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The Effect of Precipitation on Weed Infestation of Spring Barley under Different Tillage Conditions

J. Winkler, S. Chovancová

***Abstract*—**The article deals with the relation between rainfall in selected months and subsequent weed infestation of spring barley. The field experiment was performed at Mendel University agricultural enterprise in Žabčice, Czech Republic. Weed infestation was measured in spring barley vegetation in years 2004 to 2012. Barley was grown in three tillage variants: conventional tillage technology (CT), minimization tillage technology (MT), and no tillage (NT). Precipitation was recorded in one-day intervals. Monthly precipitation was calculated from the measured values in the months of October through to April. The technique of canonical correspondence analysis was applied for further statistical processing. 41 different species of weeds were found in the course of the 9-year monitoring period. The results clearly show that precipitation affects the incidence of most weed species in the selected months, but acts differently in the monitored variants of tillage technologies.

***Keywords*—**Weeds, precipitation, tillage, weed infestation forecast.

I. Introduction

WEED occurrences significantly affected by the cultivated crop species, crop rotation, and primarily by the weather conditions in individual years. A number of works points out to excessive differences in the weed infestation intensity and the species composition of weed communities [1], [2].

The tillage method influences a number of physical and biological factors present in the soil which in return affect the decomposition of organic substances. Harvest residues are differently distributed and their contact with the soil varies in the case of different tillage methods. This particularly concerns the content of water and oxygen in the soil and the temperature and structure of the soil [3].

The total porosity in most cases very closely correlates with bulk density. In general, lower values of total porosity in the case of no-tillage technologies at greater depths of the soil profile become equal to the plowed soil, and below 0.3 meters are comparable, or sometimes even more favorable. The improvement of overall porosity in the bigger depths of no-tillage systems is attributed in particular to the development of macro pores in relation to higher activity of earthworms of *Lumbricus* sp. [4]-[6] and more intensive root growth [7].

The field experiment showed that the capillary porosity P_k increased and variation of values was lower in the case of no-tillage technology, compared with tilled soil [8].

The no-tillage technology showed higher momentary moisture than the case was in the corresponding depths of plowed soil. This fact, which seems to be typical for no-tillage technologies, is attributed to the reduction of water loss resulting from leaving the harvest residues on the surface and not interrupting the pores leading to the seed bed. This results in lower evaporation, better surface absorption of water, slower drainage, no soil crust, better supply of plants with water, which is particularly important at the time of germination, and mitigation of short-term drought periods during the summer. However, the environmental aspect, mentioned by the above authors, i.e. lower erosion and higher retention capacity related to the application of no-tillage technologies remains under appreciated [6], [9]-[11]. A lower profile variability of current soil moisture in time was recorded in the case of no-tillage technology if compared with plowed soil [12]. Application of no-tillage is accompanied with higher content of soil water during dry months and periods with uneven distribution of rainfall [13].

Thus, the changes caused by tillage most significantly influence bulk density which affects the whole complex of physical properties of soil [14], i.e. porosity, air and water capacity, thermal conductivity, etc. The content, availability and movement of soil water change subsequently. Water is an important factor not only for the plants grown for the production of biomass, but also for the maintenance of soil fertility in terms of physical and chemical properties. Both surplus and shortage of soil water has harmful effects. The greatest loss of water occurs during the plowing time, and therefore we must consider the technology chosen for the tillage. This particularly concerns areas with water shortage and periods when the supply of water in the topsoil drops below a level reachable by plants [15].

The amount of precipitation influences not only soil bulk density and soil water content, but also the values of soil penetration resistance. Long-term processing of soil without plowing or shallow processing by a disc cultivator contributes to the soil compactness and water content and it was ascertained that the relationship between the penetration resistance of the soil, bulk density and soil water is linear [16].

The most decisive meteorological parameters affecting the intensity of weed infestation include rainfall. What important is

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Jan Winkler is with the Department of Agrosystems and Bioclimatology, Mendel University in Brno, Zemědělská 1, 61300 Brno, Czech Republic (phone: +420 545-133-371; e-mail: winkler@mendelu.cz)

Světlana Chovancová is with the Department of Agrosystems and Bioclimatology, Mendel University in Brno, Zemědělská 1, 61300 Brno, Czech Republic (phone: +420 775-073-220; e-mail: svetlana.chovancova@mendelu.cz).

the amount of precipitation and the time of occurrence. All of these factors affect weed seeds in the soil and co-determine their germination. The technology of soil tillage significantly affects soil properties and changes the impact of precipitation. Ultimately, these facts may jointly influence the occurrence of weeds. This contribution deals with the relation between rainfall in selected months and subsequent weed infestation of spring barley and suggests possibilities of a certain forecast of weed intensity based on the overall precipitation amount in the month concerned.

II. Material and Methodology

A. Characteristics of the Experimental Locality

The field experiment was performed at Mendel University agricultural enterprise in Žabčice, Czech Republic. This area is part of the geomorphological territory of Dyje and Svratka Basin. The altitude of the experiment is 185 meters above sea level in a flatland.

Long-term average annual temperature is 9.3°C and long-term annual aggregate precipitation is 483.3 mm. Data concerning temperature and amount of precipitation were obtained from the meteorological station in the experimental enterprise in Žabčice.

B. Description of Field Experiment

The field experiment was established in 2001 and covers the area of 2.3 ha (100 m x 225 m). The size of individual parcels is 1,000 m^2 (100 x 10 m). The seven-step crop rotation was applied in the field experiment. The succession of crops was as follows: gourd alfalfa (*Medicago sativa*) – the first year, alfalfa wheat – the second year, winter wheat (*Triticum aestivum*), forage maize (*Zea mays*), winter wheat, sugar beet (*Beta vulgaris*), spring barley (*Hordeum vulgare*).

Three variants of tillage were applied for each crop type within the seven-step crop rotation.

Tillage variants:

- *Conventional Tillage Technology (CT)*: After the harvest of a precursor crop, the stubble is treated with Kverneland chisel cultivator to the depth of ca 0.1 m. Imposition is suitable in dry summer. The subsequent operation is plowing to the depth of 0.2 - 0.24 m. It is performed by a Lemken double-sided rotary plow. The Accord seed combination is used for sowing.
- *Minimization Tillage Technology (MT):* Stubble cultivation is performed by Kverneland chisel cultivator to the depth of ca 0.1 m, ensuring shallow cultivation. The Accord seed combination is used for sowing.
- *No Tillage (NT):* The soil surface is leaved uncultivated after the harvest of the precursor crop. The Accord seed combination is used for direct sowing.

C. Evaluation of Weed Infestation and Precipitation Measurement

Weed infestation was evaluated by means of the numerical method in the spring barley growth. Weeds were counted in each variant of tillage on 1 m^2 with 24 repetitions. The evaluation was performed in years 2004 to 2012, always in the spring in the stage of spring barley sprouting and prior to the herbicide application. The names of ascertained species were used according to Kubát [17].

Precipitation was recorded in one-day intervals. Data concerning precipitation amounts were supplied by a standard meteorological station situated directly in the experimental enterprise. Monthly precipitation was calculated from the measured daily values in the months of October through to April. Final values are shown in Table I.

TABLE I
Aggregate Monthly Precipitation in Selected Months

Monitoring years	Aggregate monthly precipitation (mm)						
	October	November	December	January	February	March	April
2003_2004	57.60	31.60	51.00	41.90	27.60	59.80	34.00
2004_2005	66.20	35.00	18.00	19.40	44.40	5.80	49.50
2005_2006	6.20	23.40	30.20	22.20	26.40	46.20	50.50
2006_2007	13.90	21.40	20.80	22.70	42.20	80.80	4.40
2007_2008	37.92	30.50	26.00	15.71	10.40	32.91	29.31
2008_2009	27.31	22.11	31.12	20.00	57.61	78.10	3.60
2009_2010	21.21	55.42	37.60	46.81	22.81	9.81	53.11
2010_2011	10.41	32.81	11.11	21.42	4.61	39.30	33.21
2011_2012	22.61	1.61	14.62	27.42	7.41	2.41	19.81

D. Statistical Data Processing

Multivariate analyses of ecological data were applied in order to ascertain the effect of monthly precipitation on weed species present in spring barley. Aggregate precipitation amounts in October to April were used as environmental factors. The analyses were performed separately for each tillage variant. The optimal analysis was based on the length of the gradient detected by Detrended Correspondence Analysis (DCA). Canonical Correspondence Analysis (CCA) was used for further statistical processing. 499 permutations were calculated in the process of provability testing by the Monte-Carlo test. The data were processed by means of computer software Canoco 4.0 [18].

III. Results and Discussion

In the course of 9-year monitoring, 31 different weed species were found in the variant of conventional tillage. Average numbers of weeds in the respective years of monitoring are stated in Table II.

TABLE II
AVERAGE NUMBER OF WEEDS IN THE CONVENTIONAL TILLAGE VARIANT

Weed species (pc.m^{-2})	Year of monitoring								
	2004	2005	2006	2007	2008	2009	2010	2011	2012
Amaranthus spp.	1.1		3.6			0.3			0.1
Anagallis arvensis					0.0				
Atriplex patula					0.0				
Arctium tomentosum							0.1		
Beta vulgaris				0.4	0.4		0.0		
Cirsium arvense	0.7	0.0	1.0	0.1	0.4	0.0	0.1	0.9	0.3
Convolvulus arvensis	0.0		0.0		0.1				0.2
Echinochloa crus-galli	1.7		0.5			0.5			
Euphorbia helioscopia					0.0	0.0	0.1		
Fallopia convolvulus	0.0	0.4	0.3	0.7	3.9	1.2	0.0	0.9	0.9
Galinsoga parviflora			5.1						
Galiuma parine	0.2	0.1	0.1	0.1	0.1	0.1		0.4	
Chenopodium album			0.4	0.2	0.1	0.3	0.1		0.3
Chenopodium hybridum			1.1						0.1
Lamium amplexicaule	0.1						0.3		
Lamium purpureum						0.4			
Malva neglecta						0.1			
Microrrhinum minus					0.2			0.0	
Persicaria lapathifolia		0.0	1.1		0.0	0.6	0.1	0.1	
Plantago major							0.1		
Polygonum aviculare								0.2	
Silene noctiflora	1.0	0.5	0.1	0.4	2.1	0.3	0.9	0.8	
Sinapis arvensis	0.0	0.8	1.0	0.3	0.5		1.2	1.2	
Sonchus oleraceus						0.0	0.2		
Stellaria media	0.0				0.3				
Taraxacum officinale				0.0				0.0	
Thlaspi arvense			0.1		0.2	0.0	0.0	0.3	
Tripleurospermum inodorum				0.0	0.1	0.1			
Veronica persica	0.1				0.0		0.4	0.5	
Veronica polita		1.5	1.4		3.1	1.5	5.6	0.3	
Viola arvensis					0.3				
Number of specimen	5.0	3.5	15.9	2.3	12.0	5.5	9.4	5.5	1.9

The data concerning weed infestation of soil subject to conventional tillage were first processed by the DCA analysis. It resulted in the length of gradient amounting to 4.599. On the basis of this calculation, the Canonical Correspondence Analysis (CCA) was applied for further processing. The CCA defines the spatial arrangement of individual weed species and total precipitation in the selected months. The special arrangement is determined by the relationship between the total precipitation and the occurrence of weed species.

The variant of minimization tillage produced 39 different weed species in the monitoring period. Average numbers of weeds in the respective years of monitoring this tillage variant are stated in Table III.

The variant of no tillage produced 31 different weed species. Average numbers of weeds in the respective years of monitoring this tillage variant are stated in Table IV.

TABLE III
AVERAGE NUMBER OF WEEDS IN THE MINIMIZATION TILLAGE VARIANT

Weed species (pc.m^{-2})	Year of monitoring								
	2004	2005	2006	2007	2008	2009	2010	2011	2012
Amaranthus spp.	0.3		9.1			0.2	0.1		0.3
Anagallis arvensis					0.2				
Atriplex patula						0.0			
Arctium tomentosum							0.0		
Beta vulgaris					0.0				
Capsella bursa-pastoris			0.2	0.0			0.0		
Carduus acanthoides							0.0	0.0	
Cirsium arvense	0.8	0.7	1.5	0.2	2.5	0.2	0.5	0.7	
Convolvulus arvensis	0.0		0.3	0.7	0.3	0.8	1.5		0.1
Datura stramonium			0.0						
Echinochloa crus-galli	0.8								
Elytrigia repens				0.1					
Euphorbia helioscopia					0.0				
Fallopia convolvulus		0.3	0.1	0.0	2.6	0.5	0.1	0.1	0.3
Fumaria officinalis								0.0	
Galinsoga parviflora			4.8						
Galium aparine	0.0	1.2	1.1	1.1	0.3			0.3	
Chenopodium album	0.1		0.0		0.6		0.1	0.2	0.7
Chenopodiumficifolium									0.4
Chenopodium hybridum			0.1						
Lamium amplexicaule					0.2		1.2		
Malva neglecta			0.0						
Microrrhinum minus					0.4				
Papaver rhoeas					0.0				
Persicaria lapathifolia		0.0	0.5		0.3			0.1	
Plantago major			0.0				0.8		0.0
Polygonum aviculare					0.0				0.2
Senecio vulgaris							0.0		
Setaria pumila					0.0				
Silene noctiflora	0.2	1.1		0.0	0.5	0.1	0.1	0.3	
Sinapis arvensis		0.4	0.7	0.4	0.2		0.0	0.5	0.1
Sonchus oleraceus	0.2				0.2		0.8	0.3	
Stellaria media				0.2	0.1		0.6		
Taraxacum officinale				1.2	0.1	0.1	0.3		
Thlaspi arvense		0.0			0.4			0.7	0.4
Tripleurospermum inodorum				1.0	0.0			0.1	0.0
Veronica persica					0.8		1.2	0.5	
Veronica polita		0.3	0.5	0.2	3.3	1.3	15.9	0.2	
Viola arvensis					0.2				
Number of specimen	2.5	4.0	19.3	5.2	13.4	3.2	23.3	3.9	2.6

TABLE IV
AVERAGE NUMBER OF WEEDS IN THE NO-TILLAGE VARIANT

Weed species (pc.m^{-2})	Year of monitoring								
	2004	2005	2006	2007	2008	2009	2010	2011	2012
Amaranthus spp.	1.8		11.5			0.3	1.8		
Anagallis arvensis								0.1	
Artemisia vulgaris						0.1			
Beta vulgaris				0.0	0.1				
Capsella bursa-pastoris				0.3		0.0		1.8	
Carduus acanthoides				0.0					
Cirsium arvense	0.5	0.8	0.8	2.2	9.8	2.8	0.5		0.1
Convolvulus arvensis			0.7	0.1	1.5	0.9			1.1
Echinochloa crus-galli						0.2			0.3
Elytrigia repens				1.4					
Fallopia convolvulus	0.0		0.2		3.0	0.3	0.0		
Galinsoga parviflora			3.6						
Galium aparine		0.1	1.1	0.1	0.0			0.6	
Geranium pusillum								0.1	
Chenopodium album	0.2				7.4		0.2	0.1	0.4
Lactuca serriola			0.2				0.1	0.3	
Lamium amplexicaule					0.0			0.9	
Lamium purpureum						0.0			
Persicaria lapathifolia						0.3		0.1	
Plantago major				0.1		0.2		0.4	0.5
Polygonum aviculare			0.0		1.8			0.2	
Silene noctiflora		0.3	0.0	0.1	0.5				
Sinapis arvensis	0.0	0.4	0.4	0.5	0.0		0.0		
Sonchus oleraceus			0.8	0.0	0.4			0.5	
Stellaria media				0.3					
Taraxacum officinale				2.0	0.6			0.7	0.1
Thlaspi arvense					0.2			0.7	
Tripleurospermum inodorum	0.1	0.2		0.8	0.0		0.1	0.3	
Veronica persica								2.0	
Veronica polita		0.1	0.7	0.2	4.2	0.1		0.2	
Viola arvensis					0.0				
Number of specimen	2.8	1.8	20.0	8.2	29.6	5.1	2.8	9.0	2.5

The results are subsequently expressed by means of an ordination diagram. Weed species are shown as points; aggregate precipitation in the respective months is shown as vectors (arrows) expressing the amounts of rainfall. The minimum amount of precipitation is at the beginning of the vector and the maximum amount of precipitation lies at the end.

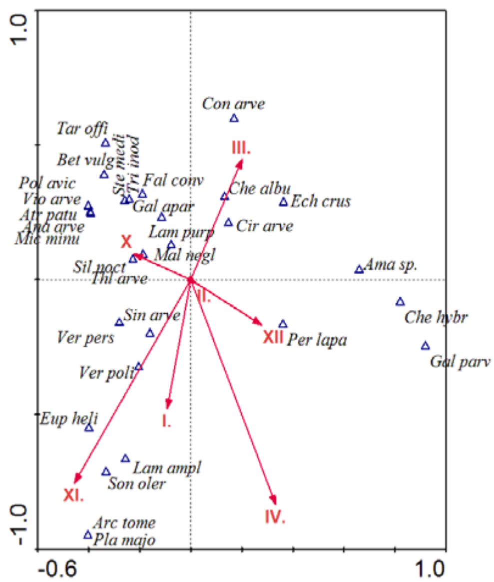

Fig. 1 Ordination diagram expressing the relationship between aggregate precipitation in selected months and weed species in the variant of conventional tillage (Trace = 1.325, F-ratio = 5.719, P-value = 0.0020)

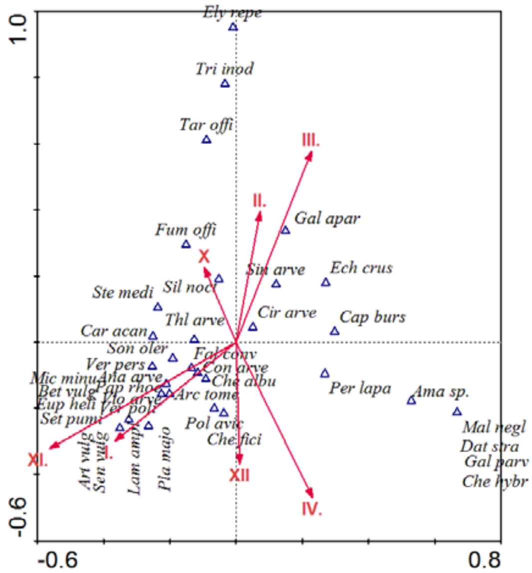

Fig. 2 Ordination diagram expressing the relationship between aggregate precipitation in selected months and weed species in the variant of minimization tillage (Trace = 2.171, F-ratio = 8.044, P-value = 0.0020)

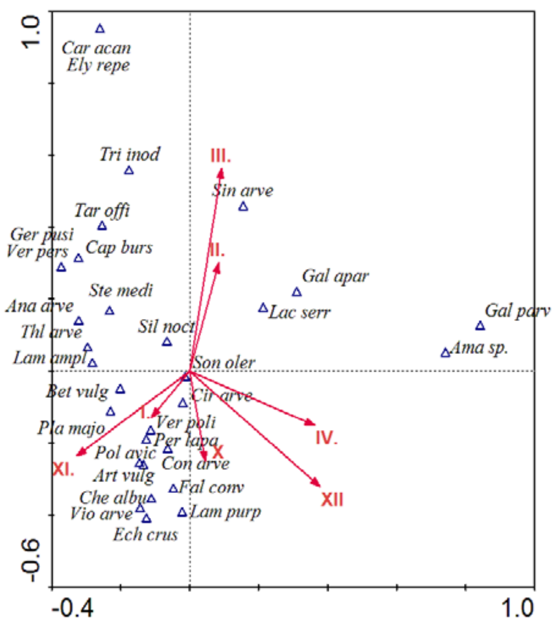

Fig. 3 Ordination diagram expressing the relationship between aggregate precipitation in selected months and weed species in the variant of no tillage (Trace = 1.947, F-ratio = 9.495, P-value = 0.0020)

Notes to Figs. 1–3: →X. aggregate precipitation for October, →XI. aggregate precipitation for November, →XII. aggregate precipitation for December, →I. aggregate precipitation for January, →II. aggregate precipitation for February, →III. aggregate precipitation for March, →IV. aggregate precipitation for April.

Ama sp. – *Amaranthus* spp., *Ana arve – Anagallis arvensis, Atrpatu – Atriplex patula, Arc tome – Arctium tomentosum, Art vulg – Artemisia vulgaris, Bet vulg – Beta vulgaris, Cap burs – Capsella bursa-pastoris, Car acan – Carduus acanthoides, Cir arve –Cirsium arvense, Con arve – Convolvulus arvensis, Dat stra – Datura stramonium, Ech crus – Echinochloa crus-galli, Ely repe – Elytrigia repens, Eup heli – Euphorbia helioscopia, Fal conv – Fallopia convolvulus, Fum offi – Fumaria officinalis, Gal parv – Galinsoga parviflora, Gal apar –Galium aparine, Ger pusi – Geranium pusillum, Che albu – Chenopodium album, Che fici – Chenopodium ficifolium, Che hybr – Chenopodium hybridum, Lac serr –Lactuca serriola, Lam ampl – Lamium amplexicaule, Lam purp – Lamium purpureum, Mal negl – Malva neglecta, Mic minu – Microrrhinum minus, Pap rhoe – Papaver rhoeas, Per lapa – Persicaria lapathifolia, Pla majo – Plantago major, Pol avic – Polygonum aviculare, Sen vulg – Senecio vulgaris, Set pumi – Setaria pumila, Sil noct – Silene noctiflora, Sin arve – Sinapis arvensis, Son oler – Sonchus oleraceus, Ste medi – Stellaria media, Tar offi – Taraxacum officinale, Thl arve – Thlaspi arvense, Tri inod –Tripleurospermum inodorum, Ver pers – Veronica persica, Ver poli – Veronica polita, Vio arve – Viola arvensis.*

The results of the CCA analysis, which assessed the influence of precipitation in the selected months on the weed occurrence under the conventional tillage are significant on the significance level of α = 0.002 for all the canonical axes (Fig. 1). Pursuant to the CCA analysis it can be established that higher amount of precipitation in October contributes to the higher weed infestation with the following species: *Atriplex patula, Beta vulgaris, Fallopia convolvulus, Galium aparine, Lamium purpureum, Malva neglecta, Microrrhinum minus, Silene noctiflora, Stellaria media, Taraxacum officinale, Thlaspi arvense, Tripleurospermum inodorum.* Precipitation in November and January contributes to the higher weed infestation with the following species: *Arctium tomentosum, Euphorbia helioscopia, Lamium amplexicaule, Plantago major, Sinapis arvensis, Sonchus oleraceus, Veronica persica, Veronica polita.* Higher amount of precipitation in March contributes to the higher weed infestation with the following species: *Cirsium arvense, Convolvulus arvensis, Echinochloa crus-galli, Chenopodium album.* Precipitation in December affected in particular the occurrence of *Persicaria lapathifolia.*

The data concerning weed infestation of soil subject to minimization tillage were first processed by the DCA analysis. The length of gradient was 5.902. On the basis of this calculation, the Canonical Correspondence Analysis (CCA) was applied for further processing.

The results of the CCA analysis, which assessed the influence of precipitation in the selected months on the weed occurrence under the minimization tillage are significant on the significance level of α = 0.002 for all the canonical axes (Fig. 2). Pursuant to the CCA analysis it can be established that higher amount of precipitation in October contributes to the higher weed infestation with the following species: *Fumaria officinalis, Silene noctiflora.* Higher precipitation in November and January contributes to the higher weed infestation with the following species: *Artemisia vulgaris, Lamium amplexicaule, Plantago major, Senecio vulgaris.* On the other hand, lower or average amounts of precipitation in November and January contribute to the higher weed infestation with the following species: *Anagallisarvensis, Arctium tomentosum, Beta vulgaris, Convolvulus arvensis, Euphorbia helioscopia, Fallopia convolvulus, Chenopodium album, Microrrhinum minus, Papaver rhoeas, Sonchus oleraceus, Setaria pumila, Veronica persica, Veronica polita, Viola arvensis.* Precipitation in December affected in particular the occurrence of *Chenopodium ficifolium* and *Polygonum aviculare*. Average and lower precipitation in February and March contributes to the higher weed infestation with the following species: *Capsella bursa-pastoris, Cirsium arvense, Echinochloa crus-galli, Galium aparine, Sinapis arvensis.*

The data concerning weed infestation of soil subject to no tillage were first processed by the DCA analysis. The length of gradient was 4.436. On the basis of this calculation, the Canonical Correspondence Analysis (CCA) was applied for further processing.

The results of the CCA analysis, which assessed the influence of precipitation in the selected months on the weed occurrence under no tillage are significant on the significance level of $\alpha = 0.002$ for all the canonical axes (Fig. 3). The results of the CCA analysis suggest that most of the species were influenced by other factors that aggregate precipitation. Higher precipitation in October, November and January contributed to the higher weed infestation with the following species: *Artemisia vulgaris, Beta vulgaris, Convolvulus arvensis, Echinochloa crus-galli, Fallopia convolvulus, Chenopodium album, Lamium purpureum, Plantago major, Veronica polita, Viola arvensis.* On the other hand, lower precipitation in these months resulted in higher occurrence of *Cirsium ravense* and *Sonchus oleraceus.* Higher precipitation in February and March contributed to the higher weed infestation with the following species: *Galium aparine, Lactuca serriola, Sinapis arvensis.*

The results clearly show that precipitation affects the incidence of most weed species in the selected months, but acts differently in the monitored variants of tillage technologies. The amount of precipitation probably affects the seed dormancy in the soil seed bank and possibly also the regeneration ability of persistent weeds. Dormancy and conditions of its termination are very specific for each species. Dormancy may be terminated or prolonged by precipitation at different times. This can later manifest itself in the decrease or increase of weed growth of a certain species.

The occurrence of *Veronica polita* species was markedly affected by precipitation in November and January in all the three tillage variants. Thus we can expect higher weed infestation by this species if precipitation is sufficient during these months.

Cirsium arvense behaved differently in different tillage variants. In the case of conventional tillage, its growth was supported by March precipitation. In the case of minimization tillage its growth was apparent if average or lower precipitation occurred in the months of February and March, and in the case of no-tillage variant, its occurrence was prompted by lower precipitation in October and January.

The growth of *Fallopia convolvulus* species on the plots with conventional tillage and no tillage was encouraged by higher precipitation in October. In the case of minimization tillage, its growth was supported by lower precipitation in November and January.

Sinapis arvensis responded differently to precipitation in the three monitored tillage variants. In the variant with conventional tillage, its occurrence was affected by lower precipitation in November. In the case of minimization tillage, its growth was supported by lower or average precipitation in February and March. On the other hand, in the case of no tillage, its higher occurrence was recorded after higher precipitation amounts in February and March.

The study of the relationship between aggregate amounts of rainfall and the level of weed infestation requires monitoring in the long run, which is demanding in terms of time and evaluation. Nevertheless, determination of the relationships will enable us predict the weed intensity and apply regulatory measures.

IV. Conclusion

The results show that precipitation in selected months significantly affects the occurrence of various weed species in spring barley. However, the response of the respective species was markedly different. Varying responses of one and the same weed species were ascertained in the monitored variants of tillage. The tillage method significantly changes the soil water regime, which is apparent also from different responses of weed to precipitation levels.

Clarification of these relationships would allow us to predict the intensity of weed growth on the basis of precipitation amount in the preceding period. Such forecast would be important for effective choice of herbicides and other methods of regulation.

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