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Historical sketch and current state of weed diversity in continental zone of Ukraine

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Abstract

Importance of the work: Over the past 50 years, changes in land use strategies from extensive to intensive, changes in landscape structure and increased agricultural production have had a substantial impact on weed diversity and the ratio of individual weed species in agroecosystems.
Objective: To determine the quantitative and qualitative changes in the species composition of weeds in the agrophytocenoses of the continental part of Ukraine and to determine the reasons for these changes based on a retrospective analysis and assessment of the current state in agricultural fields. Such information is necessary to better understand the trends in the expansion of certain species to predict and therefore counteract their expansion.
Materials and Methods: Dynamic data were analyzed based on scientific studies carried out in the eastern portion of the continental zone according to European biogeographical zoning. Data were collected on weed from 1975 to 2023 from the systematic records that had been kept during this time for a variety of investigations.
Results: Based on the findings, spanning from 1975 to the present, over 700 different species of weeds were identified from Ukraine's major crop areas. Only about 30 of the recorded species were primary weeds that substantially reduced crop yields; these species were identified in nearly all agrophytocenoses and uncultivated lands in this biogeographic zone, while the remaining 75–225 species could cause minor harm to pastures, hayfields, perennial crops and agricultural crops.
Main finding: Even though weed species have changed over time, a few species have dominated all crop types: *Cirsium arvense* (L.) Scop.; *Elymus repens* (L.) Gould; *Convolvulus arvensis* L.; *Sonchus arvensis* L.; *Stellaria media*; *Chenopodium album*; *Polygonum aviculare*; *Galium aparine*; and *Amaranthus retroflexus*. In the continental part of Ukraine, several species were either rare or extinct and not found in any of the plots in the current investigation: *Hyoscyamus niger* L.; *Knautia arvensis* L. Coult.; *Sherardia arvensis* L.; *Anthemis arvensis* L. and *Scleranthus annuus* L.

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Introduction

Historically, scientists have paid little attention to agroecosystems, since they were thought to be well-regulated and lacking in diversity, with research on biodiversity species composition mostly focusing on natural or semi-natural environments such as meadows, pastures, wetlands, and forest ecosystems (von Arx et al., 2002; Falck, 2004).

To date, there has been no published single approach to the problem of weed management. As a result of chemical plant protection agents and greater soil cultivation, scientists have decided that weeds will always be a problem in agricultural crops because both surface and flat-cut soil cultivation have made weeds more likely to grow (Carr et al., 2013). Simultaneously, some experts have argued that the higher concentration of weed seeds on the surface under no-till agriculture enhances their germination and subsequent eradication (Carr et al., 2013), whereas continuous plowing results in the emergence of stratified weeds in proximity to the soil surface, hence creating more favorable conditions for their germination (Lewis et al., 2013; Ramesh, 2015).

After the 1950s, the landscape structure of the examined territory underwent major alterations due to the increased intensity of agricultural land use, similar to Europe, as documented by Jiménez-Olivencia et al. (2021) and Delgado-Artés et al. (2022). The intricate pattern of land use, characterized by small fields and diverse vegetation along borders, has been transformed into a uniform and expansive space by the connection of fields and the removal of linear characteristics and border vegetation (Tian et al., 2014; Romanchuck et al., 2017).

Throughout history, the predominant approaches to weed management have involved chemical and mechanical methods (Kraehmer et al., 2014). The current research was based on a thorough consideration of the historical dimension of agricultural growth in Ukraine. Consequently, the full duration of the research could be partitioned into three distinct phases.

The initial phase extended until 1990, during which the control of weeds in the agrocenoses of the continental part was achieved through the application of herbicides. Gianessi (2013) reported that in the 1960s, the Soviet Union had a significant boost (50%) in grain yields on state farms due to the extensive application of herbicides. Herbicides were extensively utilized on large collective farms during the 1950s and 1980s (Bertomeu-Sánchez, 2019). According to Hossain (2015), around 46 million ha of land were treated with pesticides in 1975, with herbicides being used on 23 million ha.

The collapse of the Soviet Union in 1991 resulted in the privatization of collective farms (Lerman, 2018). Currently, Ukraine is entering the second phase of agricultural growth. The driving force during this period has been the implementation of the resolution "On land reform" (1990), the enforcement of the Decree of the President of Ukraine "On urgent measures to accelerate the reform of the agrarian sector of the economy" (1999) and Ukraine's membership in the World Trade Organization in 2008, as reported in an analytical report on the development of the agricultural land market in Ukraine (Sobkevich et al., 2011). The 1990s witnessed market reforms such as privatization, resurrection of farms, denationalization of state farms and the reorganization of collective farms into communal agricultural companies (Van Atta, 2018).

The initial stage in this second phase involved the denationalization and privatization of government-owned companies. The objective of reforming property relations in the agricultural sector was to establish an efficient agricultural land user. According to Varchenko et al. (2018), the government no longer had exclusive ownership of land holdings. For example, in 1992, all of Ukraine's agricultural land was owned by the state. However, by 1 January 2011, the state's ownership had decreased to 48.9% (Nizalov et al., 2015). Nevertheless, despite notable advancements in land relations in Ukraine, government support for agriculture was dismantled, leaving many agricultural enterprises without the financial resources they needed to obtain herbicides. The decline in pesticide usage was the primary catalyst for the decrease in wheat production across the post-Soviet countries, with Ukraine experiencing a notable impact in the 1990s (Struggle, 2012). During the early 2000s, there was a noticeable rise in the prevalence of crop weeds, which has been recognized as a major factor contributing to substantial crop damage and loss (Ramesh et al., 2017; Skydan et al., 2022).

According to Gianessi (2013), in 2002, over one-half of the corn fields in Ukraine had been subjected to herbicide treatment. Over the past 50 years, agricultural practices in the country have been more intense, leading to developments such as expanding the size of arable land and a greater reliance on chemical methods for weed control. Therefore, by 2012, the percentage of maize fields in Ukraine that were subjected to herbicide treatment had risen to 90% (Krutjakova et al., 2018). During the 1990s in Ukraine, there was a trend towards decreasing the usage of plant protection compounds, declining from 89,100 t (2.7 kg/ha) in 1991 to 32,5oo t (1.1 kg/ha) in 1995 (Krutjakova et al., 2018). According to government figures, the amount of herbicides used per hectare of arable land declined from 0.7 kg in 1997 to 0.4 kg in 2000 (State Statistics Service of Ukraine. 2020).

Following the establishment of the legislative framework for land relations in Ukraine and Ukraine's membership in the World Trade Organization in 2008, a new third phase in the advancement of agricultural output commenced (Radzivill et al., 2019) as the country gained access to global market for agrochemicals. By 2018–2019, the average amount of herbicides based on active substance per hectare had already risen to 1.3–1.4 kg (State Statistics Service of Ukraine, 2019). The overall quantity of herbicides utilized in Ukraine, based on the active substance, amounted to 24,000 t in 2017, 25,000 t in 2018, 24,000 t in 2019 and 23,000 t in 2020 (State Statistics Service of Ukraine, 2018-2020).

Conducting and analyzing research is required on the biodiversity of agroecosystems at the landscape level, rather than at the level of individual agricultural fields, as emphasized by Barral et al. (2015). Mounting evidence has been reported of a widespread decrease in arable weeds in Europe (Andersson and Milberg, 1998; Fried et al., 2009). Currently, almost 13.9 million ha of agricultural land in Ukraine are subjected to herbicide treatment (State Statistics Service of Ukraine, 2023).

So-called weed species constitute a primary component of plant biodiversity in natural phytocenoses (Fedonyuk et al., 2020; Skydan et al., 2021; Orlov et al., 2023). Within agrocenoses, a major interaction occurs between cultivated species and weeds, which plays a crucial role in determining the extent of crop losses and the overall quality of the harvest. Prior to a specific point in time, it was widely held that the weeds found in cultivated plant crops had survived due to distinct tactics and had greater resistance compared to the cultivated plants themselves (Ghersa et al., 2000). However, this hypotheses has since been considered incorrect, with the weeds playing a minimal role in managed phytocenoses (Jastrzebska et al., 2013).

The objectives of the current study were: to determine the quantitative and qualitative changes in the species composition of weeds in the agrophytocenoses of the continental part of Ukraine; and to identify the reasons for these changes, based on a retrospective analysis and assessment of the current state in agricultural fields. Such information is necessary to better understand the trends in the expansion of certain species and to predict (and therefore counteract) their expansion.

Materials and Methods

Data were examined regarding the weed dynamics derived from scientific study carried out in regions classified as the eastern part of the continental zone, as per the European biogeographical zoning system (Roekaerts, 2002). Data were gathered that covered the period from 1966 to 2023. During this period, comprehensive weed surveys were systematically undertaken during the study as parts of various research projects. Three pivotal periods were chosen: 1) before1990—during the Soviet era; 2) 1991–2009 when there was reform in the agricultural sector; and 3) 2010–present, representing the development of farming activity in Ukraine.

The current study considered the types of weeds growing in plant communities of winter wheat, corn and sunflower, as well as weeds growing on unfarmed lands in the continental part of Ukraine. In addition, consideration was given to how often and where these weeds were found. In all these crops, almost all species of weed diversity thrived.

A minimum sample size was applied of 50 individual fields to accurately assess the level of weed infestation in winter wheat (36% of investigated fields), sunflower (27%) and corn fields (37%), aiming to identify 80% of the weed species present in the surrounding area.

Production crop surveys were conducted from July to August 2022–2023 on a total of 10 ha of all investigated fields, with three repetitions. The trials were repeated 12 times using frames of 1.0 m^2 to estimate the presence of weeds in the experiments based on their species and quantified amounts. The investigation was carried out in the agricultural fields of the continental part of Ukraine and in the Zhytomyr and Kiev regions of Ukraine. The weed species in each quadrat were combined and identified using a standard flora reference book (Mosyakin and Fedoronchuk, 1999). The Statistica 12.0 software (Version 12.0; StatSoft Inc.; http://www.statsoft.com) was used to analyze the data on emerging weed seedlings.

Information regarding the numerical and descriptive makeup of weeds was assessed individually for each specific instance, enabling frequency assessment of the weeds in each field and their botanical makeup.

The field density of weeds was assessed using a 7-point scale (Vanhala et al., 2004): 0 = an absence of weeds; 1 = weeds present individually, with a minimal degree of coverage (1–3 weeds/m^2; 2 = coverage up to 5% (3–5 weeds/m^2; 3 =5–20% cultivated plants and 5–15 weeds/m^2, indicating that cultivated plants outnumbered weeds; 4 = 20–50% (20–30 weeds/m^2), with cultivated plants still dominating weeds; 5 = 50–70%, with an equivalent or greater number of weeds compared to cultivated plants, which posed a serious threat to the crop; 6 = 75–100% of the time, indicating that weeds dominated cultivated plants.

A critical criterion was the equal evaluation of data from the various periods within the framework of the experiment that was addressed by using the 7-point rating detailed above. The assessment was based on a comparison of data across three time periods, comparing each subsequent period to the previous one (control). The goal was to estimate as accurately as possible the potential decrease in biomass (defined as the number of plants and their projective coverage on the site). This reduction was expressed using a rating system: less than 0.99–none = no weeds; 1–1.99 = little weed generally and no patches; 2–2.99 = moderate (weed growth in many places and in patches); 3–3.99 = heavy (extensive weed growth in patches but no woody weeds); 4 and more = very heavy (extensive weed growth in patches, including woody weeds).

A retrospective analysis of the number and species composition of weeds was carried out based on reviews of field logs, field journals and weed maps, including a list of weed species, as well as the density of their placement per unit area. Floristic lists of the weed species identified in the arable fields in the study area were available for three periods: surveys conducted before 1990 (120 descriptions), surveys conducted from 1991 to 2009 (218 descriptions) and surveys conducted since 2010 until the present (212 descriptions). A sample of 50 fields were surveyed in August 2023 (winter wheat, 36%; sunflower, 27%; and corn fields, 37%), with the data analyzed from dissertation studies conducted in the experimental field of the Polissia National University from 1991 to the present (139 fields) and collected research data from 70 farms in the Zhytomyr region. The biogeographical regions in Europe were defined in accordance with the data of the European Environment Agency (EEA) (Roekaerts M., 2002).

The current floristic composition of the arable fields was recorded based on vegetation inventories conducted from July 2022 to September 2023, just prior to the harvest of several crop varieties. An analysis was conducted on the overall arable region.

The survey plots were positioned at a minimum distance of 20 m from field boundaries to reduce the impact of agricultural circumstances that caused variations compared to the rest of the field. The distribution of weeds was documented using Raunkier's approach (Raunkiær, 1937), entailing recording the occurrence of each individual species during the crop survey.

In total 123 fields containing crops showed signs of weediness: 89% (winter wheat 37%, sunflower 32% and corn crops 20%), while 11% were uncultivated plots (Fig. 1). The selection of survey fields for the 2023 study was based on their conformity with the Retisol soil type. The mean distance between the two chosen fields ranged from 200 m to 2 km.

The Statistica software package (Version 12.0; StatSoft Inc.; http://www.statsoft.com) was used for statistical processing of the weed diversity data on winter wheat crops in the continental part of Ukraine. The methods used involved checking for the normality of the data distribution, corresponding methods of correlation analysis and 3D XYZ Graphs–3D contour plots. A cluster dendrogram (tree diagram) of the occurrence of the most common weeds in the continental part of Ukraine was carried out using Euclidean distances package in the Statistica software.

Results and Discussion

Retrospective analysis of development of weed vegetation in continental part of Ukraine

The current review of historical data on weed species in the fields of mainland Ukraine revealed a notable decline in the average number of weed species per square meter. Prior to 1990, the average number was 32 species; however during a recent survey in 2022–2023, it decreased to 16.8 species, representing a 30% reduction. The weed species population density was 95.6 individuals/m^2 from 1975 to 1990; subsequently, it rose to 102.85 individuals/m^2 from 1991 to 2010. Fig. 2 demonstrates a correlation between the surge in weed population in the agricultural fields of mainland Ukraine and the time since 1991–2010, which is in alignment with the aftermath of the Soviet Union's dissolution, during which state assistance for agriculture was dismantled and numerous farms lacked the means to purchase herbicides. Nevertheless, the livestock sector of agricultural production was highly advanced,

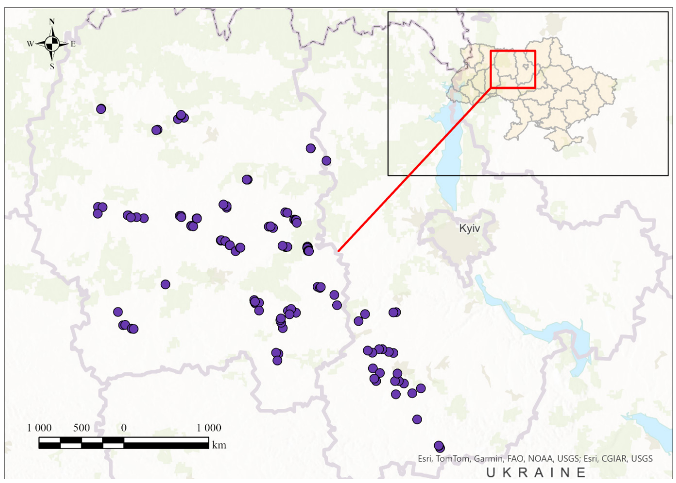


Fig. 1 Plots of weed vegetation records in agricultural fields in continental zone of Ukraine

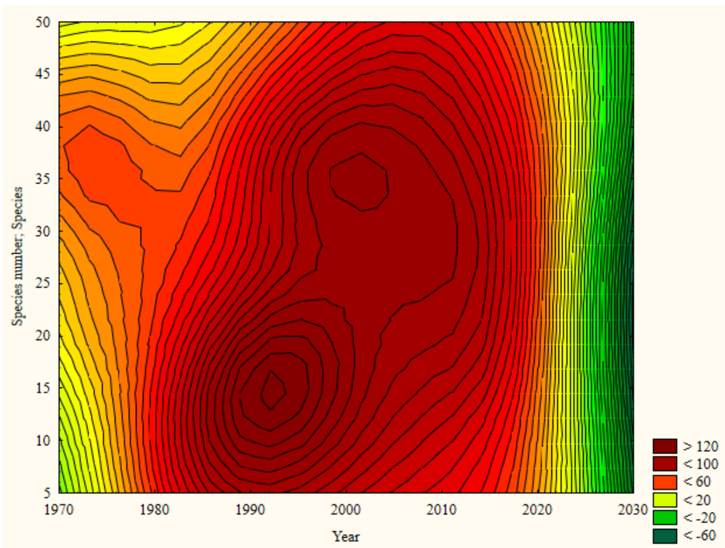
with the fertilization of agricultural crops involving the use of organic fertilizers produced on-site. Inadvertently, this practice facilitated the dispersal and proliferation of weed seeds, as indicated by a 4 yr study by Blackshaw et al. (2005), according to which the ranking of the weed seedbank was: composted manure = broadcast N fertilizer > fresh manure > banded N fertilizer.

Based on Fig. 2, it was concluded that there was an increase in weed density from 1985 onward until 2015, with a subsequent population decline, suggesting that practicing organic farming approaches led to a decline in weed infestation levels (Gallandt, 2014).

Alterations in the quantity and species composition of weeds manifested themselves as early as 2010, coinciding with the initiation of agricultural output development in Ukraine (Aviron et al., 2013). Throughout this time frame, there was a general decline in the overall prevalence of weeds in crops that was clearly linked to the increased expansion of Ukrainian farmers into the global herbicide market, promotional efforts by herbicide makers, a more rigorous approach to agricultural production and the direct motivation of agricultural producers to achieve high agricultural crop yields.

Although the diversity of weeds varied over time, all types of crops were predominantly occupied by a small number of species: *Cirsium arvense* (L.) Scop.; *Elymus repens* (L.) Gould; *Convolvulus arvensis* L.; *Sonchus arvensis* L.; *Stellaria media*; *Chenopodium album* L.; *Polygonum aviculare* L.; *Galium aparine* L.; and *Amaranthus retroflexus* L. (Campiglia et al., 2018; Krähmer et al., 2020; Hutianskyi et al., 2023). The species with the greatest distribution varied across the different time periods. Based on Baessler and Klotz (2006), the most prevalent weeds during the period leading up to 1991 were *S. media* (3.33%), *C. album* (1.55%) and *P. aviculare* (1.38%). In the 1980s, the prevalence of *G. aparine* was the highest (4.34%), followed by *C. album* (2.26%) and *S. media* (1.76%), according to Ryabchuk (2009).

According to Freeman and Lutman (2004), the lowest level of coverage has been reached since the 2000s. The species with the greatest extent of coverage were limited to *C. album* (0.70%), *F. convolvulus* (0.44%), *P. aviculare* (0.42%) and *C. arvense* (0.52%). Nevertheless, there was a noticeable rise in species with exceedingly low average coverage (Hrytsiuk et al., 2020). In fact, 75% of the species had an average cover that was less than 0.05%. Most of these species were



Years: Species number, Pieces: y = 118.0806 - 0.0464*x;
Pearson's correlation (r) = -0.1133; p = 0.2474; Coefficient of determination (R^2) = 0.0128
Years: Number of weed plants, Pieces: y = 2670.5957 - 1.3014*x;
r = -0.49156, p = 0.00000, R^2 = 0.2416

Data source: Rehland, 1989; Sozinov et al., 1993; Chernilevskyi et al., 1998; Kryvych and Biliavskyi, 1998; Naumenko and Kovalchuk, 2007; Kochyk and Vorona, 2008; Ryabchuk, 2009; Tkalich and Bokun, 2012; Borysenko, 2013; Krutjakova et al., 2018; Ivaschenko et al., 2018., Karpuk et al., 2018; Fedoniuk et al., 2019; Kurdiukova and Tyschuk, 2019; Kurdyukova, 2020; Fedonyuk et al., 2020; Hrytsiuk et al., 2020; Tanchyk et al., 2020; Matyukha, 2021; Shmatkovska et al., 2021; Sleptsov, 2021; Fedoniuk et al., 2022; Medvediev, 2022; Sokolovska, 2023; Fedoniuk and Skydan, 2023; Hutianskyi et al., 2023; Orlov et al., 2023; Kozulina et al., 2023 and data from current research.

Fig. 2 Dynamics of number and species diversity of weeds on winter wheat crops in continental part of Ukraine common agricultural weeds, including *Hyoscyamus niger* L., *Knautia arvensis* (L.) Coult., and *Sherardia arvensis* L. (Baessler and Klotz, 2006), as well as *Adonis aestivalis* L., *Anthemis arvensis* L. and *Scleranthus annuus* L. However, these species were no longer documented in the records compiled for the current study and can now be considered either rare or extinct in mainland Ukraine. New ecological niches were established because of the introduction of new species from different habitats. These species, including *Cuscuta campestris* L., *Solidago canadensis* L., *Asclepias syriaca* L., *Lepidium ruderale* L., *Lysimachia nummularia* L. *and Tanacetum vulgare* L.*,* entered new areas through the dispersal of seeds and organic fertilizers (Borysenko, 2013). In addition, the adoption of a more equitable strategy toward weed management in recent years has played a substantial role in the almost complete elimination of these species from the region's weed biodiversity.

Changes in the coverage of several species most typical for the region changed notably during the studied period (Table 1). While the cover of 16 species decreased and of two species increased significantly, only five species had fluctuating values from 1973 to 2023. Typical weed species that showed a very notable reduction were: *Consolida regalis* Gray; *Mentha arvensis* L.; *Silene noctiflora* L.; *S. media*; and *Thlaspi arvense* L. In contrast, *A. retroflexus* and *Veronica polita* Fr. had major increases in coverage.

Table 1 Weed species with notable changes in average cover (average value of weediness point scale (Vanhala et al., 2004) for all fields between periods

Species	Before 1990	1991–2009	2010 to present
Amaranthus retroflexus L.	0.00	0.66	1.83
Amarantus albus	0.00	0.01	0.16
Ambrósia artemisiifólia	0.00	0.09	0.23
Anisantha tectorum	0.06	0.08	0.07
Arenaria serpyllifolia	0.49	0.00	0.00
Atriplex tatarica L.	0.23	0.21	0.07
Bromus squarrosu	0.07	0.06	0.06
Buglossoides arvensis (L.) I.M.Johnst.	0.21	0.01	0.01
Capsella bursa-pastoris	0.42	0.08	0.05
Centaurea cyanus L.	0.98	1.01	0.89
Chenopodium album L.	2.26	2.33	1.38
Cirsium arvense	2.15	2.35	2.31
Convolvulus arvensis	1.98	1.85	1.71
Consolida regalis	1.09	0.03	0.04
Descurainia sophia (L.) Webb ex Prantl	0.39	0.03	0.16
Echinochloa crus-galli	0.68	1.01	1.35
Elymus repens	2.11	1.89	2.01
Equisetum arvense L.	1.54	1.23	1.64
Euphorbia esula	0.02	0.00	0.00
Euphorbia exigua	0.48	0.04	0.04
Euphorbia antiquorum L.	0.20	0.08	0.03
Fumaria officinalis L.	0.22	0.24	0.21
Galium aparine	0.21	3.74	0.40
Iva xanthiifolia Nutt.	0.22	0.11	0.23
Lactuca serriola L.	0.11	0.15	0.13
Lactuca tatarica (L.) C. A. Mey.	0.25	0.36	0.11
Lamium amplexicaule L.	0.36	0.14	0.01
Méntha arvénsis	1.18	0.07	0.08
Orobanche cumana Wallr.	0.16	0.03	0.04
Plantago intermedia	0.00	0.06	0.00
Polygonum aviculare L.	0.45	0.49	0.32
Polygonum convolvulus	0.95	1.25	0.56
Papaver rhoeas	0.59	0.03	0.33
Setaria glauca	0.60	0.66	0.97
Setaria viridis (L.) P. Beauv.	0.23	0.11	0.12
Silene noctiflora L.	0.33	0.21	0.02
Sinapis arvensis	0.63	0.17	0.00
Sisymbrium loeselii	0.08	0.09	0.04
Sonchus arvensis	1.98	2.56	1.86

Table 1 Continued

Species	Before 1990	1991–2009	2010 to present
Sonchus oleraceus	0.39	0.22	0.02
Stellaria media (L.) Vill.	3.43	1.76	0.55
Taraxacum officinale (L.) Weber ex F.H.Wigg.	0.09	0.06	0.07
Thlaspi arvense L.	0.25	0.02	0.00
Veronica hederifolia L.	0.99	0.18	0.00
Veronica polita Fr.	0.00	0.18	0.35
Veronica spicata L.	0.40	0.00	0.00

Data source: Rehland, 1989; Sozinov et al., 1993; Chernilevskyi et al., 1998; Kryvych and Biliavskyi, 1998; Naumenko and Kovalchuk, 2007; Kochyk and Vorona, 2008; Ryabchuk, 2009; Tkalich and Bokun, 2012; Borysenko, 2013; Krutjakova et al., 2018; Ivaschenko et al., 2018., Karpuk et al., 2018; Fedoniuk et al., 2019; Kurdiukova and Tyschuk, 2019; Kurdyukova, 2020; Fedonyuk et al., 2020; Hrytsiuk et al., 2020; Tanchyk et al., 2020; Matyukha, 2021; Shmatkovska et al., 2021; Sleptsov, 2021; Fedoniuk et al., 2022; Medvediev, 2022; Sokolovska, 2023; Fedoniuk and Skydan, 2023; Hutianskyi et al., 2023; Orlov et al., 2023; Kozulina et al., 2023 and data from current research.

The biodiversity of weeds has undergone alterations in response to changes in agricultural management and overall governmental agrarian policy. Over the past few decades, there has been a notable decline in the average number of weed species and their coverage per description, particularly for common weed species. Species richness in arable fields is primarily influenced by the complexity of the landscape matrix and the size of the plot, along with the number of field borders (Fahrig et al., 2015). Additionally, the intensity of land use, such as the application of mineral fertilizers and the use of chemicals, also plays a major role, with these developments being closely linked to collectivization and the increasing intensification of agriculture (Fedoniuk et al., 2019; Romanchuk et al., 2018; Skydan et al., 2022; and Fedoniuk and Skydan, 2023).

Despite major changes in the structure of farms, such as an increase in the number of farms and a decrease in individual farm size, caused by changes in agricultural policy after 1990, there have been only small changes in field structure during the past two periods up to the present. During this period, numerous expansive communal farm fields were subdivided into smaller plots. However, from the 2000s forward, there has been a gradual consolidation as the vast peasant farms have started utilizing shares.

Current state of weed vegetation development in continental part of Ukraine

In Ukraine, especially in its continental region, there has been a prevalence of moderate-to-severe weed infestation in field crops (90–98%). This high level of weed presence, with densities of 15 or more plants per square meter, has resulted in a reduction of crop output by 20% or more (Pysarenko et al., 2020). The weediness of agrocenoses is determined by numerous factors: the persistent selection of specific weed species and modifications in farming practices (including crop rotation); soil cultivation methods; the application of agricultural herbicides; and technological aspects of cultivating crops (Kiryushin, 2019). Weeds are indeed enduring elements of agrophytocenoses and uncultivated areas. During the current research study spanning from 1975 to the present, over 700 species of weeds were documented that had infested most of the agricultural fields in Ukraine. Out of these species, approximately 30 were primary weeds responsible for substantial crop losses (Fig. 2) and were present in nearly all agricultural fields and on uncultivated lands in both biogeographic zones. The remaining 75–225 species can cause varying degrees of harm to agricultural crops, perennial crops, hayfields and pastures. However, based on the statistical data, the annual decrease in crop output caused by weed removal was estimated on average to be 12.3–16.5% (Mayerová et al., 2018). Consequently, herbicides have been applied to almost 13.9 million ha of agricultural land in Ukraine. The presence of herbicides was particularly relevant where intensive technologies had been implemented. For example, during the cultivation of winter wheat, the herbicide load might occasionally reach 6–10 kg/ha, while for corn and beets, it can go up to 12–16 kg/ha, while vegetable crops can have a herbicide load of up to 45–50 kg/ha. On the other hand, fruit crops can have a herbicide load as high as 165 kg/ha (SuperAgronom.com, 2021). Based on the latest operational data, as of 19 October 2023, agricultural crops were protected from pests, diseases, and weeds on a total area of 37.4 million ha (State Service of Ukraine on Food Safety and Consumer Protection, 2023)). The area breakdown of treatments was: weeds = 17.0 million ha; diseases = 9.3 million ha; and pests = 9.4 million ha (State Service of Ukraine on Food Safety and Consumer Protection. 2023). Additionally, biological plant protection methods were applied on 1.1 million ha. The process of desiccation was conducted on an area exceeding 634,000 ha (State Service of Ukraine on Food Safety and Consumer Protection. 2023).

Weeds that typically dominate in crops, necessitate nearly identical conditions of growth and development with the cultivated crop. Scientists must acquire a comprehensive understanding of the adaptive mechanisms and regular responses of weeds to agrotechnological practices and herbicide application in order to develop a system that efficiently manages weed populations in crops and minimizes crop losses. Addressing this issue mandates the utilization of retrospective comparisons of agricultural systems at various stages of their development. Notably, in the last two decades, there have been substantial and transformative changes in the elements that influence the growth of weed vegetation. Primarily, this pertains to the arrangement of land usage, the configuration of cultivated regions, the implementation of short-rotation crop cycles, the adoption of minimal techniques for fundamental soil cultivation, the reduction of technological procedures and the incorporation of limited amounts of organic fertilizers. Throughout the past century, the advancement of agriculture has witnessed multiple transitional phases aimed at restructuring the approach to land utilization. The initial government decisions on the major role of corn in crop rotation can be traced back to the early 1930s; however, the substantial expansion of farmed areas for this crop did not occur until the late 1950s, when simultaneously, a discussion arose on the contrasting goals of the grass-field concept, which involved maintaining soil fertility through the cultivation of perennial grasses, and the mineral concept, which relied solely on mineral fertilizers for fertility management (Shevchenko, 2013). In the 1990s, there was an unregulated decrease in the amount of land used for growing fodder crops, with a concerning increase in the amount of land used for growing sunflowers, which posed ecological risks (Shevchenko, 2013). In the last two decades, the amount of land dedicated to growing sunflowers has risen from 10–12% to 34–37%, while the area used for growing fodder crops has declined from 29–35% to 4–6% in the overall distribution of arable land (Shevchenko, 2013). The prevalence of row crops, such as maize and sunflower, on over 50% of arable land has emerged as a crucial factor in shaping the trajectory of agricultural development. Consequently, there has been a substantial proliferation of weeds and heightened detrimental impacts. The phytocoenoses of weeds that emerged between 1957 and 1968 were a consequence of an agricultural system primarily based on crop structures dominated by non-row crops and low utilization of herbicides. Consequently, Kraehmer (2016) reported the prevalence of weeds such as *Setaria glauca* (96%), *Amarantus albus* (85%), *C. album (72%)* and *Polygonum convolvulus* (57%). Between 1980 and 1984, the increased use of row crops, such as corn and sunflower, along with the introduction of new herbicides containing atrazine and eradican in mineral oil emulsions, caused changes in the way weeds developed in cultivated plant crops. For example, *E. gruss galli* and *A. retroflexus* have undergone major changes in their phytocenosis, with the prevalence of these undesirable plants in agricultural fields having increased notably from 51% to 92% (Schwartau et al., 2023) that can be attributed to their enhanced resistance to herbicides, rendering them less susceptible to eradication (Peters and Gerowitt, 2015). The current investigation observed similar patterns, coinciding with a large decline in the population of *A. albus* and *C. album* (Fig. 3).

As shown in Fig. 3, in a single field, weed groups typically consist of 17–26 species, although in certain cases there may be a substantial number (53–200 species). The variations in the species composition, distribution and harmfulness of weeds in the agrophytocenoses of the continental region of Ukraine can be attributed to the diverse soil and climatic conditions, as well as ecological variables. The conducted analysis revealed that the mean species richness in the examined fields was 18.75 species (8–49 species) and the mean species diversity was 4.31 (2.01–5.99). Within the weed communities,

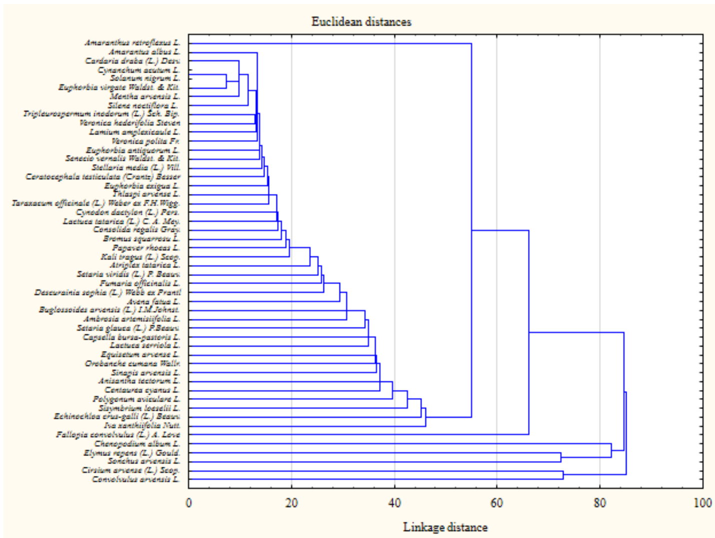


Fig. 3 Cluster dendrogram (tree diagram) of occurrence of most common weeds in continental part of Ukraine
Data source: Current research results

dicotyledonous plants were the dominant species, accounting for 89% of the total. Most of the species consisted of winter weeds, (43%), whereas summer weeds made up only 16%. It is widely recognized that young weeds exhibit varying levels of compatibility with different crops in crop rotation, and as a result, crops have diverse impacts on weeds (Bajwa, 2014). Regardless of the crop being cultivated, all the current fields surveyed had four species of weeds: *Ci. arvense*, *E. repens*, *Co. arvensis* and *S. arvensis.*

Based on their share of the weed group, *Ci. arvense, E. repens, Co. arvensis* and *S. arvensis* had a major impact on winter wheat, as the most active portion of the weed block. Without exception, all winter wheat fields contained these species, with mean numbers of during the period of growth of 30–40 pieces/m^2, whereas the projective coverage and ground mass were 16% and 9%, and 250 g and 90 g, respectively (Fig. 4).

Based on the results, there were the same weed species for all recorded regions of mainland Ukraine that were the most prevalent weeds in specific agrophytocenoses of common agricultural crops (such as winter wheat, sunflower and corn) and uncultivated lands. However, there were variations in their ranking by frequency of occurrence and quantity in the different crops and uncultivated lands, which differed majoracross various agrophytocenoses.

The predominant weed species were identified that frequently occurred in the different agrophytocenoses and on uncultivated lands based on the extensive field experiments and surveys conducted between 2022 and 2023. Additionally, the patterns of their distribution were analyzed and control strategies were developed for specific regions.

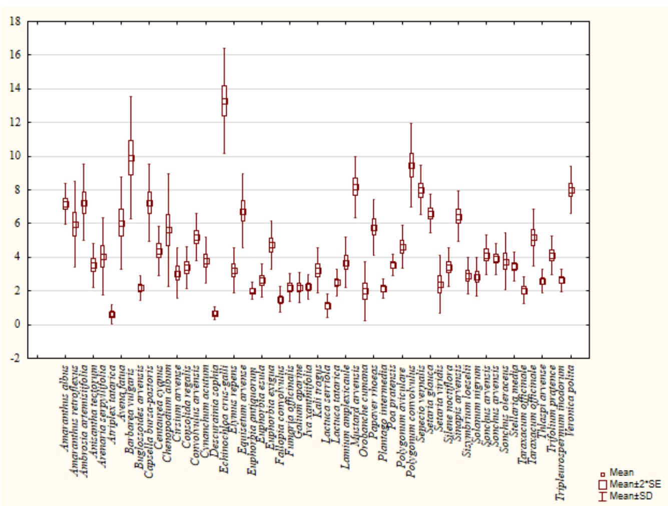


Fig. 4 Most problematic weeds in continental part of Ukraine, and their density, based on farmer surveys, where error bars represent ± SD

During the surveys, the farmers in the continental part of Ukraine indicated that of the weeds identified as the most problematic in winter, those in wheat crops were the most burdensome, with a high level of abundance for *Ci. arvense* (17.8 pieces/m^2)*, E. repens* (3.1 pieces/m^2)*, Co. arvensis* (5.1 pieces/m2), *S. arvensis* (3.8 pieces/m^2), *Ci. arvense* (2.7 pieces/m^2), *Capsella bursa-pastoris* (7.3 pieces/m^2), *Mustard arvensis* (8.1 pieces/m^2), *C. album* (6.3 pieces/m^2), *A. retroflexus* (6.1 pieces/m^2), sunflower (*Co. arvensis*) (3.3 pieces/m^2), *E. crus-galli*. (13.4 pieces/m^2), *Ci. arvense* (4.5 pieces/m^2) and *E. repens* (2.5 pieces/m^2), as shown in Fig.4.

The secondary species with a frequency of occurrence up to 50% and abundance in the range 1.0–17.3 pieces/m^2 were: *Poa pratensis* L.; *Fallopia convolvulus* (L.) A. Love; *Trifolium pratence* L.; *Kali tragus* (L.) Scop.; *Solanum nigrum* L.; *Taraxacum officinale* L.; *Amaranthus albus* L.; *Senecio vernalis* Waldst. & Kit.; *Avena fatua* L.; *Ambrosia artemisiifolia* L.; *Tripleurospermum inodorum* (L.) Sch. Bip.; and *Cynanchum acutum* L.

In the last period, in all the agrophytocenoses in the continental part of Ukraine, the share of perennial weeds, such as field birch, field thistle, Tatar lettuce and milk thistle, increased from 6–9 to 26–31% in total crop weediness. In contrast, there were decreases from 12–14 to 1–3% for: *Euphorbia virgata* Waldst. & Kit.); creeping wheatgrass (*E. repens* (L.) Gould.); grain-like core (*Cardaria draba* (L.) Desv.); and Bermuda grass (*Cynodon dactylon* (L.) Pers.). There was an increase in the influence of annual species, such as *A. artemisiifolia* and *Iva xanthiifolia* Nutt., from 0.5% to 18–63% or more. Furthermore, there was an increase in the weed influence in winter wheat crops such as *Anisantha tectorum* L. and *Veronica hederifolia* Steven.

In the phytocenoses of uncultivated lands, both in frequency of occurrence (98–100%) and in abundance (60 –1,600 pieces/m^2) the prevalent species were: *P. aviculare* L.; *A. artemisiifolia*; *Atriplex tatarica* L.; and *C. bursa-pastoris*.

In recent years, species with high seed productivity have begun to dominate the weed synusia of uncultivated land: *A. artemisiifolia*; *A. retroflexus*; *C. album*; and *I. xanthiifolia*. In addition to these species, previously secondary and new weeds are becoming more common: Canadian horsetail; short-beaked chondrilla (*Chondrilla brevirostris* Fisch. & C. A. Mey); long-spined cenchrus (*Cenchrus longispinus* (Hack.) Fernald); Faber's mouse (*Setaria faberi* F. Herrmann); and annual phalacrolom (*Phalacroloma annum* (L.) Dumort).

Some species, such as *A. retroflexus L.* and *C. album L.* were found everywhere and littered both grain and row crops, supporting uncultivated land as a potential source for the introduction and spread of new types of weeds in agrophytocenoses.

The farmer surveys in 2023 showed that multi-depth tillage and spraying crops with foliar herbicides in the fall or early spring were the most common and effective methods of weed control for the 10 most-common weed species in winter wheat agrophytocenoses. In sunflower, stubble stripping was combined with deep fall tillage, two pre-sowing cultivations and soil herbicides before or after sunflower seeding. On uncultivated lands, one or two mowings of weeds in the phases of budding and earing, or the application of continuous-action herbicides were reported.

Conclusion

This historical sketch of weed community establishment in agrocenoses in continental Ukraine used three important time periods. Up until 1990, the average number of weed species decreased notably. The number of weeds increased most from 1991 to 2010, which was consistent with the collapse of the USSR state support for agriculture, so that many agricultural enterprises did not have the financial resources to buy herbicides and so they fertilized their crops with organic fertilizers of their own production, which also contributed to the transfer of weeds and an increase in weed density from 1985 to 2015. After 2010, weed numbers and species composition decreased after the Ukrainian farmers gained access to the global markets, herbicide manufacturers launched information campaigns and agricultural production became more scientific (complex agrotechnical measures were used). From 1975 until the present, the current project identified approximately 700 weed species in Ukraine's key agriculture areas, though only about 30 species caused substantial crop losses. Nearly all agricultural and uncultivated regions in both biogeographic zones included these weeds, with the remaining 75–225 species affecting agricultural crops, perennial crops, hayfields and pastures. Although the weed biodiversity fluctuated, all crop types were dominated by *Ci. arvense*, *E. repens* , *Co. arvensis*, *S. arvensis*, *G. aparine*, *G. aparine*, *P. aviculare*, *G. aparine* and *A. retroflexus*.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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