Pak. J. Bot., 52(2): 697-701, 2020. DOI: http://dx.doi.org/10.30848/PJB2020-2(11)

THE EFFECT OF THREE TILLAGE TREATMENTS ON WEED INFESTATION IN MAIZE MONOCULTURE

SVETLANA CHOVANCOVA[1], FRANTISEK ILLEK[2] AND JAN WINKLER[1]

[1] Mendel University in Brno, Faculty of Agronomy, Brno, Zemedelska 1665/1, 61300 Brno, The Czech Republic
[2]Agroservis 1. zemedelska, 671 38 Visnove, The Czech Republic
Corresponding author's email: xchovan5@mendelu.cz.

Abstract

This study assessed the impact of using soil tillage on the weed infestation intensity and weed species composition in maize monoculture. Maize has been grown in monoculture consecutively in our research since 2001 and three treatments of soil tillage were applied: conventional tillage (CT), minimum tillage (MT) and no-tillage (NT). Maize monoculture occurs across large plots of land and due to the growth conditions of maize and emerging conservational tillage technologies a broad variety of weed species is introduced and widespread in such plots. The weed infestation in our research had been observed for four years between 2012 and 2015. An arithmetic method and the multivariate analyses of ecological data were used to determine the effect of tillage on weed infestation. The highest weed infestation mainly formed by perennial species was recorded in NT, whereas rich spectrum of annual weed species were more frequently observed in MT. Based on our results can be stated that the specific soil treatments have created different conditions not only for weed emergence, but also for soil properties. Thus, studying the effect of soil tillage treatments on weed infestation may enable further development of weed infestation prediction followed by a targeted application of herbicides leading to the farmers' cost cutting and less stress for environment.

Key words: Conventional tillage, Minimum tillage, No-tillage, CCA analysis

Introduction

Maize is the third most produced commodity on the planet today; however, there are large differences in yields following the particular conditions of a region (Faostat, 2013; Ranum *et al.*, 2014). Maize is well recognized as a wide-row crop with gradual growth at the beginning stage as well as greatly sensitive to soil erosion (Whalen & Sampedro, 2010). Additionally maize is highly responsive and suppressed by the early competitive weed species (Cerrudo *et al.*, 2012) therefore it is necessary to control the weed occurrence (Page *et al.*, 2012). Concurrently, competing with weeds for the essential resources may significantly reduce the maize crop growth (Liebman *et al.*, 2004). Insufficient weed control decreases water and nitrogen efficiency use that is the fundamental element for achieving high yields (Thomson *et al.*, 2000). Weeds and weed control practices are major worldwide agricultural concerns and many farmers heavily rely on high input cultivation management and herbicide dependent strategy (Meissle *et al.*, 2010; Vasileiadis *et al.*, 2011). Following that, the increasing ability of weed species to develop herbicide resistance is another critical challenge (Holt, 1994; Buhler *et al.*, 2000). Nevertheless, a long-term intensification of agricultural systems followed by adjusted tillage treatments in Europe (Le Féon *et al.*, 2010) have also triggered some negative impacts (soil erosion, a decrease of soil fertility and biodiversity, etc.; Matson *et al.*, 1997). However, the energy efficiency of conservational tillage (Moitzi *et al.*, 2019), urge for sustainable agriculture and the general economic pressure on cost cutting have led farmers to change their tillage management, to diminish a number of crops and optionally even to cultivate crops in a monoculture (Briggs and Walters, 2001). Additionally, according to the observation by Neugschwandtner *et al.*, (2014, 2015), tillage treatments affect both soil chemical properties and potential crop yields. Regarding to their results, NT compared to CT had resulted in improved crop yield in drier conditions, due to enhanced water availability (Neugschwandtner *et al.*, 2015). Thus, tillage treatment may also act as a selective factor for weed occurrence and prioritize the growth of some species. This is the origin of the process, which is called by Briggs and Walters (2001) the microevolution on arable lands. Therefore, the weed control strategies should be understood as an integrated science encompassing various methods (Liebman *et al.*, 2004). Accordingly, a repetitive cultivation of maize monoculture together with a soil tillage management have created a new framework not only for the cultivation of maize, but growth of weeds as well. A study of the relationship between soil tillage treatments and a level of weed infestation requires long-term monitoring which is time- and labour-demanding. However, it may serve as an effective tool for weed infestation prediction followed by a targeted application of herbicides.

Materials and Methods

Experimental site: The long-term field research is situated at the Agroservis 1. zemedelska, agriculture enterprise in Visnove (GPS 48.986816, 16.157876, Czech Republic). The experimental fields belong to the corn production area with rather flat terrain at an altitude of 230 m asl. The long-term average annual temperature is 8.5°C and annual total precipitation reaches 470 mm (data of long-term monitoring between 1961 and 1990 from the meteorological station nearest to the experimental site). The topsoil layer is a medium-heavy soil, recognized as chernozem, with the thickness of topsoil profile exceeding a depth of 0.6 m. The mean value of organic matter is 1.47 % and pH neutral (6.61).

Design and soil management: The field trail with a total area of 21.83 ha has been designed as a long-term experiment where maize has been grown consecutively on the same land since 2001. The size of each evaluated plot was 150 × 100 m for each tillage treatment applied as follows throughout the whole duration of the experiment: conventional tillage (CT) – ploughing was carried out by reversible plow with rotatable to a depth of 0.22 m. Sowing with fertilizer application was performed by sowing combinations followed by rolling in spring. Minimum tillage (MT) – shallow tillage was carried out by disc cultivator to a depth 0.10 – 0.12 m followed by sowing with fertilizer application. No-tillage (NT) – the soil surface was not being cultivated after harvesting and a direct sowing with ferilizer application was then carried out by a sowing combinations followed by rolling. It should be noted, that same industrial fertilizers were used in all tillage treatments and also the same pre-emergent and post-emergent herbicides were applied.

Methods of weed infestation assessment: The weed infestation was evaluated by numerical method where the number of individual weeds was counted in each tillage treatment of monitored plots on 1 m^2 in 30 repetitions randomly selected within the typical vegetation growth. Evaluation was conducted every year (from 2012 to 2015) in August. Overall weed control was conducted when maize was according to BBCH-scale at growth stage from 00 to 14, therefore the evaluation of weed infestation had been carried out in August (maize at growth stage 69-75), when the effects of applied herbicide were not yet significant. Following herbicide applications were not possible due to the height of crops and thus the effect of soil tillage treatments could have been evaluated. The species nomenclature follows the Key to the flora of the Czech Republic (Kubát *et al.*, 2002).

The obtained data were processed by multivariate analyses of ecological data to reveal the effect of the applied tillage treatment on the varying weed species spectrum in maize. The objective of this method is to identify the structure and relationships in a complex data set encompassing many sampling units and variables. Groupings are perceived regarding the data, similarities and differences displaying into the ordination diagrams. In our case, one grouping refers to weeds on individual plots (species composition, number of individuals) and the other grouping covers the soil tillage treatments in terms of long-term maize monoculture. Before selecting the optimal analysis characterizing the correlation between groups, the *Length of Gradient* was identified by indirect gradient analysis (DCA). Based on the revealed length of the gradient (4.007), the Canonical Correspondence Analysis (CCA) was selected for further processing. This analysis defines the spatial arrangement of particular weed species in relation to the soil tillage treatments. A total number of 499 permutations were calculated in a Monte Carlo test (Ter Braak & Smilauer, 1998).

Results

Thirty-three various species of weeds had been found on evaluated plots within the monitoring period. The average numbers of occurring weeds across treatments and years are shown in Table 1. The most abundant weed infestation had been identified in NT with average number of individuals 11.09 pcs.m^{-2} and weed species *Convolvulus arvensis* L. occurred here most often. Plots that had been influenced least by weed occurrence were those where CT was applied. An average number of individuals found in this treatment was 6.15 pcs.m^{-2} and species *Echinochloa crus-galli* (L.) P.B. was the most abundant.

The results of CCA analysis are significant at the significance level $\alpha = 0,002$ for both canonical axes and are shown in Fig. 1. Weed species and tillage treatments are displayed as points of different form and color. Following these results identified weed species were divided into 5 groups. The first group of weeds occurred mainly in CT, represented by species as follow: *Anagallis arvensis* L., *Atriplex patula* L., *Atriplex sagittata* BORKH., *Bromus sterilis* L., *Echinochloa crus-galli* L., *Euphorbia helioscopia* L., *Fallopia convolvulus* (L.) Á. LÖVE, *Polygonum aviculare* L., *Rubus* spp., and *Taraxacum* sect. *Ruderalia*. The second group of weed species was identified mostly in CT and MT, very few or none in NT: *Chenopodium hybridum* L., *Thlaspi arvense* L., and *Viola arvensis* MURRAY. The third group occurred especially in MT, represented by species as follows: *Datura stramonium* L., *Elytrigia repens* (L.) NEVSKI, and *Persicaria lapathifolia* (L.) DELARBRE. The weed species *Convolvulus arvensis*, *Stellaria media* (L.) VILL., and *Urtica dioica* L. represent a fourth group of weeds, which were found in MT and NT. The fifth group, recorded predominantly in NT is represented by species as follows: *Amaranthus* sp., *Cirsium arvense* (L.) SCOP., *Conyza canadensis* (L.) CRONQUIST, *Equisetum arvense* L., *Euphorbia cyparissias* L., *Lathyrus tuberosus* L., *Linaria vulgaris* MILL., *Sambucus nigra* L., *Setaria pumila* (POIRET) R. et SCH., *Sonchus oleraceus* L., and *Veronica polita* FRIES. It can be stated that the influence of weather conditions in each year may have influenced the intensity of weed infestation, which had been the highest during the first year of observation, yet the species spectrum diversity had been the lowest. Weed infestation of the first year had been formed mainly by species *Echinochloa crus-galli*, which occurrence had declined in following years. Additionally, the results showed that the combination of the monoculture conditions and particular soil treatment have created certain environment affecting differently the intensity (number of weeds) of weed infestation during the monitored period. Therefore, we can assume that those factors have been changing soil properties and they have been also creating different conditions for weed emergence depending on the weather. These circumstances influence not only the intensity of weed infestation but at the same time the occurrence of individual weed species.

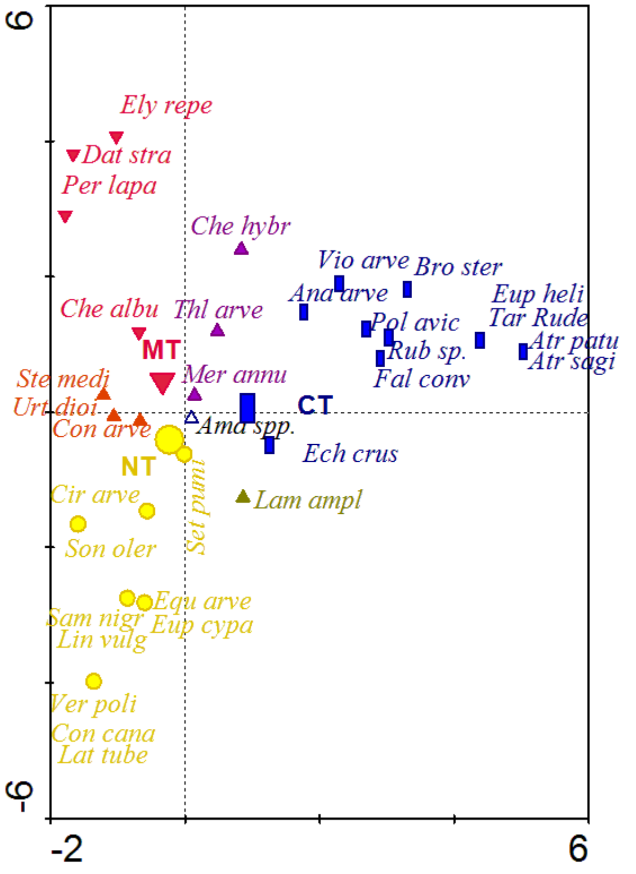

Fig. 1. CCA ordination diagram showing relations between tillage treatments and weed species in maize monoculture growths (Trace = 0.361, F-ratio = 5.905, P-value = 0.002).

Note: CT: conventional tillage, MT: minimum tillage, NT: no tillage

Legend: Ama sp. – *Amaranthus* spp., *Ana arve – Anagallis arvensis, Atr patu – Atriplex patula , Atr sagi – Atriplex sagittata, Bro Ster – Bromus sterilis, Cir arve – Cirsium arvense, Con arve – Convolvulus arvensis, Con cana – Conyza canadensis, Dat stra – Datura stramonium, Ech crus – Echinochloa crus-galli, Ely repe – Elytrigia repens, Equ arve – Equisetum arvense, Eup cypa – Euphorbia cyparissias, Eup heli – Euphorbia helioscopia, Fal conv – Fallopia convolvulus, Che albu – Chenopodium album, Che hybr – Chenopodium hybridum, Lam ampl – Lamium amplexicaule, Lat tube – Lathyrus tuberosus, Lin vulg – Linaria vulgaris, Mer annu – Mercurialis annua, Per lapa – Persicaria lapathifolia, Pol avic – Polygonum aviculare, Rub sp. – Rubus* spp., *Sam nigr – Sambucus nigra, Set pumi – Setaria pumila, Son oler – Sonchus oleraceus, Ste medi – Stellaria media, Tar Rude – Taraxacum* sect. *Ruderalia, Thl arve – Thlaspi arvense, Urt dioi – Urtica dioica, Ver poli – Veronica polita, Vio arve – Viola arvensis.*

Discussion

The significant differences are apparent between the weed species spectrum in maize monoculture under different tillage treatments. The major differences had been observed between the conventional tillage (CT) and remaining treatments of soil conservational tillage (MT, NT). CT greatly supported the occurrence of early spring species (*Anagallis arvensis*, *Fallopia convolvulus*, *Polygonum vulgare*) and late spring species (*Atriplex patula*, *Echinochloa crus-galli*, *Euphorbia helioscopia*). Overwintering weed species (*Sonchus oleraceus*, *Stellaria media*) and perennial species (*Cirsium arvense*, *Convolvulus arvensis*, *Lathyrus tuberosus*, *Linaria vulgaris*) had been observed mainly in MT and NT. Therefore, we can assume the increasing occurrence of persistent weed species with the increased popularity of soil conservation tillage (MT, NT). Species *Convolvulus arvensis* was the most frequently represented weed species overall. Its occurrence was very prevalent, particularly in NT. This perennial weed is characterized by pulpy root system easily broken, but capable to quickly regenerate (Crabtree & Westwood, 1976). According to the research of Jurado-Expósito *et al.*, (2004) the crop rotation had greatly influenced the density of species *Convolvulus arvensis* and had become an increasingly prevalent problematic species in NT management. Moreover, Burns *et al.*, (2013) considered another perennial species *Cirsium arvense* also as a problematic invasive weed, particularly of the northern hemisphere, which requires targeted management using integrating control approaches, in order to achieve a suppression of this species. Graglia *et al.*, (2006) also suggested intensive soil operations including hoeing and mowing to decrease the occurrence of above-mentioned species and to achieve a satisfactory yield as well. Other authors (Mayor & Maillard, 1995) also described the increase of perennial weeds due to the reduction of the depth of tillage. Additionally, perennial weed species can unfavorably influence the crop productivity in organic cropping (Turner *et al.*, 2007). Concurrently, the quality of the production, crop yield or cultivation operations may be aggravated by vigorous growth of perennials and their abundant occurrence (Graglia *et al.*, 2006). The most occurred species in MT was *Chenopodium album*, which is classified as a late spring species, rather thermophilous species broadly considered as typical weed species in wide-row crops (Liebman *et al.*, 2004). Based on some results (Buhler, 1992; Barberi *et al.*, 1998) can be also stated, that the cultivation management in terms of conservational tillage support the incidence of *Chenopodium album*, particularly when MT is applied. Another late spring weed species, *Echinochloa crus-galli*, had been abundantly identified in all tillage treatments. Nevertheless, its presence was dominant in CT and NT. Its great germination rate out of seeds lying on the soil surface was also well recognized by research of Chauhan and Johnson (2011). Our results are most likely the combination of both, seeds from the soil surface and large seed stock in the soil seed bank. Species *Echinochloa crus-galli* is perceived as the world's most harmful grass weed species (Rao *et al.*, 2007) with a major share in weed infestation in various crops, maize included (Holm *et al.*, 1991). Chauhan & Johnson (2011) stated that species *Echinochloa crus-galli* and others with similar germination requirements have a great potential to be very problematic in NT treatments. Moreover, when seeds can remain dormant for several years. However, the seed bank may be greatly reduced by using conventional tillage (Chin, 2001). This statement can be underpinned also by our results when the lowest average weed infestation had been observed in CT. An increasing uniformity of the flora on fields was, according to Baessler & Klotz (2006) attributed to the large extent of the agricultural intensification (e.g. the application of mineral fertilizer, crop rotation). The former typical weed species of arable lands were not able to survive the rapid intensification of the last century, so whether they have generally decreased their occurrence or had disappeared entirely. However, the average number of weed species has not changed significantly since 1990 (Baessler & Klotz, 2006).

Some other weed species not considered as typical species of arable lands in the Czech Republic (e.g. *Urtica dioica, Mercurialis annua*) had been identified on our experimental plots. Their occurrence had been observed particularly in areas of conservational tillage treatments, most likely due to the specific conditions created by maize monoculture and minimum tillage.

Conclusion

The specificity of maize monoculture and maize growth structure in general open an opportunity for forming specific weed spectrum, which has been not recognized as typical before. Identifying the importance and the effect of tillage treatments can create the new approaches and measures useful for weed management. And based on our results we have been already looking at the increasing occurrence of persistent weed species, its growing intensity depending on tillage treatment, etc. Thus, such a trend will lead to a change of the growth patterns of weeds, followed by new challenges in weed control, including the development of new active substances, herbicide application, etc.

Table 1. The average number of weed individuals and species identified in maize (pcs.m^{-2}).

Weed species	Soil tillage			Monitored year			
	CT	MT	NT	2012	2013	2014	2015
Amaranthus sp.	0.16	0.20	0.31	0.08	0.36	0.12	0.33
Anagallis arvensis L.	0.03	0.02		0.02	0.03		
Atriplex patula L.	0.05						0.07
Atriplex sagittata BORKH.	0.06						0.08
Bromus sterilis L.	0.04	0.02					0.08
Cirsium arvense (L.) SCOP.	0.40	0.71	2.78	0.81	1.66	0.48	2.23
Convolvulus arvensis L.	0.43	1.94	3.03	0.31	1.53	1.50	3.84
Conyza canadensis (L.) CRONQUIST			0.01	0.01			
Datura stramonium L.		0.43			0.41		0.17
Echinochloa crus-galli (L.) P.B.	2.48	0.98	1.86	3.68	1.77	0.87	0.79
Elytrigia repens (L.) NEVSKI		0.03					0.04
Equisetum arvense L.			0.02				0.02
Euphorbia cyparissias L.			0.16				0.21
Euphorbia helioscopia L.	0.05					0.07	
Fallopia convolvulus(L.) Á. LÖVE	0.42	0.11	0.04	0.32		0.27	0.17
Chenopodium album L.	0.79	3.13	1.08	5.27	0.11	1.00	0.29
Chenopodium hybridum L.	0.08	0.11	0.02			0.26	0.02
Lamium amplexicaule L.	0.03		0.04			0.09	
Lathyrus tuberosus L.			0.01	0.01			
Linaria vulgaris MILL.			0.02				0.02
Mercurialis annua L.	0.23	0.28	0.35		0.58	0.27	0.29
Persicaria lapathifolia (L.) DELARBRE		0.02		0.02			
Polygonum aviculare L.	0.32	0.12	0.02	0.09	0.30		0.21
Rubus sp.	0.15	0.03			0.24		
Sambucus nigra L.			0.04			0.02	0.03
Setaria pumila (POIRET) R. et SCH.	0.15	0.14	0.38		0.33	0.33	0.23
Sonchus oleraceus L.		0.02	0.06		0.10		
Stellaria media (L.) VILL.		0.08	0.10			0.16	0.08
Taraxacum sect. Ruderalia	0.02					0.02	
Thlaspi arvense L.	0.07	0.08	0.05		0.07	0.19	
Urtica dioica L.	0.12	0.53	0.73	0.06	1.20	0.46	0.12
Veronica polita FRIES			0.01	0.01			
Viola arvensis MURRAY	0.10	0.05		0.01	0.06	0.13	
Number of individuals	**6.15**	**9.01**	**11.09**	**10.70**	**8.74**	**6.22**	**9.33**

CT: Conventional tillage, MT: Minimum tillage, NT: No tillage

References

Baessler, C. and S. Klotz. 2006. Effects of changes in agricultural land-use on landscape structure and arable weed vegetation over the last 50 years. *Agri. Ecosyst. Environ*., (115): 43-50.

Barberi, P., A. Cozzani, M. Macchia and E. Bonari. 1998. Size and composition of the weed seedbank under different management systems for continuous maize cropping. *Weed Res.*, (38): 319-334.

Briggs, D. and S.M. Walters. 2001. *Plant Variation and Evolution*. (3rd Ed) Cambridge University Press, Cambridge.

Buhler, D.D. 1992. Population dynamics and control of annual weeds in corn (*Zea mays*) as influenced by tillage system. *Weed Sci.*, (40): 241-248.

Buhler, D.D., M. Liebman and J.J. Obrycki. 2000. Theoretical and practical challenges to an IPM approach to weed management. *Weed Sci*., (48): 274-280.

Burns, E.E., D.A. Prischmann-Voldseth and G.G. Graming. 2013. Integrated Management ofCanada Thistle (*Cirsium arvense*) with Insect Biological Control and Plant Competition under Variable Soil Nutrients. *Inv. Plant Sci. and Manag*., (6): 512-520.

Cerrudo, D., E.R. Page, M. Tollenaar, G. Stewart and C.J. Swanton. 2012. Mechanisms of Yield Loss in Maize Caused by Weed Competition. *Weed Sci*., (60): 225-232.

Chauhan, B.S. and D.E. Johnson. 2011. Ecological studies on *Echinochloa crus-galli* and theimplications for weed management in direct-seeded rice. *Crop Protection*, (30):1385-1391.

Chin, D.V. 2001. Biology and management of barnyardgrass, red sprangletop and weedy rice. *Weed Biol. Manag*., (1): 37-41.

Crabtree, G.D. and M.N. Westwood. 1976. Effects of weed control method and rootstock onflowering, growth and yield of apple. *J. Amer. Soc. for Hort. Sci.*, (101): 454-456.

Faostat, Food and Agriculture Organization of the United Nation. 2013. Statistics Division. Available from: http://faostat.fao.org/site/345/default.aspx.

Graglia, E., B. Melander and R.K. Jensen. 2006. Mechanical and cultural strategies to control *Cirsium arvense* in organic arable cropping systems. *Weed Res*., (46): 304-312.

Holm, L.G., J.V. Pancho, J.P. Herberger and D.L. Plucknett.1991. *A Geographic Atlas of World Weeds*. Krieger Publishing Company, Florida.

Holt, J.S. 1994. Impact of weed control on weeds: new problem and research needs. *Weed Technol*., (8): 400-402.

Jurado-Expósito, M., F. López-Granados, J.L. González-Andújar and L.García-Torres. 2004. Spatial and temporal analysis of *Convolvulus arvensis* L. populations over four growing seasons. *Europ. J. Agron*., (21): 287-296.

Kubát, K., L. Hrouda, J. Chrtek, Z. Kaplan, J. Kirschner and J. Štěpánek. 2002. *Key to the flora of the Czech Republic*. Academia, Prague.

Le Féon, V., A. Schermann-Legionnet, Y. Delettre, S. Aviron, R. Billeter, R. Bugter, F. Hendrickx and F.Burel. 2010. Intensification of agriculture, landscape composition and wild bee communities: a large scale study in four European countries. *Agric. Ecosyst. Environ*., (137): 143-150.

Liebman, M., CH.L. Mohler and CH.P. Staver. 2004. *Ecological management of agricultural weeds*. Cambridge University Press, Cambridge.

Matson, P.A., W.G. Parton, A.G. Power and M.S. Swift. 1997. Agricultural intensification and ecosystem properties. *Science*, (227): 504-509.

Mayor, J.P. and A. Maillard. 1995. Results from an over-20-years-old ploughless tillage experiment at Changins. *Revue Suisse d'Agri.*, (27): 229-236.

Meissle, M., P. Mouron, T. Musa, F. Bigler, X. Pons, V.P. Vasileiadis, S. Otto, D. Antichi, J. Kiss, Z. Pálinkás, Z. Dorner, R.van der Weide, J. Groten, E. Czembor, J. Adamczyk, J.B. Thibord, B. Melander, G. Cordsen Nielsen, R.T. Poulsen, O. Zimmermann, A. Verschwele and E. Oldenburg. 2010. Pests, pesticide use and alternative options in European maize production: current status and future prospects. *J. Appl. Entomol*., (134): 357-375.

Moitzi, G., R.W. Neugschwandtner, H.P. Kaul, H. Wagentristl. 2019. Energy efficiency of winter wheat in a long-term tillage experiment under Pannonian climate conditions. *Europ. J. Agron*., (103): 24-31.

Neugschwandtner, R.W., H.P. Kaul, P. Liebhard and H. Wagentristl. 2015. Winter wheat yields in a long-term tillage experiment under Pannonian climate conditions. *Plant Soil Environ*., (61): 145-150.

Neugschwandtner, R.W., P. Liebhard P., H.P. Kaul and H. Wagentristl. 2014. Soil chemical properties as affected by tillage and crop rotation in a long-term field experiment. *Plant Soil Environ*., (60): 57-62.

Page, E.R., D. Cerrudo, P. Westra, M. Loux, K. Smith, Ch. Foresman, H. Wright and C.J. Swanton. 2012. Why Early Season Weed Control Is Important in Maize. *Weed Sci*., (60): 423-430.

Ranum, P., J.P. Pena-Rosas and M.N. Garcia-Casal. 2014. Global maize production, utilization and consumption. *Ann. N.Y. Acad. Sci*., (1312): 105-112.

Rao, A.N., D.E. Johnson, B. Sivaprasad, J.K. Ladha and A.M. Mortimer. 2007. Weed management in direct-seeded rice. *Adv. in Agron.*, (93): 155-255.

Ter Braak, C.J.F. and P. Smilauer. 1998. CANOCO Reference Manualand User's Guide to Canoco for Windows: Software for Canonical Community Ordination, Microcomputer Power, New York.

Thomson, T.L., T.A. Doerge and R.E. Godin. 2000. Nitrogen and water interactions in subsurface drip irrigated cauliflower. *Soil Sci. Soc. Amer. J.*, (64): 412-418.

Turner, R.J., G. Davies, H. Moore, A.C. Grundy and A. Mead. 2007. Organic weed management: a review of the current UK farmer perspective. *Crop Prot.*, (26): 377-382.

Vasileiadis, V.P., M. Sattin, S. Otto, A. Veres, Z. Pálinkás, R. Ban, X. Pons, P. Kudsk, R. Van der Weide, E. Czembor, A.C. Moonen and J. Kiss. 2011. Crop protection in European maize-based cropping systems: current practices and recommendations for innovative integrated pest management. *Agri. Syst.*, (104): 533-540.

Whalen, J.K. and L. Sampedro. 2010. *Soil ecology and management.* CABI Publishers, Wallingford.

(Received for publication 26 July 2018)