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Segetal Diversity in Selected Legume Crops Depending on Soil Tillage

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Abstract: The aim of the paper was to determine weed infestation expressed by weeds number and weed weight and other index under a three different tillage system: no-tillage (NT), reduced tillage (RT), and ploughing tillage (CT) in two legume species crops: pea and narrowed-leaved lupine. The research proved that growing legume under no-tillage conditions caused the increasing weed infestation. Weather conditions in each of the study years were shown to influence the weed infestation. The dry weight of weeds was higher in narrow-leaved lupine by 7% in flowering stage assessment and by 6% before harvest than in pea crop. The weeds number in the conventional tillage system in the flowering stage in pea and lupine crops was 24 and 26 plants·m^{-2}, respectively, under the reduced tillage conditions it was 33 and 29% higher, while under no-tillage it was 58 and 67% higher. In all tillage systems the dominant species were *Chenopodium album* L., *Viola arvensis* L., *Anthemis arvensis* L., and *Cirsium arvense* L. The results prove that soil tillage system affect weed infestation of legume crops.

Keywords: tillage system; weed infestation; biological diversity; reduced tillage; no-till; ploughing; legume

1. Introduction

The tillage method is one of the most important agrotechnical factors affecting the weed flora of cultivated crops [1,2]. Soil tillage systems can be divided into three basic groups: (1) conventional (traditional) tillage with the use of a plough, (2) reduced tillage, and (3) no-till system with direct sowing [3].

Conservation tillage, compared with ploughing tillage, causes decreasing labour and energy costs in the process of production. This system favorably affects the condition of soil environment [4,5]. It also reduces water erosion, temperature variations, and increases content of organic substances in the soil [6,7]. However, it may cause an increase in weed infestation [8,9].

Reduced tillage systems, which may cause changes at species composition and the number of occurring weeds, favor the development of monocotyledonous and perennial weeds. It also leads to the faster spread of perennial than annual weeds. In reduced tillage systems, there is lower movement of seeds than in the conventional (plough) system; therefore, most of the weed seeds are generally placed in the upper soil layer [10,11]. The method of tillage effects the depth of the weed seeds placement in the soil, and also on their accesses to the light. This has importance in relation to species which require short access to light with the aim of stimulating their germination [12]. Loosening of the topsoil in the cultivation without plowing favors the germination of weed seeds, whereas an effect of the traditional plough is that a considerable part of seeds is transferred to the deeper layers of soil, which greatly complicates their germination and emergence. The number, and species composition, of weed infestation depends also on crop species [13] and even on its variety [14].

Most of studies conducted so far concerned with the effect of soil tillage systems on weed infestation of crops, refer to cereals [15–19]. However, in the last years, the study directed to the evaluation of the possibility to use reduced tillage in the other crops, especially in the cultivation of legumes has been carried out [20–22].

The presented problem has great meaning in regard to the growing interest of farmers with reduced methods of various crop species cultivation, including legumes. Crops with legumes are particularly prone to weed infestation, and their weed control is a great problem because of the low number of herbicides approved to use at their cultivation.

The aim of the study was to determine weed species composition under a different tillage system in legume crops.

2. Materials and Methods

2.1. Field Experiment and Cultivation Management

The field experiment was carried out for three growing seasons: 2017–2019, at the Agricultural Experimental Unit in Grabów [51°21′18″ N 21°40′09″ E] (Masovian Voivodeship, Poland) belonging to the Institute of Soil Science and Plant Cultivation—State Research Institute in Puławy (Lublin voivodeship) (Figure 1). The experimental site is located in a moderate continental climatic zone. The experimental factors were as follows: (A) the legume species: pea (Batuta cultivar and narrow-leaved lupine (Regent cultivar); (B) tillage system: direct sowing (NT), reduced tillage (RT), and ploughing (CT). The experiment was set up in split-plot design with four replications, on a soil belonging to a good wheat complex, class IIIb. The soil was characterized by the following nutrient content: (mg·100 kg^{-1} soil): *p* 15.7–22.0; K 9.2–20.4 and Mg 5.9–7.6. The organic carbon content was 0.74–0.83%. Soil pH, as determined in 1-N KCl, was 5.4–6.3. The previous crop were cereals.

Figure 1. Localization of the study site. Source: Public Domain, https://commons.wikimedia.org/w/index.php?curid=89531 [23].

The experimental area was 720 m^2. A single plot area of 30 m^2 and for harvest—15 m^2. The density (units·m^{-2}) of legume was 200, in row intercropping–100. In all the years of the study the seeds were sown in the first 10 days of April. Mineral fertilization was applied at following rates: N—15 kg· ha^{-1}, P_2O_5—50 kg·ha^{-1}, 75 kg·ha^{-1}. All fertilizers were applied before sowing the legumes. In each growing season, chemical preparations was used to reduce weed infestation of the crops. Two herbicides were used on each crop in growing season, the same herbicides in all tillage systems (2017—Boxer 800 SC (prosulfocarb 800 g l^{-1}; 78.43%)—1 × 2.5 l·ha^{-1}, Stomp Aqua 416 SC (pendimethalin 455 g l^{-1})—1 × 2.0 lha^{-1}, in 2018 and 2019—Boxer 800 SC—1 × 3.0 lha^{-1}, Stomp Aqua 416 SC—1 × 3.5 lha^{-1}, Fusilade Super 150 EC (fluazifop-P-buty 150 g l^{-1}; 15.8%—1 × 1.0 lha^{-1}). Plants were harvested at full maturity stage of pea (BBCH 89) in the third 10 days of July and narrow-leaved lupine (BBCH 89) in the first 10 days of August.

2.2. Analysis of Weed Flora

Analyses of species composition, number of weeds, and dry matter of weeds were determined after collection using the weed-picking frame method. The weeds were collected from a frame with dimensions of 0.5×1 m, with four replications in each crop field.

Tillage effects on weed population composition were assessed in each field on two terms:

1. The tillering stage of legume (BBCH 61–65).
2. The seed ripening stage (before the legume harvest) (BBCH 89–92).

Weed species nomenclature followed Mirek et al. [24]. Dry matter of weeds was determined after drying at 55 °C for 4 days.

For comparison of weed infestation of legume species in dependent on cropping method, the biomass index was determined and calculated for three years (2017–2019) according to the formula by Patriquin [25]:

$$biomass\ index = \frac{crop\ biomass \times 100}{weed\ biomass + crop\ biomass} \quad (1)$$

2.3. Diversity Indicators

The weed structure composition in the studied crops was also described using two index: the Shannon–Wiener index index (H') and the Simpson dominance index (SI). The Shannon's index is an indicator of species diversity. Its value determines the probability that two sampled individuals will belong to different species. The Simpson index (SI) describes the probability of occurring two individuals of the same species.

The Shannon–Wiener diversity index (H') and the Simpson dominance index (SI) were calculated according to the following formula [26,27]:

$H' = -\Sigma\ pi\ ln\ pi$
$SI = \Sigma\ pi^2$
where:
$pi = n/N$,
n—number of individuals in species,
N—total number of individuals in the sampling area, and
ln—the natural log.

2.4. Weather Conditions

In the experiment period (2017–2019), weather conditions varied between all the years (Table 1). In 2017 the highest amount of rainfall was noted in spring in April, exceeded by 77% the long-term average. In June and the first 10 days of July was recorded a small amount of precipitation (32.6 and 9.7 mm, respectively) and was lower than the long-term average by 54.1 and 65.0%, respectively. In the first 10 days of August there were very small amount of precipitation (0.9 mm). In 2018, the amount of precipitation in May (97.4 mm) and July (118.5 mm) exceeded the average from multi-years by 70.9 and 41.1% respectively, which favored the yields of legume. During April and June the total precipitation was only 65% and 63% of the long-term average, respectively. In 2019 total precipitation during growing season of legumes was the smallest (252.4) compared to earlier two years. In July was recorded a small amount of precipitation and was lower than the long-term average by 30.0%.

Table 1. Course of weather conditions during the vegetation periods.

Specification	Month						Sum/ Average III-VIII
	III	IV	V	VI	VII	VIII	
				2017			
Precipitation (mm)	35.8	69.1	34.4	32.6	86.3	55.3	313.5
Temperature °C	5.7	7.5	13.9	18.1	18.6	19.6	13.9
				2018			
Precipitation (mm)	14.1	25.3	97.4	44.6	118.5	70.6	370.5
Temperature °C	−0.1	13.3	17.0	18.4	20.4	20.2	14.9
				2019			
Precipitation (mm)	22.2	37.5	51.5	51.2	20.2	69.8	252.4
Temperature °C	5.4	9.8	13.1	21.7	18.7	20.2	14.8
* Average precipitation from multi-year (mm)	30.0	39.0	57.0	71.0	84.0	75.0	356.0
Mean temperature from multi-year °C	1.6	7.7	13.4	16.7	18.3	17.3	12.5

* Mean for 1871–2000.

2.5. Statistical Analysis

The date presented are the mean values from the years 2017–2019, as a result of a similar reaction of the plant examined to different soil tillage system during three study years. The results were statistically analyzed with the use of the variance analysis using Statistica v.10.0 program. Tukey's multiple comparison test was used to compare differences between the means for soil tillage system while confidence intervals for the means of LSD ($\alpha = 0.05$) were used.

3. Results and Discussion

Tillage system caused significant differences in weed infestation of the legume crops (Tables 2 and 3; Figures 2 and 3). On average over the period of the study, in both legume species (pea and lupine) cropped in no-tillage system (NT), dry weight of weeds assessed in the flowering stage was higher by 55 and 14%, respectively, than in plough tillage (CT). While in the second term of assessment the relation was: 50 and 15%, respectively. The weeds air dry weight did not differ between reduced tillage (RT) and no-tillage system in pea crop in term before harvest only in the third year of the study. The higher weed air-dry weight was found in term before harvest legume. Analysis of weed infestation in both species crop showed that the dry weight of weeds was higher in narrow-leaved lupine by 7% in flowering stage assessment and by 6% before harvest than in pea crop.

Table 2. Dry weight of weeds ($g \cdot m^{-2}$) in different tillage system in the flowering stage in 2017–2019.

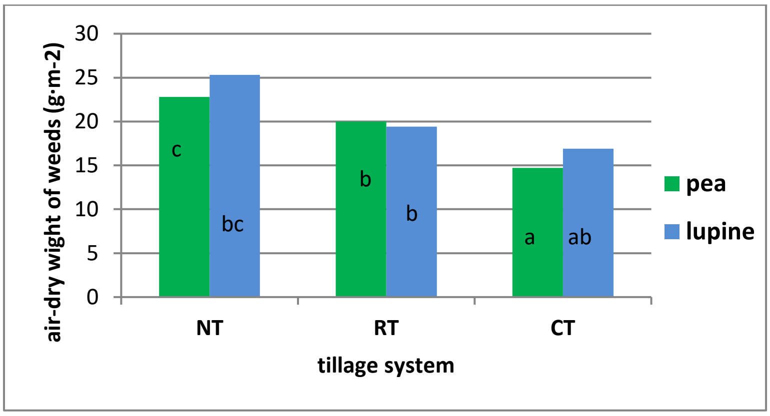
Tillage System	Crop Species					
	Pea			Narrow-Leaved Lupine		
	2017	2018	2019	2017	2018	2019
NT	17.2^{c}	28.2^{c}	22.9^{c}	18.2^{c}	30.5^{c}	27.1^{c}
RT	15.1^{b}	25.6^{b}	19.2^{b}	16.0^{b}	22.0^{b}	20.1^{b}
CT	12.0^{a}	16.9^{a}	15.2^{a}	13.5^{a}	19.2^{a}	18.0^{a}
Mean	14.8	23.6	19.1	15.9	23.9	21.7

NT—no-tillage, RT—reduced tillage, CT—plough tillage. Different letters denote significant differences ($p < 0.05$) of the air-dry weight of weed among different tillage system (CT and NT and RT). The same letter means it is not significantly different.

Table 3. Dry weight of weeds (g·m^{-2}) in different tillage system in term before harvest in 2017–2019.

Tillage System	Crop Species					
	Pea			Narrow-Leaved Lupine		
	2017	2018	2019	2017	2018	2019
NT	27.9 ^{c}	24.6 ^{c}	25.9 ^{c}	29.0 ^{c}	25.9 ^{c}	28.7 ^{c}
RT	22.2 ^{b}	20.0 ^{b}	24.3 ^{b}	20.2 ^{b}	21.6 ^{b}	25.9 ^{b}
CT	16.9 ^{a}	14.2 ^{a}	13.2 ^{a}	17.8 ^{a}	15.8 ^{a}	14.9 ^{a}
Mean	22.3	19.6	21.1	22.3	21.1	23.2

NT—no-tillage, RT—reduced tillage, CT—plough tillage. Different letters denote significant differences ($p < 0.05$) of the air-dry weight of weed among different tillage system (CT and NT and RT). The same letter means it is not significantly different.



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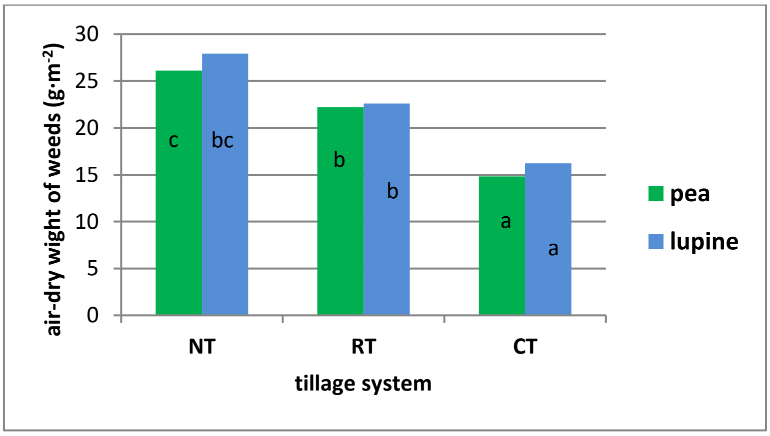

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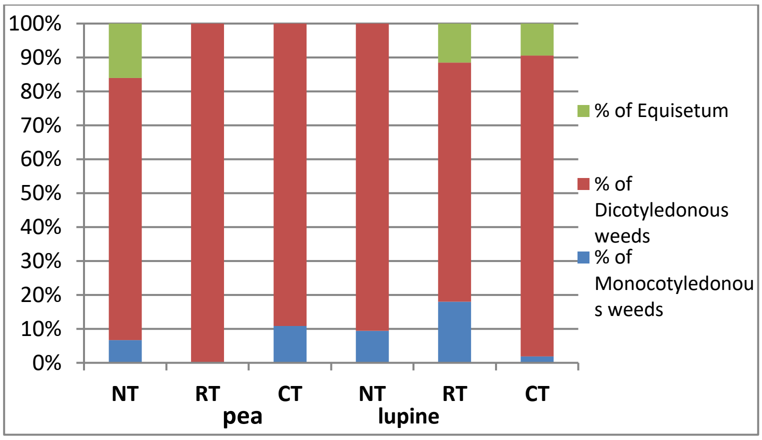
Figure 2. Average (for the years of research) air-dry weight of weeds (g·m^{-2}) in different tillage system in term: (**a**) flowering stage and (**b**) before harvest. NT—no-tillage, RT—reduced tillage, CT—plough tillage.

Weed infestation of the legume crop expressed as dry weight of weeds in estimated in the flowering stage was highest in the second year of the experiment (2018), which was characterized by a higher amount of precipitation than the other years of the experiment, while in term of estimate before harvest for no-tillage (NT) and plough tillage (CT) system in the first year of the study (2017) and for reduced tillage (RT) in the third year of the study (2019).

The average number of weeds differ significantly in the three tillage systems studied (Tables 4 and 5).



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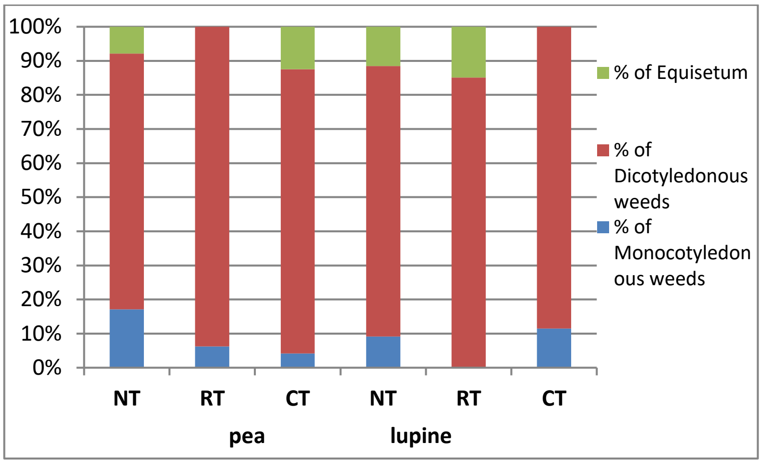

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Figure 3. Percentage of monocotyledonous, dicotyledonous, and equisetum in total number of weeds in different tillage system in term: (**a**) in flowering stage (%) and (**b**) before harvest (mean for 2017–2019). NT—no-tillage, RT—reduced tillage, CT—plough tillage.

The number of weeds (for all years of the study) in the CT system in the flowering stage in pea and lupine crops was 24 and 26 plants·m^{-2}, respectively, under the reduced tillage conditions it was 33 and 29% higher, while under NT system it was 58 and 67% higher. While in term of assessment before harvest the number of weeds in the CT system was 23 and 26.5 plants per m^2 for pea and legume, respectively, under reduced tillage system it was 22 and 15% higher, while under NT system 40 and 49% higher.

A higher weed infestation under reduced soil tillage treatment as compared to plough (conventional tillage) has been confirmed by studies of Peigné et al. and Gruber and Claupein [28,29]. Demjanová et al. [30] found that soil simplification of soil was caused significantly higher weed matter compared ploughing. Similarly, Woźniak et al. [31] and Vakali et al. [32] found that a higher number of weeds in cereal crops occurred in no-tillage and reduced tillage systems than in conventionally ploughed crops. Armengot et al. [33] also recorded that total weed was higher under reduced tillage. In the study by Woźniak [34], no-tillage system significantly increased the number and weed air-dried matter in wheat crop as compared to conventional tillage.

Table 4. Weed species composition in pea and lupine crop depending on tillage systems in flowering stage (plants·m^{-2}) (average for the years of research).

Weed Species	A/P *	Pea			Narrow-Leaved Lupine		
		Tillage System					
		NT	RT	CT	NT	RT	CT
Echinochloa crus-galli (L.) *P. Beauv.*	A	2.5 ^{b}	2.0 ^{b}	1.0 ^{a}	2.0 ^{a}	-	3.0 ^{b}
Elymus repens (L.) Gould	P	4.0	-	-	2.0	-	-
Sum of Monocotyledonous weeds		6.5 ^{c}	2.0 ^{b}	1.0 ^{a}	4.0 ^{a}	-	3.0 ^{b}
Anthemis arvensis L.	A						
Aphanes arvensis L.	A		3.0				2.0
Centaurea cyanus L.	A	-	-	4.5		5.0 ^{b}	3.0 ^{a}
Chenopodium album L.	A	5.0 ^{b}	3.0 ^{a}	5.5 ^{b}	5.0 ^{a}		5.0 ^{a}
Cirsium arvense (L.) Scop	P	4.5 ^{a}	5.5 ^{b}	4.0 ^{a}	0.5 ^{a}	5.0 ^{b}	7.0 ^{c}
Convolvulus arvensis	P						
Geranium dissectum L.	A	4.5	-	-	4.0		
Plantago major L.	A	2.5 ^{a}	2.0 ^{a}		4.0		
Polygonum aviculare L.	A		3.0			4.5 ^{b}	1.5 ^{a}
Polygonum persicaria L.	A	3.5 ^{a}		3.5 ^{a}	4.5 ^{b}	4.0 ^{b}	2.0 ^{a}
Senecio vulgaris L.	A	1.5				4.5	
Sonchus arvensis L.	A	4.0 ^{b}	6.0 ^{c}	2.5 ^{a}	1.5 ^{a}	6.0 ^{b}	2.5 ^{a}
Sonchus asper L.	A				5.5	4.5	
Stellaria media (L.) Vill.	A	3.0 ^{a}	4.0 ^{a}	-	5.5		
Viola arvensis Murr.	A	-	3.5	-	4.0		
Sum of Dicotyledonous weeds		28.5 ^{b}	30.0 ^{b}	20.0 ^{a}	34.5 ^{b}	28.5	23.0 ^{a}
Eguisetum arvense L.	P	3.0 ^{a}	-	3.0 ^{a}	5.0 ^{a}	5.0 ^{a}	-
Total		38.0 ^{c}	32.0 ^{b}	24.0 ^{a}	43.5 ^{c}	33.5 ^{b}	26.0 ^{a}
Number of species		11	9	7	12	8	8

* A—annual, P—perennial, NT—no-tillage, RT—reduced tillage, CT—plough tillage. Different letters denote significant differences ($p < 0.05$) of the number of weed species among different tillage system (CT and NT and RT). The same letter means it is not significantly different.

When analyzing the weed infestation of two legume species, a significantly higher number were found in lupine crop under the NT system as compared to the CT system (Tables 4 and 5) The differences between those two species were insignificant.

Weed flora biodiversity occurring in legume grown under different tillage systems showed a similar weed species composition but same differences in number of species occurred (Tables 4 and 5). In all tillage systems the dominant species were *Chenopodium album* L., *Viola arvensis* L., *Anthemis arvensis* L., and *Cirsium arvense* L. Reduced tillage was accompanied by a larger number of *Centaurea cyanus* L. volunteer than in the two other systems.

In crops grown in no-tillage system, there was a larger number of weed species than in the other cultivation systems (Tables 4 and 5). There was also a higher number of perennial species: *Equisetum arvense* L., *Plantago major* L., and *Sonchus arvensis* L. in comparison to the traditional ploughing system. Reduced cultivation was characterized by a higher occurrence of *Fallopia convolvulus*, *Viola arvensis* L., *Chenopodium album* L., *and Cirsium arvense* L. (Tables 4 and 5). While in crops in ploughing system, there was a larger number of *Chenopodium album* L., *Cirsium arvense* L., and *Polygonum persicaria* L. Further, Clements et al. [35] found that *Chenopodium album* L. dominated the weed population in ploughing in comparison with ploughing and no-tillage system.

Table 5. Weed species composition in pea and lupine crop depending on tillage systems before harvest (plants·m^{-2}) (average for the years of research).

Weed Species	A/P *	Pea			Narrow-Leaved Lupine		
		Tillage System					
		NT	RT	CT	NT	RT	CT
Echinochloa crus-galli (L.) P. Beauv	A	2.0 ^{a}	-	2.5^a	3.5 ^{b}	5.5 ^{c}	0.5 ^{a}
Elymus repens (L.) Gould	P	0.3	-	-	-	-	-
Sum of Monocotyledonous weeds		2.3 ^{a}	-	2.5 ^{a}	3.5 ^{b}	5.5 ^{c}	0.5 ^{a}
Anthemis arvensis L.	A	-	6.0	-	4.0	-	5.0
Artemisia vulgaris L.	P	-	1.5 ^{a}	5.0 ^{b}	1.0 ^{a}	-	4.0 ^{b}
Centaurea cyanus L.	A	7.5	-	-	3.0 ^{a}	5.0 ^{b}	-
Chenopodium album L.	A	1.5 ^{a}	-	6.0 ^{b}	4.0 ^{b}	3.5 ^{b}	2.5 ^{a}
Cirsium arvense (L.) Scop	P	7.0 ^{b}	-	4.5 ^{a}	-	-	5.0
Fallopia convolvulus (L.) Á. Löve	A	-	5.5	-	1.5 ^{a}	5.5 ^{b}	-
Galium aparine L.	A	-	-	-	2.5	-	-
Geranium dissectum L.	A	1.5 ^{a}	1.5 ^{a}	-	5.0 ^{b}	3.0 ^{a}	-
Plantago major L.)	A	4.0 ^{a}	6.5 ^{b}	-	4.5 ^{a}	6.5 ^{b}	-
Solanum nigrum L	A	2.0	-	-	-	4.5	-
Viola arvensis Murr.	A	3.0 ^{a}	7.0 ^{c}	5.0 ^{b}	8.0 ^{b}	5.0 ^{a}	7.0 ^{b}
Sum of Dicotyledonous weeds		26.5	28.0	20.5	33.5	21.5	23.5
Eguisetum arvense L.	P	5.5	-	-	-	3.5 ^{a}	2.5 ^{a}
Total		34.3 ^{c}	28.0 ^{b}	23.0 ^{a}	37.0 ^{c}	30.5 ^{b}	26.5 ^{a}
Number of species		10	6	5	10	9	7

* A—annual; P—perennial. NT—no-tillage, RT—reduced tillage, CT—plough tillage. Different letters denote significant differences ($p < 0.05$) of the number of weed species among different tillage system (CT and NT and RT). The same letter means it is not significantly different.

The statistical analysis showed that the examined factors modified the share of monocotyledonous and dicotyledonous species in total number of weed. Average for the all the years of the study the highest percentage in weeds composition was dicotyledonous species regardless on soil tillage systems and term of assessment. In no-tillage system in the first term of assessment, the share of dicotyledonous species was significantly lowest, whereas the share of the monocotyledonous species was lower than in simplificated systems. The no-tillage system increased the percentage of monocotyledonous species and decreased the percentage of dicotyledonous species in the structure of weeds. While in the term before harvest, the highest percentage of dicotyledonous was in no-tillage system in lupine crop and the lowest in the pea crop in the same of tillage system (Figure 3).

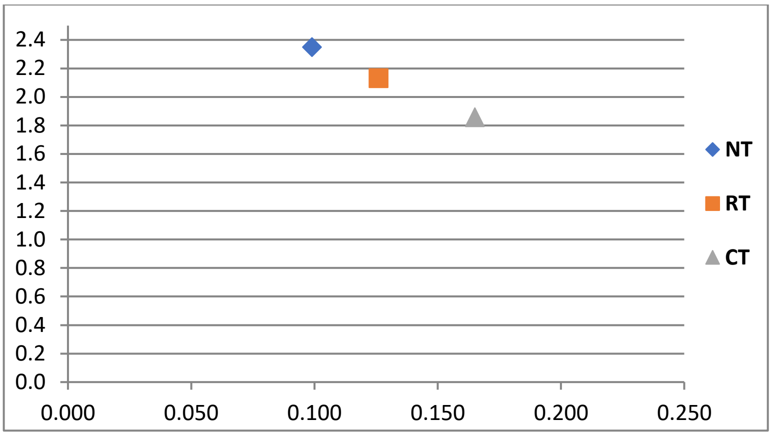
The agrophytocenosis of legume crop found in flowering stage included 18 weed species while 14 belonged to annual weeds (77.8%). Twelve weed species (three perennial and nine annual) where noted in legume grown in no-tillage system. While in the second term of assessment (before harvest) the agrophytocenosis included 14 weed species (4 perennial weeds).

The share of perennial weed species in the no-tillage system was higher than in the ploughing and reduced tillage systems. It is mean that soil simplification promotes an increase in perennial weeds in the field (Tables 4 and 5). Study of Bilalis et al. [36] stated that three annual weed species occurred in large number in the ploughing and reduced tillage systems, while one perennial weed species often occurred in the no-tillage system.

A total of 10 weed species (mean for two terms of assessment) occurred in legume crop grown in no-tillage (NT) system and 8 in reduced tillage (RT) and 7 in conventional tillage (CT).

The evaluation of the biological diversity of the segetal flora in flowering stage showed that the Shannon–Wiener index (H′) and the Simpson index (SI) measured for pea crop differ significantly in no-tillage system and reduced tillage, but significantly differences was found between conventional tillage and other tillage systems. Analysis of segetal flora diversity in term before harvest showed no-significantly differences between all tillage system in both legume species. Weed biodiversity of legume crop as measured by Shannon's index was the highest under no-tillage system—2.20 and 1.71

(average for two terms) for pea and lupine crop respectively, due to the most even percentage of weed species in the community. The no-tillage system was characterized by the lowest value of Simpson dominance index—average for two terms and for both legume species—0.12 (Figures 4 and 5).



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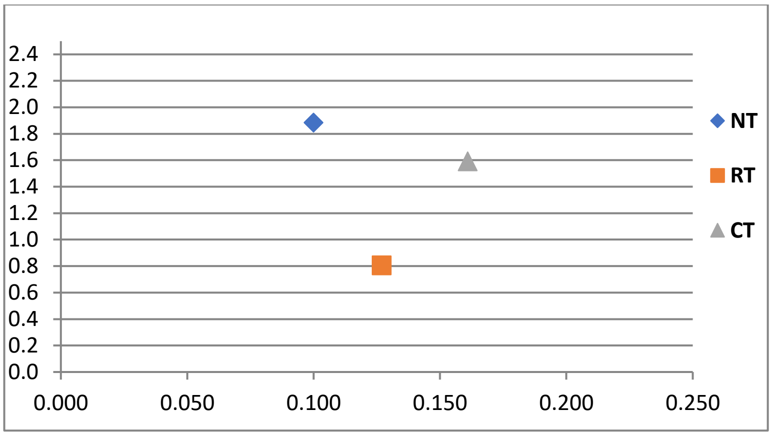

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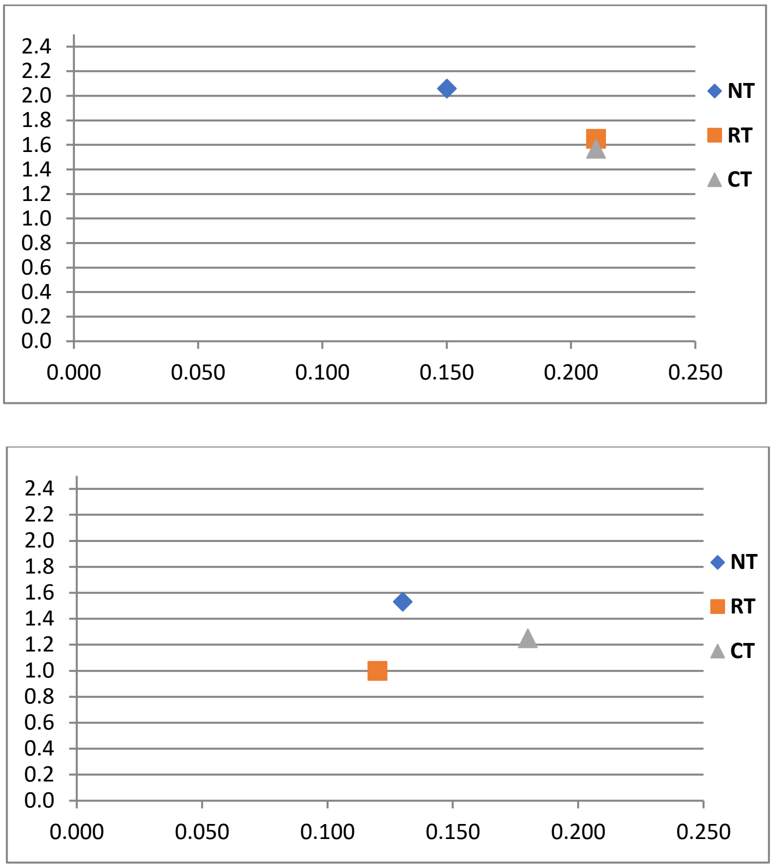
Figure 4. Shannon–Wiener's diversity index (*H'*) and Simpson's dominance index (*SI*) of the weed community in (**a**) pea, (**b**) lupine crop in flowering stage depending on the tillage system (mean for 2017–2019). NT—no-tillage, RT—reduced tillage, CT—conventional tillage.

The highest value of Simpson's index was found under conventional tillage—especially in flowering stage—0.17 and 0.21 for pea and lupine respectively, due to the domination of three weed species: *Chenopodium album* L., *Cirsium arvense* L., and *Centaurea cyanus* L.

The study results of Santín-Montanyá et al. [37] and Gawęda et al. [38] paper, show that weed community diversity, as expressed by the Shannon index, increased under the NT system. Sebayang and Rifai [39], point out that the weed matter in the soybean crop did not differ significantly between conventional tillage, reduced, and no-tillage. Nonetheless, many authors recorded that the no-tillage system increases weed infestation of crops [40–42]. Results of our study have been confirmed by Feledyn-Szewczyk et al. [43], who found that weed biodiversity as expressed by diversity indices was the highest under reduced soil tillage. Study of Legere et al. [44], the tillage system has little impact on weed diversity but according to those authors soil tillage system plays an important role in shaping the weed species composition. Furthermore, Sans et al. [45], did not find significant differences in Shannon's diversity index values for weed communities in cereal crops. However those authors point out a significantly higher degree of weed infestation in the reduced tillage system compared to the conventional system.



(**a**) (**b**)

Figure 5. Shannon–Wiener's diversity (*H'*) and Simpson's dominance (*SI*) indices of the weed community in (**a**) pea and (**b**) lupine crop before harvest depending on the tillage system (mean for 2017–2019). NT—no-tillage, RT—reduced tillage, CT—conventional tillage.

Another authors [20,46] stated that tillage system modifies soil properties, and thus influences plant growth and development. Campiglia et al. [47] and Gawęda et al. [40] found increasing number of perennial weeds in no-tillage system. Velykis and Satkus [48] point out that no-tillage system caused a change in the composition of weed species compared to the conventional system. It caused the increase of the occurrence of *Galium aparine* and *Chenopodium album* in the legume crop. Gawęda et al. [40] found that the NT positively influences the segetal diversity in the soybean crop compared to the CT system.

Biomass index was additional factor indicating the degree of weed infestation. The lowest values of this index were found for no-tillage system of both legume species crop (average 91.6%), which shows a high percentage of weed matter in the total biomass of legume crop per unit area, while the highest values of the biomass index were recorded for pea crop grown in conventional tillage (94.6%), yet they did not significantly differ from the other tillage system, where the value of this index was also very high (Figure 6). On average, from all of the years of the study, the highest index of relation between legume seeds yield and weeds dry matter was in no-tillage soil system, where the lowest yields in such as cropping method was noted (Figure 6). In this system, the highest air-dried weed matter was noted. While the lowest index in legume (pea and lupine) grown in ploughing system.

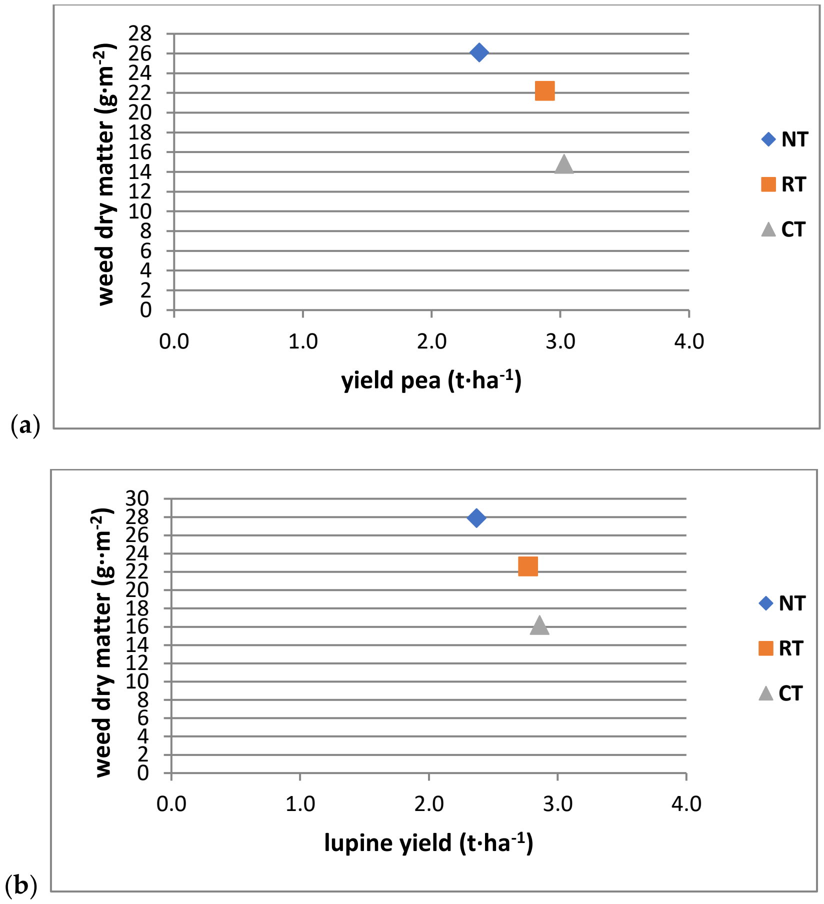


Figure 6. Relation between weeds dry matter seeds and yield of (**a**) pea, (**b**) legume.

4. Conclusions

Simplifications in soil tillage increased the contribution of weeds in legume crops. A higher number of weeds per 1 m^2 was recorded in ploughless tillage (no-tillage system), whereas 35% less on the plot with plough tillage. Weed infestation expressed by weeds number was higher by 9.1% in the first term (in the flowering stage) than in the second term (ripening of pods and seeds). The number of weeds in both the evaluation terms was also determined by the applied tillage method. As in the flowering stage as before harvest of legume crops, the highest infestation occurred in no-tillage soil system.

The dry weight of weeds was higher in narrow-leaved lupine by 7% in flowering stage assessment and by 6% before harvest than in pea crop. The number of weeds in the plough tillage system in the flowering stage in pea and lupine crops was 24 and 26 plants·m^{-2}, respectively, under the reduced tillage conditions it was 33 and 29% higher, while under no-tillage it was 58 and 67% higher.

Diversified soil tillage influenced the biodiversity of weed in legume crops field. In the first term of evaluation, 12 weed species (average for both legume species) were recorded on the plot with no-tillage soil, while 40% less weed species were occurred in plough (conventional) tillage.

Shannon's diversity index had highest values and Simpson's dominance index had lowest values in no-tillage systems, which showed their high biodiversity importance. The evaluation of the biological diversity of the segetal flora in flowering stage showed that the Shannon–Wiener index (H') and the Simpson index (SI) measured for pea crop differ significantly in no-tillage system and reduced tillage, but significantly differences was found between conventional tillage and other tillage systems.

In all tillage systems the most numerous species were *Chenopodium album* L., *Viola arvensis* L., *Anthemis arvensis* L., and *Cirsium arvense* L. Reduced soil tillage was accompanied by a larger number of *Centaurea cyanus* L. volunteer than in the other systems.

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