreased by 5.4-12.4 cm in a clay loam soil and in a loamy soil by 11.4-14.0 cm. Intercrops of oats, in some cases barely and triticale, were taller than sole crops.

Crop Productivity

The biggest complementary effects and thus biggest yield advantages are seen to occur when the component crops markedly differ morphologically, phenologically, or physiologically [13] and have different growing periods, thereby making their major demands on resources at different times [23].

The intercrops were dominated by cereals (Table 3). With a substantial reduction of grain number per intercropped pea (9-15 grains in Joniskelis and 6-8 grains in Dotnuva) the number of cereal grains per ear increased by up to 14 grains. At both experimental sites, the grain number in intercropped oat panicle was significantly higher compared to a sole oat crop; however, the grain number per barly ear was significantly lower irrespective of the growing method. The 1,000-grain weight was inversely proportional to the number of grains per ear, panicle, and pea stem. In a loamy soil (Dotnuva), the 1,000-grain weight of pea varied little except for the intercrop with oats. However, in a clay loam soil (Joniskelis), the 1,000-grain weight of pea was significantly lower when intercropped with barley and triticale. The 1,000-grain weight of intercropped cereals increased (except for oats in Dotnuva) compared to cereal sole crops. The highest

Table 3. Plant density and productivity parameters of intercrops and sole crops.

Cropping strategy	Crop component	Productive stems per m^2		Crop height cm		Number of grains per plant (stem)		1,000-grain weight g	
		Dotnuva	Joniskelis	Dotnuva	Joniskelis	Dotnuva	Joniskelis	Dotnuva	Joniskelis
Ps	pea	109	81	56.7	49.2	16	20	230.5	246.5
P+SWi	pea	48	34	42.9	36.9	9	6	219.2	233.9
	cereal	298	235	70.5	72.4	40	36	36.1	38.4
	total/average*	346	268	66.5	67.9	36	32	71.9	85.4
P+SBi	pea	40	37	43.6	38.2	8	8	217.8	217.3
	cereal	292	195	54.7	58.7	22	23	48.1	47.4
	total/average*	332	231	53.6	55.5	20	21	87.3	86.8
P+Oi	pea	58	28	42.7	39.7	8	5	203.3	201.5
	cereal	258	247	82.5	89.4	52	52	32.2	36.1
	total/average*	316	275	75.1	84.4	44	48	61.6	53.9
P+STi	pea	48	43	45.3	43.8	10	11	222.9	221.5
	cereal	238	168	80.9	79.6	46	37	39.3	42.4
	total/average*	286	211	74.8	72.2	40	31	73.4	112.3
SWs	cereal	478	355	72.8	74.7	35	34	35.1	36.8
SBs	cereal	398	307	57.8	56.6	22	22	45.9	45.0
Os	cereal	442	343	80.9	84.9	43	38	32.2	32.7
STs	cereal	368	334	79.4	82.8	41	37	37.5	42.1
LSD_{05}	pea	-	-	5.23	4.17	3.9	1.6	14.17	23.06
	cereal	-	-	8.08	6.97	4.6	10.6	5.43	3.89
	total/average*	63.1	52.0	8.03	6.72	4.6	9.9	19.50	17.97

Sole crop: Ps – pea, SWs – spring wheat, SBs – spring barley, Os –oat, STs – spring triticale;
Intercrop: P+SWi – pea and spring wheat, P+SBi – pea and spring barley, P+Oi – pea and oat, P+STi – pea and triticale.
* total productive stems, weighted average – height of crop, number of grain per plant (stem), 1000-grain weight

1,000-grain weight was obtained in intercrops with barley, and the lowest 1,000-grain weight was found in an oat sole crop and intercropped with pea.

The growing methods (sole crop and intercrop) had a significant effect on the aboveground biomass weight of crops (Dotnuva – $p < 0.01$ and Joniskelis – $p < 0.05$) (Table 4).

The productivity of cereals influenced the total aboveground biomass of the majority of the intercrops. In a loamy soil, the aboveground biomass of pea accounted for 16.8-20.2%, in a clay loam soil for 7.4% (pea/oat intercrop), and for 29.6% (pea/triticale intercrop) of the total intercrops' yield. At both experimental sites the dry matter of the aboveground biomass of wheat, oat, and triticale (Dotnuva) intercropped with pea was significantly higher compared with that of a sole pea crop. Intercrops of oat (Joniskelis) and barley (Dotnuva) produced higher aboveground biomass compared with sole oat and barley crops. Other investigated sole cereal crops yielded slightly more compared with intercrops.

NPK Concentrations in Grain

The different competitive conditions of pea did not significantly influence nitrogen (N) concentration in grain; however, N content significantly ($p < 0.01$) varied in cereal grains. The grain N concentration of intercrops was by 0.9-3.0 mg·kg^{-1} (Dotnuva) and 0.8-1.7 mg·kg^{-1} (Joniskelis) higher compared to sole cereal crops. The highest increase in N concentration occurred in wheat, triticale, and oat grain in Dotnuva.

At the Joniskelis site with its more fertile clay loam soil (available P_2O_5 and K_2O 140-150 and 205-225 mg·kg^{-1} soil, respectively), the intercropped pea tended to increase P and K concentrations in grains. On a less productive loam soil (available P_2O_5 and K_2O 74-79 and 135-140 mg·kg^{-1} soil, respectively) at the Dotnuva site, the concentration of P in pea grains was significantly lower in oat intercrop. However, the concentration of K was found significantly lower in pea intercropped with wheat. The growing method (intercropping or sole crop) had a positive significant

Table 4. Aboveground biomass and nutrient concentration in the grain yield of intercrops and sole crops.

Cropping strategy	Crop component	Aboveground biomass DM g·m^{-2}		Nutrient concentration in grain mg·kg^{-1}					
				N		P		K	
		Dotnuva	Joniskelis	Dotnuva	Joniskelis	Dotnuva	Joniskelis	Dotnuva	Joniskelis
Ps	pea	678.1	521.4	37.2	33.6	4.57	4.91	9.4	9.6
P+SWi	pea	163.5	151.2	37.3	34.5	4.31	4.92	8.7	9.6
	cereal	701.3	720.8	22.2	20.0	4.12	4.10	4.3	3.6
	total/average*	864.8	873.1	24.9	23.6	4.16	4.30	5.6	5.1
P+SBi	pea	127.0	117.4	36.9	33.1	4.51	5.23	9.2	9.8
	cereal	486.9	434.2	19.6	18.7	4.35	4.09	4.9	3.7
	total/average*	613.9	551.6	24.2	21.8	4.38	4.31	6.3	4.9
P+Oi	pea	726.6	73.5	37.0	33.3	4.22	4.94	8.8	9.7
	cereal	146.5	913.3	18.5	17.4	3.77	3.80	4.2	3.2
	total/average*	873.1	986.8	22.4	19.1	3.94	3.91	5.3	3.8
P+STi	pea	651.9	222.3	36.9	33.4	4.36	4.93	9.2	9.6
	cereal	164.7	529.3	22.0	23.4	4.05	4.42	4.4	3.8
	total/average*	816.6	751.6	25.3	27.5	4.12	4.64	5.7	6.2
SWs	cereal	911.2	969.5	19.2	18.7	3.96	4.06	4.2	3.8
SBs	cereal	612.6	605.0	17.9	17.7	4.18	4.01	4.7	3.5
Os	cereal	956.2	917.6	17.6	16.6	3.61	3.65	3.8	3.1
STs	cereal	829.6	869.6	19.5	21.7	3.95	4.23	4.3	3.5
LSD_{05}	pea	-	-	2.00	1.31	0.220	0.430	0.66	0.75
	cereal	-	-	0.99	2.64	0.250	0.350	0.47	0.52
	total/average*	102.8	334.88	1.41	3.01	0.220	0.354	0.39	0.79

Sole crop: Ps – pea, SWs – spring wheat, SBs – spring barley, Os – oat, STs – spring triticale;
Intercrop: P+SWi – pea and spring wheat, P+SBi – pea and spring barley, P+Oi – pea and oat, P+STi – pea and triticale.
*total/average – total aboveground biomass, weighted average – nutrient (N, P, K) concentration in grain

($p<0.01$) influence on the P and K concentrations in cereal grains (Dotnuva), while in Joniskelis the only intercropping significantly ($p < 0.01$) influenced the P concentration in grains.

Weed Infestation in Intercrops

Crop species vary in their ability to suppress weeds and to tolerate weed interference [8]. Cereal has a stronger ability for weed suppression than pea [26]. A host of crop characteristics, including leaf angle, leaf area index, canopy duration [27], crop stature [28], maximal relative growth rate [28], allelopathic potential [29], and many other attributes contribute to cultivar effects on weeds.

Weed Number

In the organic cropping system in fully germinated crops, weed density does not significantly differ between sole crops and intercrops (data not shown). Many site-specific soil characteristics such as field history and formation of the seed bank, soil and meteorologic properties [11], and crop growth technologies [2] influence weed germination. The further survival of weeds depends on the crop's ability to suppress weed growth.

At Dotnuva and Joniskelis all investigated crops significantly ($p < 0.01$) reduced total and annual weed number during the cereal grain filling stage (BBCH 73) compared with the sole pea. In intercrops, the total weed number was slightly higher compared with sole cereal crops (Table 5). The strongest weed suppression was determined in the higher plant densities of intercrops and sole crops at Dotnuva. However, the number of weeds was by 26.1-46.3% lower in intercrops compared to pea sole crop. In lower density crop (Joniskelis), the number of weeds in intercrops was by 22.4-31.0% lower except for the oat sole crop and intercropped with pea. The oat stood out by a strong weed suppression ability: the number of weeds was by 72.5% lower in sole crop, and by 63.8% in pea intercropped with oat compared to pea sole crop.

Table 5. The influence of intercrops and sole crops on the variation of weed number and air-dry mass.

Cropping strategy	Weeds	Weeds m^{-2}		Variationl[#] ± weeds m^{-2}		Air-dry mass $g \cdot m^{-2}$	
		Dotnuva	Joniskelis	Dotnuva	Joniskelis	Dotnuva	Joniskelis
Ps	annual	55.9	64.3	-9.4	-1.3	43.6	37.5
	perennial	8.4	7.0	+0.2	+6.2	16.2	3.6
	total	64.3	71.3	-9.2	+4.9	59.8	41.1
P+SWi	annual	39.0**	42.6*	-25.2	-13.9	13.4**	16.0**
	perennial	4.6	8.1	-1.1	+4.1	5.6*	19.6
	total	43.6**	50.7*	-26.3	-9.8	19.0**	35.6
P+SBi	annual	34.1**	46.3	-39.2	-5.1	7.9**	22.4*
	perennial	7.3	7.9	+0.1	+6.1	5.1*	4.8
	total	41.4**	54.2*	-39.1	+1.0	13.0**	27.2
P+Oi	annual	31.0**	21.3**	-38.2	-30.4*	7.3**	5.7**
	perennial	8.1	4.5	-0.2	+0.3	8.0	9.6
	total	39.1**	25.8**	-38.4	-30.1**	15.3**	15.3**
P+STi	annual	41.6**	43.3*	-24.4	-15.3	10.6**	24.4
	perennial	5.9	7.8	+0.2	+2.6	9.1	36.0*
	total	47.5**	51.1*	-24.2	-12.7	19.7**	60.4
SWs	annual	32.5**	41.3*	-36.5*	-7.2	7.1**	8.1**
	perennial	4.8	8.1	0.0	+4.9	3.1**	30.7
	total	37.3**	49.4**	-36.5*	-2.3	10.2**	38.8
SBs	annual	34.2**	48.3	-41.0**	-9.8	4.3**	11.1**
	perennial	5.9	7.0	-0.1	+5.0	5.5*	19.5
	total	40.1**	55.3*	-41.1*	-4.8	9.8**	30.6
Os	annual	29.3**	18.3**	-51.8**	-24.7*	3.4**	2.3**
	perennial	5.2	1.3	+0.4	+0.3	5.8*	1.8
	total	34.5**	19.6**	-51.4*	-24.4*	9.2**	4.1**
STs	annual	40.1**	39.5**	-24.8**	-19.2	6.0**	13.6**
	perennial	7.0	9.7	-1.6	+5.2	6.7*	19.9
	total	47.1**	49.2**	-26.4**	-14.0	12.7**	33.5

[#] Differences between weed numbers during the cereal grain filling stage (BBCH 73) and weed number after complete emergence in spring (BBCH 32–34);
*differences are statistically significant compared to the control at $p<0.05$, **– at $p < 0.01$;
Sole crop: Ps – pea, SWs – spring wheat, SBs – spring barley, Os –oat, STs – spring triticale;
Intercrop: P+SWi – pea and spring wheat, P+SBi – pea and spring barley, P+Oi – pea and oat, P+STi – pea and triticale.

According to the total weed number, annual weeds significantly and similarly decreased at Dotnuva and Joniskelis, except for the barley intercrop and sole crop at Joniskelis. At both experimental sites, the different crops had no significant influence on the variation of perennial weed number. Only at Joniskelis (in clay loam soil) was a marked trend of perennial weed number decreases seen in oat sole crop and intercropped with pea.

Weed Number Variation during the Growing Season

At Dotnuva, the total weed number decreased by 9.2-51.4 weeds m^{-2} during the growing season – from the weed complete emergence (cereal stem elongation stage BBCH 32-34) to the cereal grain filling stage (BBCH 73) (Table 5). An essential decrease (26.4-51.4 weeds m^{-2}) in annual and total weed number was observed in cereal sole crop com-

Table 6. The share of the most important weed species in the total weed structure in intercrops and sole crops.

The most important weed species	Share in total structure of weeds (%)					
	Dotnuva			Joniskelis		
	BBCH 32-34	BBCH 73		BBCH 32-34	BBCH 73	
	number		air-dry mass	number		air-dry mass
Viola arvensis Murray	3.1-5.8	0.0-3.4	0.0-0.9	5.1-9.3	5.5-9.8	0.4-1.8
Veronica arvensis L.	0.6-2.4	0.0-0.7	0.0-02	9.8-16.8	11.2-25.5	0.8-4.9
Thlapsi arvense L.	0.8-5.3	0.0-1.6	0.0-1.1	5.3-12.1	0.0-5.2	0.0-2.7
Polygonum persicaria L.	0.2-1.7	0.3-3.0	0.2-2.3	0.0	0.0	0.0
Polygonum aviculare L.	0.2-3.6	0.6-5.6	0.3-3.8	0.0	0.0	0.0
Galium aparine L.	0.0	0.0	0.0	7.6-13.3	4.3-6.8	1.4-10.9
Fallopia convolvulus (L.) A. Löve	1.4-4.7	0.6-5.7	0.2-8.1	5.0-9.9	10.2-21.3	3.3-22.0
Fumaria officinalis L.	0.0	0.0	0.0	0.8-2.5	0.0-1.0	0.0-0.9
Stellaria media (L.) Vill	3.5-6.3	1.3-5.7	0.8-8.0	16.1-26.9	11.2-17.4	4.2-21.3
Chenopodium album L.	81.3-51.2	56.1-69.6	31.9-61.1	7.6-12.8	8.5-19.7	2.3-19.3
Chaenorchium minus (L.) Lange	2.5-6.5	0.0-2.8	0.0-0.7	0.0	0.0	0.0
Lamium purpureum L.	1.9-4.1	0.9-4.8	0.2-2.4	0.0	0.0	0.0
Sonchus arvensis L.	0.2-2.6	0.5-4.5	1.4-24.2	0.5-3.4	2.6-9.8	0.5-10.4
Cirsium arvense (L.) Scop.	0.2-6.7	0.6-9.6	0.6-44.9	0.3-6.6	1.2-12.5	1.6-78.0
Taraxacum officinale F.H. Wigg.	0.7-3.9	0.3-1.1	0.1-4.3	0.0	0.0	0.0
Annual weeds	88.4-94.3	79.3-89.4	37.0-72.9	91.9-98.7	82.6-93.4	20.9-91.2
Perennial weeds	5.7-11.6	10.6-20.7	27.1-63.0	1.3-8.1	6.6-19.7	8.9-79.1

pared to pea sole crop. The decreasing of weed number in intercrops was obvious (24.2-39.1 weed m^{-2}), but not significant. The variation of perennial weed numbers was not marked.

At Joniskelis, the decrease in total weed number in the majority of the investigated crops during the growing season was not very marked (2.3-30.1 weeds m^{-2}), like at Dotnuva. There were no distinct differences between the respective intercrops and sole cereal crops. However, the number of weeds was higher in pea sole crop and intercropped with barley compared to that in the spring period. This variation of weed number was influenced by the uneven distribution of perennial weeds, which resulted in a considerable increase in weed number. Therefore, the essential decrease in annual and total weed number was obtained in crops with a high competitive ability, such as oat sole crop and intercrop. According to literature, oats are characterized by allelopathic traits: roots of oats educe allelochemicals-phenolic acids [29] that impede weed seed germination and subsequent growth.

Weed Air-Dry Mass

The sole crops and intercrops had a greater effect on weed air-dry mass reduction than on weed number. The highest reduction in total weed air-dry mass occurred in sole crops (47.1-50.6 g·m^{-2} or 78.8-84.6%) and intercrops (40.1-46.8 g·m^{-2} or 67.1-78.3%) compared with pea sole crop at Dotnuva. The cereal species differed only insignificantly in their weed suppression ability in the intercrops. At Joniskelis, at lower crop densities and high incidence of perennial weeds, weed air-dry mass was by 1.9-3.1-fold higher than in Dotnuva. A significant reduction occurred only in the mass of annual weeds (except for the intercrop of triticale). The air-dry mass of annual weeds decreased in sole crops and intercrops by 23.9-35.2 g·m^{-2} or 63.7-93.9% and 15.1-31.8 g·m^{-2} or 40.3-84.8%, respectively (except for pea intercropped with triticale).

Total weed mass significantly decreased in oats sole crop (37.0 g·m^{-2} or 90.0%) and intercropped with pea (25.8 g·m^{-2} or 62.8%), compared with sole pea crop. The variation of the total weed air-dry mass influenced perennial weed mass by sharing more than half (55.1-79.1%) of the total weed mass in the investigated crops (except for oats). Reduction of mass per weed decreased viability and number of mature seeds [1, 13]. When weed pressure is high, reduced weed air-dry mass translates directly into grain yield [21].

Weed Species Composition

The predominance of annual weed species (88.4-98.7%) can be explained by their very good adaptation to the existing soil and climate conditions and soil tillage regime [30] (Table 6). Such weed species are characterized by higher soil nutrient assimilation compared to agricultural plants [1].

In a loamy soil (Dotnuva), plant diversity in the crop rotation was higher (at cereal stem elongation growth stage BBCH 32-34). Out of the 12-13 species present, *C. album* was dominant. Whereas at Joniskelis in cereal-based rotation there were fewer (7-9) weed species, of which the most frequent were *S. media*, *Veronica arvensis*, *G. aparin*., *C. album*, and *F. convolvulus*. At both experimental sites the prevalent perennial weed species were *C. arvense* and *S. arvensis*. Researchers present various data on weed species variation: diversity of weed species was decreased [31], or remained without significant changes [32] in intercrops compared with sole crops. In our study we found no distinct changes in weed species due to the short experimental period.

At a cereal grain-filling stage (BBCH 73) the composition of weed species changed: annuals decreased and perennials markedly increased. In the total weed structure, the share of the annual weeds *T. arvense* and *S. media* (Dotnuva, Joniskelis), *G. aparine* and *F. officinalis* (Joniskelis), and *Viola arvensis* and *Veronica arvensis* (Dotnuva) decreased. The annual weed species *F. convolvulus* and *C. album*, *Veronica arvensis* (Joniskelis), and perennial weeds species *S. arvensis* and *C. arvense* increased. At Dotnuva, the biggest share of the total weed air-dry mass was formed by the weed species: *C. album*, *S. arvensis*, *C. arvense*, at Joniskelis – *F. convolvulus*, *S. media*, *C. album*, and *C. arvense*.

Discussion

In an organic cropping system, intercrops have potential advantages in utilizing local resources, reducing production inputs, and increasing sustainability in agricultural practice [26]. Cultivation of cereal intercrops with peas can result in a reduction in total crop stand density; however, in most cases the height of cereal crops increased as well as ear productivity parameters and nutrient concentrations in grain. Pea productivity indicators (grain number, 1,000-grain weight) declined (Table 2). In the intercrops, due to growth advantages at early growth stages [26] (and morphological and physiological peculiarities), cereals were dominant compared with peas [33]. Interspecific competition improves the growth of the dominant species, nutrient uptake, and productivity at the expense of the other species growing in the intercrop [34]. Better and extra utilization of environmental resources give intercrops advantages over sole crops [22, 35]. The intercrops allowed an increase of contribution of N2 fixation to total N accumulation of pea crops in the intercrop [28], and reduction of soil mineral N after harvest compared to pea sole crop [20]. As a result, intercrops with pea provide perfect conditions for cereals that are demanding in terms of nitrogen [25]. In Danish and German experiments, the accumulation of phosphorous (P), potassium (K), and sulphur (S) was 20 % higher in the intercrops (50:50) than in the respective sole crops [36]. Many researchers suggest that density and species proportions had a small effect on total grain yield [35, 37]. Of the cereals tested, oats exhibited a higher competitive power because of their well-developed root system and a good adaptation to growing in a wide range of soils [1]. Some researchers have pointed out that when two or more crops are growing together, each must have adequate space to maximize cooperation and minimize competition between them [16, 38]. Bilalis et al. (2010) indicated that shade was clearly a key factor in weed suppression. This is achieved by blocking the ecological niche of annual weeds [27] and distinguishing between early and late resource competition of the intercrop components [38].

In our study, organically grown intercrops exhibited a similar weed suppression to that of sole cereal crops. Weed suppression depended on the productive crop density. At Dotnuva (loamy soil), the total weed number and air-dry mass significantly decreased ($r = -0.908$, $p<0.01$; $r = -0.797$, $p<0.01$, respectively) with increasing productive density within the range 109-478 stems m^{-2}. However, at Joniskelis (clay loam soil), the productive density was lower (81-355 stems m^{-2}) and only the annual weed air-dry mass reduced ($r = -0.889$, $p<0.01$). At Joniskelis (in lower density crops), the different cereal species showed marked competitive advantages against weeds. In clay loam soil, the total and annual weed number decreased ($r = -0.871$, $p<0.01$, $r = -0.830$, $p<0.01$, respectively) with increasing crop heights. Of all intercrops, oat/pea intercrop showed the strongest weed suppression. Its suppressive power was twice as high as that of other investigated intercrops. The weakest weed suppression was exhibited by the pea/barley intercrop. Pea/wheat and pea/triticale intercrops gave similar weed suppression.

Studies carried out in five countries showed that the control of weeds was similar in sole barley and in intercrops, and no difference was established between the substitutive and the additive intercrops [39]. The data from both experimental sites suggest that the total and annual weed air-dry mass significantly decreased ($r = -0.764$, $p<0.05$; $r = -0.797$, $p<0.05$, respectively) with increasing stem number of cereals. Also, the reduction of total and annual weed numbers increased during the growing period ($r = -0.739$, $p<0.05$; $r = -0.723$, $p<0.05$, respectively). The number of pea plants in intercrops did not have any significant influence on weeds. Peas had low competitive ability due to the slow initial growth rate of seedlings [39], quite wide interlines, and late development of a competitive canopy [26]. Higher soil N availabilities entailed increased leaf areas of cereal and competition for light [40]. A. Dibet et al. (2006) also highlighted the importance of soil N in crop competition with weeds [39].

At Joniskelis site, the statistical relationships established between crops' aboveground biomass and total weed number (19.6-71.3 weeds m^{-2}), and variation of weed number during the growing period (from +4.9 to -30.1 weeds m^{-2}) were significantly inverse ($r = -0.734$, $p<0.05$; $r = -0.728$, $p<0.05$, respectively). The crops' aboveground biomass consistently and statistically significantly decreased ($r = -0.761$, p<0.05) with increasing air-dry mass of annual weeds from 2.3 to 37.5 g m^{-2}. However, the correlation between the total weed air-dry mass and crops' aboveground biomass was non-significant. At Dotnuva the weed number and air-dry mass did not exert any influence on aboveground biomass. Protasov (1995) reported that if numbers of weeds are below the threshold of harmfulness, the plants become a compatible share of agrophytocenosis and have a positive impact on the ecological state and productivity. Also, it is influenced by weed species differing, in harmfulness rate [41].

Conclusions

1. Under organic cropping conditions, cereals dominated and determined total crop productivity in pea/cereal intercrops. In most intercrops, grain number per productive stem and 1,000-grain weight, and concentration of N, P, K in cereal grains increased compared to sole crops. The dry matter of the aboveground biomass of wheat, oat, and triticale (Dotnuva) intercropped with pea was significantly higher compared with that of sole pea crop. Oat (clay loam soil) and barley (loamy soil) intercropped with pea produced the highest aboveground biomass compared with oat and barley sole crops.
2. At both experimental sites, intercrops exhibited similar weed suppression power to that of sole cereal crops. At the grain filling stage (BBCH 73), sole cereal crops and their intercrops with pea significantly ($p<0.0.1$) reduced the total and annual (except for intercrop of barley and sole barley in Joniskelis) weed number compared with pea sole crop. In all investigated intercrops, during the growing season from the complete weed emergence (cereal growth stage BBCH 32-34) to cereal grain filling stage (BBCH 73) the total weed number decreased by 24.2-39.1 weeds m^{-2} (loamy soil) and 9.8-30.1 weeds m^{-2} (except for pea/barley intercrop) (clay loam soil). In loamy soil, the total and annual weed air-dry mass was significantly reduced, whereas in clay loam soil, the reduction of weed mass was determined by only annual weeds. According to reduction of weed number and air-dry mass, the intercrops can be ranked in the following order: pea/oat > pea/wheat and pea/triticale > pea/barley. The productive crop density significantly influenced the reduction of total weed number ($r = -0.908$, $p < 0.01$) and air-dry mass ($r = -0.797$, $p < 0.01$), and annual weed mass ($r = -0.889$, $p < 0.01$). In higher density crops a reduction was recorded only for annual weed mass; the suppression of total weeds depended on the crop height ($r = -0.871$, $p < 0.01$).
3. In loamy soil (Dotnuva), the remaining number of weeds (34.5-64.3 weed m^{-2}) during cereal maturity stage did not have any significant effect on crop aboveground biomass. In the lower density crops in clay loam (Joniskelis), the aboveground biomass significantly declined with weed number variation from 19.6 to 71.3 weeds m^{-2}.

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