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Species composition and density of weeds in a grain maize crop depending of soil tillage

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Abstract. *The study was carried out during 2014-2016 on slightly leached chernozem soil type. The species composition and density of weeds were studied in grain maize grown after previous crop wheat under the following main soil tillage types: ploughing at 24-26 cm, chisel plough at 24-26 cm and no-tillage (direct sowing). The additional tilths of the areas with ploughed and loosened soil included single disking in autumn and double pre-sowing harrowing in spring. A total herbicide was applied for control of the emerging weeds in the variant with direct sowing. The weed control was done according to the standard technology for growing of the crop in this region – treatment with herbicides at stage 3rd-5th leaf of the plants. Weed infestation was read in spring prior to the pre-sowing tillage, immediately before the vegetation treatment with herbicides, and after harvesting. The type of main soil tillage had a statistically significant effect on the species composition and the density of weeds in the grain maize crops grown after previous crop wheat. The use of ploughing, in parallel with the use of chemicals for weed control, decreased the weed infestation in the maize crops. The lower density of weeds under this main soil tillage type was related to changes in the composition and the relative percentage of the respective species in the total infestation. The use of tilths without turning the surface layer and no-tillage in the crop rotation, in spite of the application of herbicides, contributed to the increase of the amount of weeds. The reason for this was the higher variability of weed species typical for shallow tillage types.*

Keywords: direct sowing, herbicides, infestation, ploughing, slightly leached chernozem, treatment

Introduction

Soil tillage was one of the first agricultural activities of the ancient humans after they became sedentary. This activity was aimed at loosening the surface soil layer to make favourable conditions for planting seeds and development of the agricultural plants and destroying the undesirable vegetation inside the crop.

Maize ranks third in production, following wheat and rice. It is high in carbohydrates, fats, proteins and some of the important vitamins and minerals (Stoyanova and Petkova, 2009). Maize occupies about 14% of the arable land in EU-28. This crop is grown primarily for grain (56%) and forage (40%), and the produced sweet corn (4%) is for direct human consumption. The fodder obtained from maize and most of the grain maize are for animal feed. The remaining quantities of maize are for direct human consumption in the form of polenta or flour (CEPM, http://www.maizeurop.com/structure/cepm/chiffres/).

The production potential of maize becomes evident when the optimal combination of a complex of factors is present, which includes the hybrids used, the agro ecological and climatic conditions, and the applied agricultural technologies (Delibaltova, 2014, 2018; Kirchev, 2016). Besides the changeable agro ecological conditions, another factor, which may reduce the yields obtained from this crop, is the competition with weeds for environmental resources (Rajcan and Swanton, 2001). The competitiveness of the weed plants depends of their growth rate and their species affiliation, the availability of nutrients at their habitat, the applied agronomy practices and the type of the agricultural crop they grow (Quasem and Hill, 1995).

Over 200 weeds have been detected in the areas occupied with maize in the EU countries, which are the main producers of this crop; they include both dicotyledonous and monocotyledonous species (Dewar, 2009). Due to its comparatively slow initial growth rate, maize is rather susceptible to weed vegetation competition (Głowacka, 2011). Its growing at wide inter-row spacing allows using mechanical control of weeds (Raffaelli et al., 2005). However, due to their incomplete destruction in the rows of the maize crop, this

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method is not efficient enough (Abdin et al., 2000). The weed infestation during the growth season of maize may decrease the grain yield by 28-100% (Pandey et al., 2001).

Shrestha et al. (2002) pointed out that the development of strategies for integrated control of weeds in contemporary agriculture requires knowledge on the mechanisms, which affect the composition of the weed flora. In this relation, the soil tillage types involved in crop rotation are one of the practices, which influence the species in the weed associations and their density. The soil tillage systems are specific and depend on the type of crop, the soil and the climate (Rasmussen, 1999).

The mass introduction of chemicals in contemporary agriculture and the aim of lessening the energy expenses have contributed to a revision of the use of deep ploughing as a main type of soil tillage for growing spring crops; this type of soil tillage is juxtaposed to technologies based on minimal and no-tillage and tillage without turning the surface soil layer, ensuring good yields while significantly saving labour, fuels and equipment (Astier et al., 2006; Liu et al., 2009; Boomsma et al., 2010; Sharma et al., 2011; Videnović et al., 2011; Zhang et al., 2011; Aikins et al., 2012; Wyngaard et al., 2012; Qingjie et al., 2014; Yankov et al., 2014; Salem et al., 2015).

The aim of this investigation was to study the species composition and density of weeds in a grain maize crop depending on the applied main soil tillage type.

Material and methods

The investigation was carried out during 2014-2016 in the area of General Toshevo town, situated in the South Dobrudzha region. This region occupies the north-eastern part of Bulgaria and shares boundaries with Romania to the north, with the Black Sea to the east, with the Ludogorie plateau to the west and with the Varna-Provadia plain to the south. Geographically, it is the southern part of the Dobrudzha plateau, which reaches to the north through the territory of Romania to the mouth of the Danube River.

The main soil type in this area is slightly leached chernozems. Their mechanical composition ensures favourable soil moisture regime (Yolevsky et al., 1959). The soil reaction is neutral (pH=7). The thickness of the humus horizon is about 0.70 m. These soils contain moderate reserves of total nitrogen. The reserves of P_2O_5 are from low to moderate, and of K_2O – from moderate to good.

The analysis of the meteorological data showed that the investigation was carried out in years with variable climatic conditions. The air temperature in April, at the end of which maize emerges, was higher than normal in 2014 and 2016 (Figure 1). The mean diurnal air temperature in April of 2015 was close to the norm. The rest of the months, when the active vegetative growth of maize occurred, were warmer than normal, with the exception of May 2016 and June 2014. The precipitation sum during the vegetative growth in 2014 was by 40.4% higher than the norm. In each of the years, the amount of rainfalls was close to the climatic sum (2016). Year 2015 was with a lower sum of vegetative growth rainfalls – 180.5 mm, which constituted 63.0% from the mean long-term sum. Although the amount of rainfalls over the investigated years varied, they were comparatively evenly distributed and ensured normal development of the maize plants.

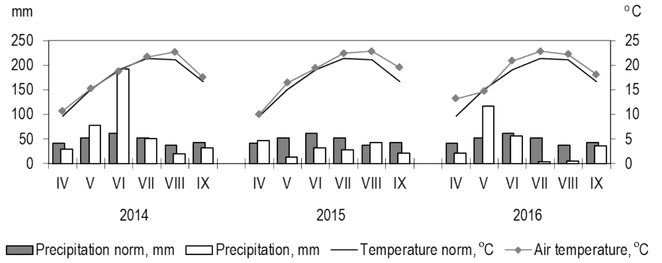

Figure 1. Air temperature and precipitation during the vegetation period of 2014-2016

For the purposes of this study, variants with grain maize grown after previous crop wheat were analyzed. The species composition and density of the weeds were studied, using the following types of main soil tillage – ploughing at 24-26 cm, treatment of the crop with herbicide during the vegetative growth of plants [conventional tillage (CT)] – check variant; chisel plough at 24-26 cm, treatment of the crop with herbicide during the vegetative growth of plants (CP); no-tillage – NT (direct sowing), treatment of the crop with herbicide during the vegetative growth of plants.

The main soil tillage was done early, in August. The additional tilths of the ploughed and loosened areas included single disking in autumn, and double pre-sowing cultivation with harrowing in spring. A total herbicide was applied once or twice to destroy the emerging weeds in the variant with direct sowing. In the cases of strong infestation, spraying was applied in autumn and in spring, prior to planting. In the cases without weeds, only a single pre-sowing spraying was used.

The grain maize was planted at sowing norm 55 000 plants/ha. For chemical control of the weeds, the most widely used herbicide for this crop in Bulgaria and in Dobrudzha region – 2.4 D-Amine (1.2 L ha^{-1}) was applied at stage 3^{rd} – 5^{th} leaf.

The readings on the species composition and density of the weeds were performed three times during the year. The first reading was done in spring, prior to the pre-sowing tillage. The second reading was done immediately before the vegetative treatment of the maize crop with herbicide, and the third one – at harvesting.

The weeds were determined as a total number by species, in eight replications, along the diagonals of the experimental plots. The size of the reading area of each replication was 1 m^2, 0.7x1.45 m, respectively, in order to take into account the species composition and density of the weeds inside the rows and in the spaces between them in all investigated variants.

In order to follow the statistical significance in the species composition of the weeds in a grain maize crop grown under different types of main soil tillage and different meteorological conditions over the years of study, as well as the interaction between them, dispersion and regression analyses were carried out.

Results and discussion

During the investigation, a total of 10 weed species were determined. After direct sowing, the total number of weeds read in spring was the highest – 22.97 plants/m^2 (Table 1). Next came chisel ploughing without turning the surface layer. The lowest was the number of weeds after traditional ploughing. Among the weeds registered prior to the pre-sowing tilths, *Amaranthus retroflexus* L. was predominant after ploughing, *Sinapis arvensis* L. – after chisel ploughing, and *Polygonum convolvulus* L. – after direct sowing. *Sinapis arvensis* L. ranked second in density after ploughing, and *Arenaria serpyllifolia* L. – after chisel ploughing and no-tillage. It should be noted that the species composition of the weeds after ploughing was more limited in comparison to the tillage without turning of the soil layer and direct sowing. Under these alternative ways for main soil tillage, the species composition of weeds was enriched with the occurrence of *Papaver rhoeas* L., *Viola tricolor* L., *Convolvulus arvensis* L. and *Cirsium arvense* L. At the same time, before applying the spring pre-sowing practices, *Sinapis arvensis* L. was not observed in the areas with direct sowing. The statistical results were significant at different levels of P.

Table 1. Species composition and density of weeds prior to pre-sowing tillage for a grain maize crop

Weed species and number (m^2)	CT	CP	NT
Arenaria serpyllifolia L.	2.01	4.13^{c}	4.97^{c}
	^{a} LSD $_{0.05}$	^{b} LSD $_{0.01}$	^{c} LSD $_{0.001}$
	1.05	1.43	2.04
Sinapis arvensis L.	3.29	3.85	—
	^{a} LSD $_{0.05}$	^{b} LSD $_{0.01}$	^{c} LSD $_{0.001}$
	0.60	0.97	1.45
Polygonum convolvulus L.	2.66	2.74	5.51^{c}
	^{a} LSD $_{0.05}$	^{b} LSD $_{0.01}$	^{c} LSD $_{0.001}$
	0.62	0.91	1.29
Galium aparine L.	0.61	0.87	1.14^{a}
	^{a} LSD $_{0.05}$	^{b} LSD $_{0.01}$	^{c} LSD $_{0.001}$
	0.48	0.64	0.97
Amaranthus retroflexus L.	4.07	1.71^{c}	2.28^{c}
	^{a} LSD $_{0.05}$	^{b} LSD $_{0.01}$	^{c} LSD $_{0.001}$
	0.52	0.67	0.93
Anthemis arvensis L.	2.28	3.12^{a}	3.57^{b}
	^{a} LSD $_{0.05}$	^{b} LSD $_{0.01}$	^{c} LSD $_{0.001}$
	0.80	1.08	1.55
Papaver rhoeas L.	-	1.67^{c}	1.92^{c}
	^{a} LSD $_{0.05}$	^{b} LSD $_{0.01}$	^{c} LSD $_{0.001}$
	0.63	0.87	1.14
Viola tricolor L.	-	1.53^{b}	1.67^{c}
	^{a} LSD $_{0.05}$	^{b} LSD $_{0.01}$	^{c} LSD $_{0.001}$
	0.85	1.12	1.59
Cirsium arvense L.	—	0.64^{c}	0.86^{c}
	^{a} LSD $_{0.05}$	^{b} LSD $_{0.01}$	^{c} LSD $_{0.001}$
	0.28	0.36	0.45
Convolvulus arvensis L.	-	-	1.05^{c}
	^{a} LSD $_{0.05}$	^{b} LSD $_{0.01}$	^{c} LSD $_{0.001}$
	0.31	0.39	0.56
Total	14.92	20.26^{c}	22.97^{c}
	^{a} LSD $_{0.05}$	^{b} LSD $_{0.01}$	^{c} LSD $_{0.001}$
	2.82	3.60	4.77

*CT- conventional tillage; CP- treatment of the crop with herbicide during the vegetative growth of plants; NT- no-tillage.

At stage 3rd – 5th leaf of maize, prior to the application of herbicides during the vegetative growth of the plants, the total number of weeds was the highest after tillage without turning of the soil layer and no-tillage (Table 2). After ploughing, the total weed infestation was within 9.70 plants/m^2. At this stage of maize development, the applied intensive tilths, which destroyed a high percentage of the weed seeds and the emerging weeds (Ozpinar and Ozpinar, 2011), as well as the faster rate of emergence and development of the maize plants, probably contributed to the decrease of the total number of the weeds after ploughing. The data show that at this stage of the crop development, *Amaranthus retroflexus* L. was the weed with predominant density after all types of main soil tillage. In contrast to all other weed species, the numbers of which decreased in comparison to what was determined earlier in spring, the density of this weed increased during the above period of time. This can be explained by the biology of *Amaranthus retroflexus* L., which requires higher soil temperature for seed germination (Baskin and Baskin, 1977; Wiese and Binning, 1987). *Sinapis arvensis* L. ranked second in density of weeds after ploughing and chisel ploughing, and *Anthemis arvensis* L. ranked second after direct sowing. *Viola tricolor* L. disappeared from the list of weed plants identified in spring after tillage without turning the surface soil layer and no-tillage. The statistical results were significant at different levels of P.

Table 2. Species composition and density of weeds prior to the application of herbicide in a grain maize crop

Weed species and number (m^2)	CT	CP	NT
Arenaria serpyllifolia L.	0.90	1.85[b]	1.31
	[a] $LSD_{0.05}$	[b] $LSD_{0.01}$	[c] $LSD_{0.001}$
	0.68	0.93	1.29
Sinapis arvensis L.	1.26	1.68	—
	[a] $LSD_{0.05}$	[b] $LSD_{0.01}$	[c] $LSD_{0.001}$
	0.49	0.77	1.21
Polygonum convolvulus L.	1.32	1.64	1.67
	[a] $LSD_{0.05}$	[b] $LSD_{0.01}$	[c] $LSD_{0.001}$
	0.82	1.10	1.64
Galium aparine L.	0.44	0.72	0.86
	[a] $LSD_{0.05}$	[b] $LSD_{0.01}$	[c] $LSD_{0.001}$
	0.55	0.72	1.00
Amaranthus retroflexus L.	4.73	2.56[a]	2.99[a]
	[a] $LSD_{0.05}$	[b] $LSD_{0.01}$	[c] $LSD_{0.001}$
	1.70	2.53	3.71
Anthemis arvensis L.	1.05	1.12	2.64[c]
	[a] $LSD_{0.05}$	[b] $LSD_{0.01}$	[c] $LSD_{0.001}$
	0.37	0.46	0.60
Papaver rhoeas L.	-	1.04[a]	1.41[b]
	[a] $LSD_{0.05}$	[b] $LSD_{0.01}$	[c] $LSD_{0.001}$
	0.80	1.09	1.55
Cirsium arvense L.	-	0.71[c]	0.98[c]
	[a] $LSD_{0.05}$	[b] $LSD_{0.01}$	[c] $LSD_{0.001}$
	0.36	0.49	0.62
Convolvulus arvensis L.	-	-	0.85[c]
	[a] $LSD_{0.05}$	[b] $LSD_{0.01}$	[c] $LSD_{0.001}$
	0.32	0.40	0.58
Total	9.70	11.32	12.71
	[a] $LSD_{0.05}$	[b] $LSD_{0.01}$	[c] $LSD_{0.001}$
	3.72	5.68	8.45

*CT- conventional tillage; CP- treatment of the crop with herbicide during the vegetative growth of plants; NT- no-tillage.

After harvesting of maize, total weed infestation was the highest after direct sowing – 4.59 plants/m^2 (Table 3). After all types of main soil tillage during this period, *Amaranthus retroflexus* L. and *Anthemis arvensis* L. were observed in decreasing density. After chisel ploughing, the dangerous infestation with *Cirsium arvense* L. persisted, and after direct sowing *Cirsium arvense* L. and *Convolvulus arvensis* L. were also persistent. Other authors have also pointed out that the use of these types of tillage can increase the infestation with perennial weeds (Haakansson, 1995; Demjanová et al., 2009; Ozpinar and Ozpinar, 2011; Yankov et al., 2015). After ploughing, the predominant weed species at that time was *Amaranthus retroflexus* L. According to Carr et al. (2013), the changes in the soil tillage systems often lead to the supplanting of some weed species by others in the cultivated areas and to changes in their density. The statistical results were significant at different levels of P.

Table 3. Species composition and density of weeds at harvesting of grain maize crop

Weed species and number (m^2)	CT	CP	NT
Amaranthus retroflexus L.	0.75	1.23^{b}	1.77^{c}
	^{a}LSD $_{0.05}$	^{b}LSD $_{0.01}$	^{c}LSD $_{0.001}$
	0.29	0.41	0.63
Anthemis arvensis L.	0.61	0.99	1.37^{a}
	^{a}LSD $_{0.05}$	^{b}LSD $_{0.01}$	^{c}LSD $_{0.001}$
	0.73	0.98	1.37
Cirsium arvense L.	—	0.43^{c}	0.74^{c}
	^{a}LSD $_{0.05}$	^{b}LSD $_{0.01}$	^{c}LSD $_{0.001}$
	0.22	0.26	0.39
Convolvulus arvensis L.	—	—	0.71^{c}
	^{a}LSD $_{0.05}$	^{b}LSD $_{0.01}$	^{c}LSD $_{0.001}$
	0.28	0.34	0.47
Total	1.36	2.65^{a}	4.59^{c}
	^{a}LSD $_{0.05}$	^{b}LSD $_{0.01}$	^{c}LSD $_{0.001}$
	0.89	1.35	2.71

*CT- conventional tillage; CP- treatment of the crop with herbicide during the vegetative growth of plants; NT- no-tillage.

The results from the dispersion analysis showed that the meteorological conditions during the year and the types of main soil tillage for maize influenced the degree of weed infestation (Table 4). Their effect on the studied parameter was significant at P=0.001. Among the investigated factors, the meteorological conditions of the year had the highest effect on the species composition and density of the weeds – 4.77%. The percentage of the *type of main soil tillage* was a little lower – 2.94%. The double interaction of the studied indices, except of the combination of *type of main soil tillage* x *meteorological conditions of the year*, was also statistically significant (P=0.001). The combination *species composition of the weeds x type of main soil tillage* was with the highest relative importance – 24.02%. The triple interaction between the studied factors was significant at P=0.05, and its relative importance was 0.97%.

Table 4. Significance of independent and combined effects of the investigated factors

Source of variation	df	Mean Square	F	Sig
Factor A. Species composition of weeds	9	141.905	503.929	.000
Factor B. Main soil tillage type	2	46.116	163.767	.000
Factor C. Year conditions	2	28.443	101.007	.000
$A_{x}B$	18	25.824	91.704	.000
$A_{x}C$	18	1.377	4.890	.000
$B_{x}C$	4	0.120	0.425	.791
$A_{x}B_{x}C$	36	0.523	1.858	.004

The Duncan test allowed tracing the effect of the separate levels of the factors on the investigated agronomy parameter (Table 5). With regard to the effect of the applied types of soil tillage on the density of the registered weed species over years of study, the test formed two groups for the ephemeral weed *Arenaria serpyllifolia* L. Ploughing, which limited the development of this weed as a result of the applied more intensive soil tilths, fell within the first group. The tillage without turning the surface soil layer and the no-tillage, in which weed control was predominantly chemical, were in the second group. According to Melander et al. (2007), the minimal tilths are to a much higher degree dependent on the use of herbicides for control of the weed vegetation, than the intensive types of soil tillage.

Concerning the effect of the type of main soil tillage on the density of the registered early spring weeds, the test applied to *Sinapis arvensis* L. formed three groups. The first group included direct sowing, after which no infestation with this weed was registered. This plant species prefers well cultivated soils, while this technology increases the compactness of the surface soil layer under the effect of physical and climatic factors (Yankov, 2007). The test placed ploughing in the second group, and chisel ploughing – in the third, where the density of *Sinapis arvensis* L. was the highest. In the other two plant species belonging to the group of early spring weeds identified after the investigated types of soil tillage, two groups were formed. In *Polygonum convolvulus* L., ploughing and chisel ploughing contributed to less favorable conditions for the development of this weed species. Probably, the reason for this were the mechanical cultivations of the soil applied to these variants. The test placed direct sowing in the second group. In this variant, there was no mechanical impact on the soil, which probably conditioned the higher seed reserves of this weed species. Légère et al. (2013) found out that the areas, where long-term no-tillage was used, contained 50% to 80% more weed seeds than the cultivated areas. In *Galium* *aparine* L., the test also divided the types of main soil tillage into three groups. Ploughing limited the development of this weed, while after chisel ploughing and direct sowing its density increased. This shows that the applied agronomy practices in these variants are insufficient to suppress the development of the plant species.

Table 5. Statistical groups of the applied soil tillage types based on the species composition and density of weeds determined in a grain maize crop (Duncan)

Weed species and number (m2)	Main soil tillage type Groups/Values		
	CT	CP	NT
Arenaria serpyllifolia L.	a/2.91	b/5.98	b/6.28
Sinapis arvensis L.	b/4.55	c/5.53	a/0.00
Polygonum convolvulus L.	a/3.98	a/4.38	b/7.18
Galium aparine L.	a/1.05	b/1.59	c/2.00
Amaranthus retroflexus L.	c/9.55	a/5.50	b/7.04
Anthemis arvensis L.	a/3.94	b/5.24	c/7.58
Papaver rhoeas L.	a/0.00	b/2.71	c/3.33
Viola tricolor L.	a/0.00	b/1.53	b/1.67
Cirsium arvense L.	a/0.00	b/1.78	c/2.58
Convolvulus arvensis L.	a/0.00	a/0.00	b/2.61

*CT- conventional tillage; CP- treatment of the crop with herbicide during the vegetative growth of plants; NT- no-tillage.

In the late spring weed *Amaranthus retroflexus* L., the test distributed the types of main soil tillage also in three groups. Chisel ploughing fell within the first group. It was followed by direct sowing and ploughing. This weed possesses high capacity to propagate and can form thousands of seeds, which have low and irregular germination rate, and the process can go on for several years. The greater density after direct sowing was probably due to the accumulation of a higher amount of weed seeds in the surface soil layer (Benvenuti and Miele, 2001). The strong development of this weed in ploughed areas is due to the fact that this plant species prefers well cultivated lands – warm, humid, drained and with good reserves of nutrients (Ghorbani et al., 1999). These conditions probably caused the germination of a greater number of seeds.

With regard to the effect of the type of main soil tillage on the density of the registered winter-spring weeds, the applied test formed two groups in *Viola tricolor* L. The intensive types of soil tillage used in ploughing suppressed the development of *Viola tricolor* L., and therefore the test placed this variant in a separate group. In the other group, this weed went together with tillage without turning the soil layer and the no-tillage, where the applied agronomy practices were insufficient to overpower its development. In *Anthemis arvensis* L. and *Papaver rhoeas* L. Duncan test formed three groups. The first included ploughing, the second – chisel ploughing, and the third – direct sowing; i.e. the density of these weeds increased with the decrease of the intensity of the applied soil tillage.

A similar tendency was also observed in the deep-rooted weed *Cirsium arvense* L. Its strong propagation after direct sowing showed that this plant species was difficult to control only by using total and system herbicides. It is also necessary to combine mechanical and chemical means for control of the persistent perennial weeds. In the second weed *Convolvulus arvensis* L. two groups were formed. The test placed ploughing and chisel ploughing in the first group; in these types of tillage the applied integrated control of weeds prevented the infestation with the weed species. Direct sowing was in the second group, in which the deep-rooted perennial weeds could not be easily controlled by chemicals only. Buhler et al. (1994) also reported higher infestation with *Convolvulus arvensis* L. after long-term use of reduced soil tillage types as compared to the systems involving tillage of maize with mouldboard.

Regression analysis was applied to determine what the correlation between the year conditions was, the used types of main soil tillage and the species composition and density of weeds in a grain maize crop. Based on the established models (Table 6) and the obtained experimental data, a graphical model of the respective equations was made (Figure 2). The respective weight coefficients were designated with b_i, with b_1 – the infestation with ephemeral weeds, with b_2 – infestation with early spring weeds, with b_3 – infestation with late spring weeds, with b_4 – infestation with winter-spring weeds, and with b_5 – infestation with deep-rooted weeds.

On the basis of the applied analysis, it was found out that in years with rainfalls close to the norm in the region of Dobrudzha, the late spring weeds (b_3) emerging after ploughing were with the highest weight coefficient. This type of main soil tillage for grain maize had negative influence on the development of the ephemerals (b_1) and the deep-rooted weeds (b_5) because the respective coefficients were negative. After chisel ploughing without turning the surface layer, the winter-spring weeds (b_4) had the highest effect on the parameter density of weeds in the crop. The ephemerals (b_1), the winter-spring (b_4) and the deep-rooted (b_5) weeds were with the highest weight coefficient after direct sowing.

In years with rainfalls above the norm after ploughing, the early spring weeds (b_2) had the highest effect on the infestation of the maize crops. The negative effect of this soil tillage type on the development of the deep-rooted perennial weeds (b_5) increased. After chisel ploughing, the early spring (b_2) and the deep-rooted perennial (b_5) weeds had the highest impact on the density of weeds in the crop. After no-tillage, the highest weight coefficient was again that of the ephemerals (b_1), the winter-spring (b_4) and the deep-rooted (b_5) weeds.

Table 6. Regression models of the effect of the main soil tillage type on the weed density in a grain maize crop at different amounts of rainfalls during the vegetative growth of plants

General regression model	$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5$
	Rainfalls close to the norm
CT	$Y = 0.044 – 0.048x_1 + 0.195x_2 + 0.487x_3 + 0.013x_4 – 0.749x_5$
CP	$Y = 0.823 + 0.284x_1 + 0.301x_2 + 0.229x_3 + 0.384x_4 + 0.131x_5$
NT	$Y = 1.254 + 0.461x_1 + 0.154x_2 + 0.370x_3 + 0.513x_4 + 0.460x_5$
	Rainfalls above the norm
CT	$Y = 0.104 + 0.110x_1 + 0.290x_2 + 0.218x_3 + 0.095x_4 – 1.132x_5$
CP	$Y = 2.021 + 0.189x_1 + 0.376x_2 + 0.083x_3 + 0.280x_4 + 0.799x_5$
NT	$Y = 1.913 + 0.429x_1 + 0.107x_2 + 0.106x_3 + 0.498x_4 + 0.833x_5$
	Rainfalls below the norm
CT	$Y = 0.545 – 0.143x_1 + 0.334x_2 + 0.531x_3 – 0.121x_4 – 1.015x_5$
CP	$Y = 1.279 + 0.318x_1 + 0.513x_2 + 0.042x_3 + 0.134x_4 + 0.112x_5$
NT	$Y = 1.366 + 0.482x_1 + 0.204x_2 + 0.278x_3 + 0.380x_4 + 0.684x_5$

*$\mathbf{x_1}$- density of ephemeral weeds; $\mathbf{x_2}$- density of early spring weeds; $\mathbf{x_3}$- density of late spring weeds; $\mathbf{x_4}$- density of winter-spring weeds; $\mathbf{x_5}$- density of deep-rooted perennial weeds

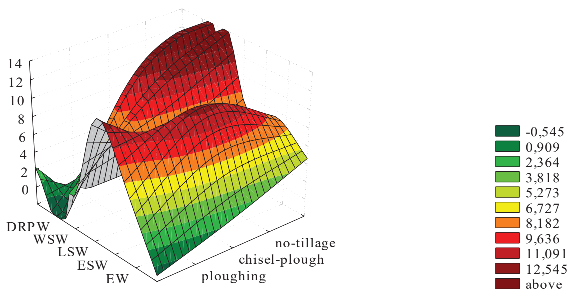

Figure 2. Graphic presentation of the regression model of the parameter weed species composition and density (EW– ephemeral weeds; ESW– early spring weeds; LSW– late spring weeds; WSW– winter-spring weeds; DRPW– deep-rooted perennial weeds)

At rainfalls below the norm, the late spring weeds (b_3) were with the highest weight coefficient after ploughing. The negative effect of this type of main soil tillage on the development of the deep-rooted perennial weeds (b_5) was present in this case, too. After chisel ploughing, the highest effect of the weed infestation of the grain maize crops was that of the early spring weeds (b_2). After direct sowing, the tendency remained the same – the ephemerals (b_1), the winter-spring (b_4) and the deep-rooted perennial weeds (b_5) were with the highest weight coefficient.

The regression model gives an idea about the expected value of the specific parameter according to the year conditions under the different main soil tillage types included in the model and applied to the growing of grain maize.

Conclusion

It was found that: (i) the type of main soil tillage had a statistically significant effect on the species composition and the density of the weeds in the grain maize crops grown after previous crop wheat; (ii) the use of ploughing, in parallel with the use of chemicals for weed control, decreased the weed infestation in the maize crops; the lower density of weeds under this main soil tillage type was related to changes in the composition and the relative percentage of the respective species in the total infestation; (iii) the use of tilths without turning the surface layer and no-tillage in the crop rotation, in spite of the application of herbicides, contributed to the increase of the amount of weeds; the reason for this was the higher variability of weed species typical for shallow tillage types.

References

Abdin O, Zhou X, Cloutier D, Coulman D, Faris M and Smith D, 2000. Cover crops and interrow tillage for weed control in short season maize (*Zea mays*). European Journal of Agronomy, 12, 93-102.
doi: 10.1016/S1161-0301(99)00049-0

Aikins S, Afuakwa J and Owusu-Akuoko O, 2012. Effect of four different tillage practices on maize performance under rainfed conditions. Agriculture and Biology Journal of North America, 3, 25-30. doi: 10.5251/abjna.2012.3.1.25.30

Astier M, Maass J, Etchevers-Barra J, Peña J and de LeónGonzález F, 2006. Short-term green manure and tillage management effects on maize yield and soil quality in an Andisol. Soil and Tillage Research, 88, 153-159. doi: 10.1016/j.still.2005.05.003

Baskin J and Baskin C, 1977. Role of temperature in the germination ecology of three summer annual weeds. Oecologia, 30, 377-382. doi: 10.1007/BF00399768

Benvenuti S and Miele M, 2001. Quantitative analysis of emergence of seedlings from buried weed seeds with increasing soil depth. Weed Science, 49, 528-535.
doi: 10.1614/0043-1745(2001)049[0528:QAOEOS]2.0.CO;2

Boomsma C, Santini J, West T, Brewer J, McIntyre L and Vyn T, 2010. Maize grain yield responses to plant height variability resulting from crop rotation and tillage system in a long-term experiment. Soil and Tillage Research, 106, 227-240. doi: 10.1016/j.still.2009.12.006

Buhler D, Stoltenberg D, Becker R and Gunsolus J, 1994. Perennial weed populations after 14 years of variable tillage and cropping practices. Weed Science, 42, 205-209. doi: 10.1016/j.still.2009.12.006

Carr P, Gramig G and Liebig M, 2013. Impacts of organic zero tillage systems on crops, weeds, and soil quality. Sustainability, 5, 3172-3201. doi: 10.3390/su5073172

Delibaltova V, 2014. Response of maize hybrids to different nitrogen applications under climatic conditions of Plovdiv region. International Journal of Farming and Allied Sciences, 3, 408-412.

Delibaltova V, 2018. Comparative study of grain maize hybrids in the region of north-east Bulgaria. In: Proceedings of the IX International Agricultural Symposium "Agrosym 2018", pp. 139-145.

Demjanová E, Macák M, Đalović I, Majerník F, Týr Š and Smatana J, 2009. Effects of tillage systems and crop rotation on weed density, weed species composition and weed biomass in maize. Agronomy Research, 7, 785-792.

Dewar A, 2009. Weed control in glyphosate-tolerant maize in Europe. Pest Manag Sci, 65, 1047-1058. doi: 10.1002/ps.1806

Ghorbani R, Seel W and Leiferr C, 1999. Effects of environmental factors on germination and emergence of *Amaranthus retroflexus*. Weed Science, 47, 505-510.

Głowacka A, 2011. Dominant weeds in maize (*Zea mays* L.) cultivation and their competitiveness under conditions of various methods of weed control. Acta agrobotanica, 64, 119-126.

Haakansson S, 1995. Weeds in agricultural crops. 1. Life-forms and occurrence under Swedish conditions. Swedish Journal of Agricultural Research, 25, 143-154.

Kirchev H, 2016. Comparative study of early and mid-early grain maize hybrids in the conditions of Southern Dobrogea. Research Journal of Agricultural Science, 48, 63-69.

Légère A, Shirtliffe S, Vanasse A and Gulden R, 2013. Extreme grain-based cropping systems: When herbicide-free weed management meets conservation tillage in northern climates. Weed Technology, 27, 204-211. doi: 10.1614/WT-D-12-00074.1

Liu C, Jin S, Zhou L, Jia Y, Li F, Xiong Y and Li X, 2009. Effects of plastic film mulch and tillage on maize productivity and soil parameters. European Journal of Agronomy, 31, 241-249. doi: 10.1016/j.eja.2009.08.004

Melander B, Holst N, Jensen P, Hansen E and Olesen J, 2007. Apera spica-venti population dynamics and impact on crop yield as affected by tillage, crop rotation, location and herbicide programs. Weed Research, 48, 48-57. doi: 10.1111/j.1365-3180.2008.00597.x

Pandey A, Prakash V, Singh R and Mani V, 2001. Integrated weed management in maize (*Zea mays*). Ind. J. Agron., 46, 260-265.

Qasem J and Hill T, 1995. Growth, development and nutrient accumulation in *Senecio vulgaris* L. and *Chenopodium album* L. Weed Research, 35, 87-196. doi: 10.1111/j.1365-3180.1995.tb02032.x

Ozpinar S and Ozpinar A, 2011. Influence of tillage and crop rotation systems on economy and weed density in a semi-arid region. Journal of Agriculture, Science and Technology, 13, 769-784.

Qingjie W, Caiyun L, Hongwen L, Jin H, Sarker K, Rasaily R, Zhonghui L, Xiaodong Q, Hui L and Mchugh A, 2014. The effects of no-tillage with subsoiling on soil properties and maize yield: 12-Year experiment on alkaline soils of Northeast China. Soil and Tillage Research, 137, 43-49. doi: 10.1016/j.still.2013.11.006

Raffaelli M, Barberi P, Peruzzi A and Ginanni M, 2005. Mechanical weed control in maize: Evaluation of weed harrowing and hoening systems. Agricol. Medit., 135, 33-43.

Rajcan I and Swanton C, 2001. Understanding maize-weed competition: resource competition, light quality and the whole plant. Field Crops Research, 71, 139-150. doi: 10.1016/S0378-4290(01)00159-9

Rasmussen K, 1999. Impact of ploughless soil tillage on yield and soil quality: A Scandinavian review. Soil and Tillage Research, 53, 3-14. doi: 10.1016/S0167-1987(99)00072-0

Salem H, Valero C, Muñoz M, Rodríguez M and Silva L, 2015. Short-term effects of four tillage practices on soil physical properties, soil water potential, and maize yield. Geoderma, 237-238, 60-70. doi: 10.1016/j.geoderma.2014.08.014

Stoyanova A and Petkova R, 2009. Crude protein content in grain maize. In: Proc. of International Science conference "Economics and Society development on the Base of Knowledge", I, pp. 260-264.

Sharma P, Abrol V and Sharma R, 2011. Impact of tillage and mulch management on economics, energy requirement and crop performance in maize-wheat rotation in rainfed subhumid inceptisols, India. European Journal of Agronomy, 34(1), 46-51. doi: 10.1016/j.eja.2010.10.003

Shrestha A, Knezevic S, Roy R, Ball-Coelho B and Swanton C, 2002. Effect of tillage, cover crop and crop rotation on the composition of weed flora in a sandy soil. Weed Research, 42, 76-87. doi: 10.1046/j.1365-3180.2002.00264.x

Videnović Ž, Simić M, Srdić J and Dumanović Z, 2011. Long term effects of different soil tillage systems on maize (*Zea mays* L.) yields. Plant, Soil and Environment, 57, 186-192. doi: 10.17221/443/2010-PSE

Wiese A and Binning L, 1987. Calculating the threshold temperature of development for weeds. Weed Science, 35, 177-179.

Wyngaard N, Echeverría H, Sainz Rozas H and Divito G, 2012. Fertilization and tillage effects on soil properties and maize yield in a Southern Pampas Argiudoll. Soil and Tillage Research, 119, 22-30. doi: 10.1016/j.still.2011.12.002

Yankov P, 2007. Change of volume compactness of the slightly leached chernozem in Dobroudja region under the effect of long-term use of some soil tillage systems. Field Crops Studies, IV, 87-94 (Bg).

Yankov P, Drumeva M and Plamenov D, 2014. Variations of maize yield and some quality indices of grain depending on the type of main soil tillage. Agricultural Science and Technology, 6, 184-186.

Yankov P, Nankova M, Drumeva M, Plamenov D and Klochkov B, 2015. Species composition and density of weeds in a wheat crop depending on the soil tillage system in crop rotation. Agricultural Science and Technology, 7, 94-97.

Yolevsky M, Macheva K and Petkov P, 1959. The soils in the trial field of Dobrudzha Agricultural research institute and the trial fields in Karvuna, Tolbukhin district, and Suvorovo, Varna district. Research papers of DSNI, III, 5-62 (Bg).

Zhang S, Li P, Yang X, Wang Z and Chen X, 2011. Effects of tillage and plastic mulch on soil water, growth and yield of spring-sown maize. Soil and Tillage Research, 112, 92-97. doi: 10.1016/j.still.2010.11.006