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Long-term monitoring of arable lands infestation in the steppe zone of Ukraine

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Arable lands in Ukraine are heavily infested with weed seeds. However, their actual potential infestation is very changeable and has not yet been reliably established; besides, the available data are contradictory. Therefore, the goal of our work was to identify the dynamics of changes and the nature of arable lands infestation in the Steppe zones of Ukraine based on the results of multi-year monitoring. The researches were conducted in the Steppe zone of Ukraine, which included three subzones as follows: Northern Steppe, Southern Steppe and Dry Steppe. Soil samples were taken in late autumn, winter or early spring periods in order to determine the weed seeds content. It has been established that over the past 25 years, potential soil infestation in the subzones of the Northern Steppe and Southern Steppe has increased by 2.5 times, while in Dry Steppe it has increased by 2.8 times and has reached 227.7–235.7 thousand pcs/m^2. Such soil infestation by weed seeds exceeds the economic threshold of harmfulness by 75–80 times. The species composition of weed seeds was represented by 83–93 species. *Amaranthus retroflexus, Echinochloa crus-galli, Setaria viridis* and *Setaria glauca* predominated in the total seed's composition. The seeds ratio of various species of weeds in the soil has changed over the past 25 years. The roles of *Amaranthus retroflexus, Chenopodium album, Setaria viridis, Fumaria schleicheri* and *Descurainia sophia* has decreased, while the role of *Ambrosia artemisiifolia, Cyclachaena xanthiifolia, Xanthium albinum, Lactuca serriola* and others has increased. The ratio of monocotyledonous and dicotyledonous species was approximately equal, that is 50.8% and 49.2%. The number of seedlings of weeds has increased by 32% over the past 20 years and reached 1.511 pcs/m^2. In the group of spring weeds, the number of *Xanthium albinum, Cyclachaena xanthiifolia* and *Ambrosia artemisiifolia* seedlings has increased, while the number of *Fumaria schleicheri, Chenopodium album* and *Sinapis arvensis* seedlings has decreased. Among the winter and wintering weeds, the role of such ephemeral as *Microthlaspi perfolatium, Holosteum umbellatum* and *Viola arvensis* has increased, while *Consolida regalis, Sisymbrium loeselii* and *Descurainia sophia* has decreased. The infestation of arable lands with perennial and parasitic species has increased.

Key words: Ukraine; Steppe zones; Arable lands; Potential infestation; Weeds

Introduction

The most important link in modern farming technology is the protection of crops of cultivated plants against weeds, which are considered to be the main factor that destabilizes the industry (Kurdyukova, Konoplia, 2018, 2012; Nagy, 2017; Oley, 2011; Berti, et al., 2008; Oerke & Dehne, 2004). Despite the enormous costs spent annually on controlling weeds, the infestation of crops does not decrease, but even increases. According to the infestation degree, 70% of cultivated lands of Ukraine are characterized by high level of infestation, more than 20% are characterized by medium level of infestation and only less than 10% are characterized by low level of infestation (Tanchik, Babenko, 2012). Quarantine plant species, in particular *Ambrosia artemisiifolia* L., *Acroptilon repens* (L.) DC., *Solanum angustifolium* Houst. ex Miller, *Cenchrus longispinus* (Hack.) Fernald, species of *Cuscuta* L. *Orobanche* L. *Phelipanche* Pomel genera, etc. were found in 75% of agricultural lands (Kurdyukova, Konoplia, 2012).

According to various data, over the past 20 years, 372 to 801 species of weed plants were found in crops of cultivated plants of Ukraine, whereof 129 species were the most persistent and difficult to control (Kurdyukova, Konoplia, 2012; Ivashchenko, 2001). During the growing season, 2 to 5 thousand of seedlings of weeds were observed in crops and up to 70 thousand seeds/m^2 were observed in uncultivated lands (Kurdyukova, Konoplia, 2018). With such arable land's infestation and lack of proper control of weeds in crops, the yield of cultivated plants of drill planting decreased on average by 30–50%, plants of sowing in broad drills decreased by 44–88% or more, and in heavily infested areas it decreased by 2.0–3.5 times. In many cases, the weeds completely suppressed cultivated plants in separate areas or fields, and no crop was gathered at all (Kurdyukova, Konoplia, 2018; Ivashchenko, 2001). Total annual loss of grain yield caused by weeds reached 18–20 million tons, in addition to 20 million tons loss of sugar beets, 3.5 million tons of oilseeds, 4.2 million tons of potatoes and 1.9 million tons of vegetables (Kurdyukova, Konoplia, 2018, 2012; Ivashchenko, 2001). According to most researchers, the main reason for the appearance of weed component in agrophytocenoses is the high potential arable lands infestation, whose value is very changeable and has not yet been reliably established in Ukraine (Kurdyukova, Konoplia, 2018, 2012, 2010; Ivashchenko, 2001).

Over the past 20 years, numerous sources cited the same values regards the potential infestation in different soil and climatic zones, that is from 1.14 to 1.71 billion seeds/ha (Kosolap, 2011; Ivashchenko, 2001). Other sources indicate significantly smaller (100 thousand to 200 million seeds/ha) or bigger (14 billion seeds/ha) amount of seeds in 0–30 cm soil layer). Sometimes the difference in seed burials for the same conditions was found even in the same sources. For example, the information on the page 9 of classic research by A.A. Ivashchenko (2001) indicates that there were 100 million to 4 billion seeds in 0–30 cm layer of arable land of Ukraine, while the information on the page 56 indicates 1.14 to 1.71 billion seeds/ha.

It was believed that the main weed seed burials were accumulated due to the high seed productivity of most species growing on cultivated lands (69–73%), as well as their supply with organic fertilizers (25–30%). Only 1–2% was due to other supplies (Rotches-Ribalta, 2015). In some cases, it was indicated that potential soil infestation was 81–375 million seeds/ha in fields without organic fertilizers, while in fertilized ones, it amounted to 1.5 to 4.0 billion seeds/ha (Soroka et al., 2012). It was emphasized in many works that violations in crop rotation, as well as simplified soil treatment systems and incorrect use of herbicides were considered the main reasons for the high potential soil infestation with weed seeds (Kraehmer & Jabran, 2016; Hanzlik, 2016; Kurdyukova et al., 2010; Avav & Oluwatayo, 2006). In recent years, it has been proven that 92–95% of all seeds entered the soil upon their shedding from plants growing in this field and only 5–8% of them entered the soil in other ways (Kurdyukova, Konoplia, 2018). Moreover, seed burials were replenished annually and increased on average by 33% according to some authors and by 19–72% or more according to others (Kurdyukova, Konoplia, 2018, 2010; Ivashchenko, 2001). Some experiments showed that over the past 24 years they have decreased on average by 69–94%. Thus, the actual state of potential arable lands infestation in Ukraine, especially in recent years, remains undetermined, the available data are contradictory as they were obtained 10–20 years ago and require clarification.

The goal of our work was to track the dynamics of arable lands infestation in the Steppe zones of Ukraine based on long-term monitoring.

Research Methodology

Herbological monitoring was carried out by expeditionary route method during 2000–2019 in the Steppe zone of Ukraine, which included three subzones: Northern Steppe, Southern Steppe, and Dry Steppe (Figure 1).

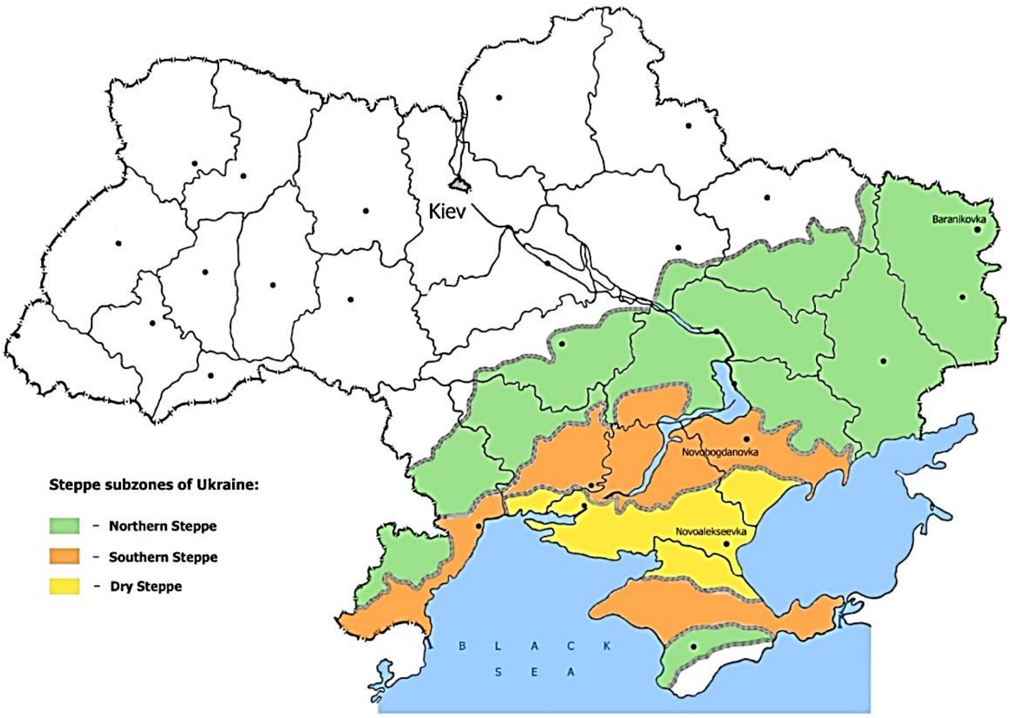

Figure 1. Study area in the Steppe zone of Ukraine.

Expedition trips were carried out according to previously planned routes. Along the routes, samples were taken to determine potential weed seed burials in 0–30 cm soil layer by means of Shevelev design sampler. With a field area of up to 100 ha a total of 18 samples were taken, with a field area of more than 100 ha a total of 25 samples with a total mass of 2 kg were taken. Total survey area exceeded 24 million hectares. Surveys of arable lands and selection of soil samples was carried out according to common methods in the late autumn after the end of plant vegetation, in winter or in early spring before seed germination.

When examining the individual field crop rotations in several farms of each subzone, stationary methods were used for prediction and developing the measures of infestation control. In this regard, quantitative and qualitative changes in weed seed burials were recorded in each crop rotation on permanent (stationary) accounting plots with an area of 10 ha annually for 20 years. Soil samples with a total mass of 2 kg were taken on each accounting plot in 12 places. Seeds taken from the soil were washed with water and their number in the sample was calculated and extrapolated per 1 m^2. In the Northern Steppe subzone, our surveys were carried out in Baranikovka Village, Lugansk Region with total area of 600 ha; in the Southern Steppe subzone they were carried out in Novobogdanovka Village, Zaporizhia Region with total area of 450 ha; in the Dry Steppe subzone they were carried out in Novoalekseevka Village, Kherson Region with total area of 500 ha. Seed identification was performed according to several field guides (Kurdyukova, Konoplia, 2018; Kraehmer, 2016; Kosolap, 2011; McCarty et al., 2008; Maysuryan, Atabekova, 1978).

Results

We found that the potential infestation of 0–30 cm of soil layer during the years of research was high in all Steppe subzones of Ukraine. Seed burials naturally increased on average by 10.1–11.1% that is by 5.48–6.04 pcs/m^2 $\cdot 10^3$ and reached 235.0–235.9 seeds/m^2 $\cdot 10^3$ by the beginning of 2019. The species composition of weed seeds also increased by more than 1.2–1.4 times and reached 83–93 species. Over the past 25 years, potential soil infestation in the Northern Steppe and Southern Steppe subzones increased by 2.5 times, while in Dry Steppe subzones it increased by 2.8 times and reached maximum value (227.7–235.7 seeds/m^2 ·10^3) in 2016–2019 (Table 1).

Table 1. Dynamics of potential soil infestation with weed seeds in the Steppe subzones of Ukraine.

Period	**Northern Steppe**		**Southern Steppe**		**Dry Steppe**	
	seeds/m^2·10^3	**species number**	**seeds/m^2 ·10^3**	**species number**	**seeds/m^2 ·10^3**	**species number**
1995-1999*	90.7	58	92.2	71	84.6	76
2000–2004	162.4	65	168.5	77	193.8	91
2005–2010	209.3	74	230.1	80	235.9	92
2011–2015	227.5	79	231.7	84	235.0	92
2016–2019	227.7	83	233.8	86	236.7	93

*According to N. Konoplya (Konoplya, 2000).

Table 2. Dynamics of changes in species composition of weed seeds in the Northern Steppe subzone of Ukraine, (% of the total number).

Species	**Period**					**Changes, %**
	1995-1999*	**2000-2004**	**2005–2010**	**2011–2015**	**2016–2019**	
Echinochloa crus-galli	19.5	15.8	16.1	17.0	18.3	−1.2
Setaria viridis	18.0	17.9	18.0	17.1	16.0	−2.0
Setaria glauca	16.5	16.5	15.2	16.3	16.0	−0.5
Amaranthus retroflexus	20.8	17.9	16.1	14.0	13.8	−7.0
Chenopodium album	5.6	4.3	3.8	3.1	1.8	−3.8
Descurainia sophia	2.8	2.1	2.0	1.8	1.6	−1.2
Sinapis arvensis	1.5	1.3	1.1	0.7	0.5	−1.0
Senecio vulgaris L.	1.1	0.6	0.4	0.2	0.1	−1.0
Cirsium arvense (L.) Scop.	0.7	0.6	0.7	0.7	0.8	+0.1
Thlaspi arvense L.	0.7	0.8	0.8	0.5	0.4	−0.3
Ambrosia artemisiifolia	0.2	0.7	3.4	6.3	9.5	+9.3
Cyclachaena xanthiifolia	0.1	0.3	1.1	3.9	6.1	+6.0
Fumaria schleicheri	1.4	1.2	0.7	0.3	0.1	−1.3
Consolida regalis	0.3	0.2	0.1	0.1	0.1	−0.2
Galium aparine L.	0.1	0.2	0.2	0.3	0.3	+0.2
Lactuca serriola	0.1	0.2	0.2	0.2	0.3	+0.2
Capsella bursa-pastoris (L.) Medik.	0.5	0.3	0.3	0.3	0.3	−0.2
Solanum nigrum L.	0.1	0.1	0.2	0.1	0.1	± 0.0
Xanthium albinum	0.1	0.3	0.7	2.7	3.5	+3.4
Convolvulus arvensis L.	0.2	0.2	0.2	0.3	0.3	+0.1
Other species	9.7	18.5	18.7	14.0	10.1	+0.4
Total	100	100	100	100	100	100

*According to N. Konoplya (2000).

Particularly sharp increase in seed burials was observed between 1995 and 2000 (1.8–2.3 times), which is obviously explained by the decrease in general efficiency in agriculture during the agricultural sector reformation and transition to new forms of agriculture. Over the next 10 years, potential soil infestation increased by 22–37%, and starting from 2005 to the present it has been fixed and stably maintained at the level of 209.3–235.9 pcs/m^2 ·10^3. Such soil infestation with weed seeds exceeds the economic threshold of harmfulness by more than 75–80 times and guarantees a very high actual infestation of crops by all types of weeds. *Amaranthus retroflexus*, *Echinochloa crus-galli*, *Setaria viridis* and *S. glauca* prevailed among the species diversity of weed seeds in all Steppe subzones of Ukraine. The specific gravity of their seeds in total soil infestation reached 64.3%, while for all other species it reached only 35.7% (Table 2).

The ratio of seeds of various weeds species has changed significantly in total infestation. The role of *Amaranthus retroflexus, Chenopodium album, Setaria viridis, Fumaria schleicheri, Descurainia sophia*, decreased, while the role of *Ambrosia artemisiifolia, Cyclachaena xanthiifolia, Xanthium albinum, Lactuca serriola* and others increased. The ratio of monocotyledonous and dicotyledonous species during all years of research was approximately equal, i.e., 50.8% and 49.2%. Noticeable changes have also occurred in the species and numerical structure of seedlings of weeds. Thus, in the Northern Steppe subzone during the growing season, the number of seedlings of weeds over the past 20 years has increased by 32% and reached 1.511 pcs/m^2 (Table 3).

In spring weeds, the number of seedlings of *Xanthium albinum, Cyclachaena xanthiifolia, Ambrosia artemisiifolia,* has increased, while the number of *Fumaria schleicheri, Chenopodium album, Sinapis arvensis* has decreased. Among winter and wintering species, the role of such ephemeral species as *Microthlaspi perfoliatum, Holosteum umbellatum,* and *Viola arvensis,* has increased, while the number of *Consolida regalis, Sisymbrium loeselii,* and *Descurainia sophia* has decreased. Arable lands infestation with perennial weed species, especially *Lactuca tatarica* (L.) C.A. Meyer and parasitic species, especially *Orobanche cumana* Wallr. has increased. Similar changes occurred in the Southern Steppe and Dry Steppe subzones.

Table 3. Dynamics of weeds diversity and abundance in the Northern Steppe subzone of Ukraine in 2000–2019.

Species	Period				Changes, %
	2000–2004		2016–2019		
	seeds/m²	% of total amount	seeds/m²	pcs/m²	
Number of seedlings during the growing season	1144	100	1511	100	+32
Spring weeds	759	66.3	975	64.6	+28
Amaranthus retroflexus	138	12.2	159	10.5	+15
Ambrosia artemisiifolia	32	2.3	116	7.7	+263
Chenopodium album	64	5.6	23	1.5	–64
Cyclachaena xanthiifolia	4	0.4	21	1.4	+425
Echinochloa crus-galli	156	13.6	180	11.9	+15
Fumaria schleicheri	44	3.9	9	0.6	–80
Fallopia convolvulus (L.) A. Löve	11	1.0	14	0.9	+27
Setaria viridis+S. glauca	185	16.3	268	17.7	+45
Sinapis arvensis	31	2.7	19	1.3	–39
Solanum nigrum	14	1.2	16	1.1	+14
Xanthium albinum	9	0.8	53	3.5	+489
Others weeds	71	6.3	97	6.5	+37
Winter and wintering weeds	359	31.4	493	32.6	+37
Capsella bursa-pastoris	87	7.6	84	5.6	–3
Consolida regalis	46	4.0	29	1.9	–59
Erigeron canadensis L.	15	1.3	20	1.3	+33
Descurainia sophia	32	2.8	14	0.9	–56
Galium aparine	10	0.9	17	1.1	+70
Holosteum umbellatum	12	1.4	78	5.2	+550
Lactuca serriola	9	0.8	12	0.8	+33
Microthlaspi perfoliatum	8	0.6	54	3.6	+575
Sisymbrium loeselii	40	3.4	17	1.1	–58
Thlaspi arvense	43	3.7	45	3.0	+5
Viola arvensis	18	1.6	26	1.7	+44
Others weeds	39	3.3	97	6.4	+149
Perennial plants	12	1.1	20	1.3	+67
Cirsium arvense	4	0.4	7	0.5	+75
Convolvulus arvensis	5	0.5	6	0.4	+20
Lactuca tatarica	1	0.1	5	0.3	+400
Others weeds	2	0.1	2	0.1	± 0
Biennial and parasitic plants	14	1.2	23	1.5	+64

Conclusion

Over the past 25 years, the potential arable land infestation in the Steppe subzone of Ukraine has increased by 2.5–2.8 times and reached 227.7–235.7 thousand of seeds/m^2. We reported the noticeable change in biological and environmental structure of weeds on cultivated lands. The specific gravity of spring xerophytic species (*Echinochloa crus-galli, Setaria viridis, Setaria glauca*), the species with high seed productivity (*Ambrosia artemisiifolia, Cyclachaena xanthiifolia, Xanthium albinum, Lactuca serriola*) and wintering ephemeral like *Microthlaspi perfoliatum, Holosteum umbellatum,* and *Viola arvensis,* as well as perennial and parasitic plants has increased. The number of mesophytes and hygrophytes, namely *Persicaria maculosa* S.F. Gray, *Bidens tripartita* L., *Fumaria schleicheri, Equisetum arvense* L., *Chenopodium album,* and *Consolida regalis* has decreased.

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