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Phytocenotic analysis of segetal flora as an indicator of agroecosystem stability under long-term herbicide application

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Abstract. The study aimed to identify patterns in the restructuring of the segetal flora and changes in the functional stability of the cereal agrocenosis under the influence of various herbicide control systems. Methods of square plots, geobotanical description, biometric and weight measurements, morphological and biological grouping, vegetation testing, soil chemical analysis, plot-by-plot yield recording and analysis of variance were used. The study determined that in the control plot, the total number of species was 24, the number of families was 10, the average number of species per 1 m^2 was 8.6, and the number of dicotyledonous species was 17. Under the integrated system, these figures were 22, 9, 7.8 and 16, respectively, i.e., they remained closer to the control values. The Shannon index ranged from 2.42 in the control to 1.31 following prolonged application of the acetolactate synthase inhibitor, whilst under the integrated system it was 2.28. The cover of the dominant species increased to 36.7%, whilst the number of rare species decreased to 1, indicating increased dominance and a narrowing of the community's reserve pool. Quantitative indicators also changed significantly: weed density decreased from 128 to 36 plants/m^2, fresh weight from 486 to 142 g/m^2, dry weight from 148 to

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47 g/m², and projective cover from 62 to 18%. With prolonged application of the acetolactate synthase inhibitor, the Morishita aggregation index reached 1.74, the number of herbicide-tolerant species was 8, the average root depth of the dominant species was 24.8 cm, and the weight of 1,000 seeds was 2.76 g. Functional indicators confirmed this pattern: the density of the soil seed bank decreased from 42.8 to 21.7 thousand seeds/m², nitrogen removal by weeds decreased from 31.5 to 9.6 kg/ha, and crop yield losses decreased from 27.4 to 6.9%. Practical significance of the study lay in the fact that its results can be used by agronomists, researchers and grain producers to select weed control systems that not only reduce weed infestation but also preserve the structural stability of the agroecosystem

Keywords: segmental flora; herbicides; dominant species; herbicide-tolerant species; agrocenosis; herbicide control systems; floristic structure

Introduction

The research relevance is determined by widespread and prolonged use of herbicides in cereal crops and the accumulation of changes affecting not only the level of weed infestation but also the structure of the weed flora. Such research is necessary, as long-term use of chemical control systems affects the species composition, dominance, spatial distribution of weeds and the functioning of the agrocenosis. Phytocenotic analysis makes it possible to track changes in the organisation of weed communities under the influence of different herbicide application regimes and to establish a link between the structure of the flora and indicators of agroecosystem stability. The problem addressed in this study arises from interrelated difficulties in studying the segetal flora of cereal crops. The abundance or biomass of weeds was prioritised, whilst floristic structure, coenotic indicators, biological and ecological characteristics of dominant species, and the functional consequences of their presence were reported separately. This complicates the comparison of herbicidal pressure with changes in species composition, seed regeneration, resource utilisation and losses in crop productivity. Such an approach requires a careful consideration of the segetal flora as a structural and functional component of the agroecosystem.

In the context of climate change, A.M. Lishchuk *et al.* (2025) examined the segetal phytobiota as a factor of ecological risk in agro-phytocenoses. Changes in species composition, the spread of more resilient components and an increase in the phytosanitary burden were linked to environmental transformation and the growing difficulty of controlling weed flora. From the perspective of ecological safety, A.M. Lishchuk *et al.* (2024) analysed the impact of segetal flora on the condition of agrophytocenoses under the influence of external stress factors. The spread of adventitious and competitively active species was accompanied by a disruption of the structural balance of crops and a reduction in the resilience of the cultivated component. Using data from winter wheat crops, S. Okrushko (2023) compared phytocenotic and chemical approaches to weed control. Dicotyledonous species predominated in the segetal flora, and varying intensities of weed control were accompanied by a restructuring of the weed layer and changes in competitive interactions within the crop. In line with the agroecological approach, R. Gómez-Gómez (2024) proposed a distinction between the concepts of weeds and segetal vegetation. The segetal component was regarded not merely as a target for suppression, but as an element of the agroecosystem linked to biodiversity and the choice of control methods.

Under conditions of water stress, M. Özkil *et al.* (2025) assessed the impact of various weed control strategies on the status of associated soil organisms within the crop phytocenosis. Different levels of weed cover suppression were accompanied by changes in the density of phytoparasitic nematodes and revealed a link between the control system and the biotic background of the agrocenosis. In a comparison of crop rotation systems, H.T. Nguyen & M. Liebman (2022) investigated the composition of weed communities in simpler and more diverse farming systems. Greater crop diversity was accompanied by changes in the composition, density and aboveground biomass of weeds, which made it possible to consider the structure of the community as an indicator of the stability of the agrosystem.

In the context of the transition to conservation agriculture, D. Derrouch *et al.* (2022) observed functional shifts in the composition of weed communities following the introduction of conservation agriculture. An increase in species richness, α-functional diversity and the proportion of gramineous forms was accompanied by an increase in average seed weight and the spread of species with a summer-winter germination pattern. Within integrated weed management systems, S. Cordeau *et al.* (2022) assessed the long-term consequences of contrasting approaches to weed control following many years of application. More integrated systems were associated with higher species richness, greater weed density and changes in the taxonomic and functional structure of the flora.

In the context of the Mediterranean agrolandscape, A. Boutagayout *et al.* (2025) summarised agroecological practices for sustainable weed management. Intensive land-use patterns were associated with the spread of resistant ecotypes and a simplification of vegetation cover, whilst agroecological approaches were linked to the preservation of biodiversity and the ecological balance of agrosystems. In modelling the response of weed communities, F.H. Oreja *et al.* (2022) traced how changes in the density of individual species altered community diversity under varying intensities of herbicide use. Changes in the abundance of dominant and associated components explained the impact of herbicide programmes on community structure and its subsequent restructuring. Regarding effects of herbicide exposure, H. Wang *et al.* (2024) investigated the impact of herbicide residues on soil multifunctionality and the microbial community. Increased concentrations of herbicide residues were accompanied by a reduction in microbial diversity, changes in the composition of the microbiome, and a decline in soil functions related to nutrient cycling. In a comparison of herbicide strategies and crop rotations, M. Mayerová *et al.* (2022) analysed the effects of forty years of applying various chemical control schemes and crop rotations on weed communities at two sites in the Czech Republic. The composition of the flora depended not only on the herbicide load but also on the structure of the crop rotation, which made it possible to track changes in weed communities under the influence of combined agronomic factors.

The relationship between prolonged herbicide exposure, phytocenotic restructuring of the segetal flora and functional indicators of agroecosystem stability in cereal crops remained understudied. The study aimed to determine the impact of various herbicide control systems on the floristic structure, coenotic organisation, biological and ecological characteristics of dominant species, and functional indicators of agroecosystem stability in cereal crops. The objectives of the study were to determine changes in the floristic composition of the segetal flora, to assess the coenotic, quantitative, spatial and biological-ecological characteristics of dominant species, and to compare the functional indicators of the agroecosystem under different herbicide control systems.

Materials and Methods

The study was conducted in 2025 on a winter wheat production plot in the village of Verkhnia Syrovatka, Sumy District, Sumy Oblast, Ukraine. The subject of the study was the agrocenosis of the "Shestopalivka" variety of winter wheat. This variety was selected due to its consistent crop establishment, good adaptation to the conditions of the north-eastern Forest-Steppe, and relatively uniform plant development, which made it possible to assess changes in the segetal flora without any significant influence from varietal heterogeneity. During the experiment, the principles of Good Experimental Practice were adhered to in accordance with standards EPPO PP 1/181 and EPPO PP 1/152, and field work was conducted following requirements to prevent unjustified disturbance of the biotic components of the agroecosystem (European and Mediterranean Plant Protection Organization, 2012; 2021). Weather conditions in 2025 were contrasting: the early spring period was characterised by sufficient moisture and moderate temperatures, whilst the second half of the growing season saw prolonged rainless periods, rising air temperatures and a decline in productive moisture reserves in the arable layer. This hydrothermal regime intensified competition between cultivated plants and weeds, whilst at the same time creating conditions for the establishment of species with greater ecological resilience. The plot was characterised by typical low-humus, medium-loam chornozem. In the 0-30 cm topsoil layer, the humus content was 3.21%, the pH of the salt extract was 6.7, the nitrate nitrogen content was 16.8 mg/kg, the available phosphorus content was 54.7 mg/kg, and the exchangeable potassium content was 88.9 mg/kg. The previous crop was soya. Primary tillage involved disc harrowing the stubble to a depth of 6-8 cm and ploughing to a depth of 20-22 cm, whilst pre-sowing tillage consisted of cultivation with levelling of the field surface. In all five treatments, the same background mineral nutrient level of N60P60K60 was maintained. Sowing took place in the third decade of September 2024 with a row spacing of 15 cm. The experiment was set up using a randomised block design with four replicates, as this number of replicates ensured a statistically reliable comparison of the treatments and reduced the influence of natural heterogeneity in the soil cover within the field. The area of a single plot was 50 m^2, and the survey area was 32 m^2. Five treatments were compared: a control without herbicides; long-term application of an ALS inhibitor (mesosulfuron-methyl + iodosulfuron-methyl-sodium); long-term application of synthetic auxins (dicamba + MCPA (2-methyl-4-chlorophenoxyacetic acid)); herbicide rotation (prosulfocarb → clodinafop-propargyl + carfentrazone-ethyl); and an integrated control system (flufenacet + diflufenican + pre-emergence harrowing + agronomic measures). Agronomic measures referred to stubble ploughing and early spring harrowing. All herbicide applications were conducted using a HARDI Commander 3200 boom sprayer (HARDI International A/S, Denmark) in the morning between 06:00 and 09:00 or between 6:00 and 9:00 p.m., at wind speeds not exceeding 3-4 m/s and air temperatures up to 25°C; the application rate of the working solution was 200 l/ha.

The total number of species of the segetal flora was recorded at designated sample plots using a 1 m^2 metal frame and an Eschenbach Mobilux 6× LED handheld magnifying glass (Eschenbach Optik GmbH, Germany). All morphologically identified weed species found within the survey area were included in the final list. The number of families and the number of genera were determined following taxonomic analysis of the species list using a Leica EZ4 W stereomicroscope (Leica Microsystems, Germany) and a Dell Latitude 7030 Rugged Extreme field tablet (Dell Technologies, USA) for digital recording of the floristic matrix. The number of families was taken to be the number of botanical families represented by at least one identified species, and the number of genera was defined as the number of genera within which at least one species was recorded. The average number of species per 1 m^2 was calculated as the average number of species across all survey plots using formula (1):

$$\overline{\Sigma_1} = \frac{\Sigma \sigma_j}{\kappa}, \tag{1}$$

where $\bar{\Sigma}_1$ – average number of species per 1 m^2, pcs; σ_j – number of species on j-th experiment plot, pcs; κ – number of experiment plots. Floristic richness index, units, was calculated as the ratio of the total number of species to the number of families, using formula (2):

$$K_{\phi} = \frac{\upsilon}{\varpi}, \tag{2}$$

where K_{ϕ} – floral density coefficient, pcs; υ – total number of species of the segetal flora, pcs; ϖ – number of families, pcs. Number of monocotyledonous species, pcs., and the number of dicotyledonous species, were determined following the biomorphological grouping of the flora according to leaf venation pattern, seedling shape, tillering node morphology and the overall structure of the primary shoot, using an OPTIKA SZM-LED1 stereo microscope (OPTIKA Srl, Italy). Shannon species diversity index, units, was calculated based on the relative proportion of each species in the total weed population following digital processing of the floristic matrix in PAST 4.13 using formula (3):

$$\mathcal{H} = -\sum \rho_i \ln \rho_i, \tag{3}$$

where H – Shannon's species diversity index, pcs; ρ_i – share of i-th species in the total number of the segetal flora; ln – natural logarithm; i – serial number of the species in the floristic list. The number of dominant species was determined by counting individual plants of each species using a Zebra TC57 field data collector (Zebra Technologies Corp., USA). Species were classified as dominant if their proportion of the total weed population exceeded 10%. The number of co-dominant species was determined using the same set of survey data. Co-dominant species were defined as those whose proportion of the total number was 5-10%. The cover of the dominant species, %, and the total cover of the three leading species, %, were assessed using a Braun-Blanquet Grid Frame 100 cells (Royal Eijkelkamp, Netherlands). These indicators were defined as the proportion of the survey grid's area vertically covered by the leaves and stems of a single dominant species or, collectively, by the three species with the highest proportion in the community. The calculation was performed using formula (4):

$$P_{\alpha} = \frac{\lambda_{\alpha}}{\lambda_{100}} \times 100, \tag{4}$$

where P_{α} – dominant view coverage, %; λ_{α} – number of cells in the frame occupied by the vertical projection of the dominant feature; λ_{100} – total number of cells in the accounting grid. Average abundance, as measured on the Braun-Blanquet scale (score), was determined during the geobotanical survey, with the field scores subsequently converted into numerical values. The following gradations were used on the scale: 1 – numerous individuals with coverage of up to 5%; 2 – coverage of 5-25%; 3 – 25-50%; 4 – 50-75%; 5 – 75-100%. The assessment was conducted independently by two specialists with higher education in biology at each site; where discrepancies exceeded one point, a joint re-examination was conducted, after which the average value was calculated:

$$\overline{B_{BB}} = \frac{\sum \beta_t}{\mu}, \tag{5}$$

where $\bar{B}_{BB}$ – average abundance on the Braun-Blanquet scale, points; β_t – abundance score at the t-th test site; μ – number of experimental plots; t – site number. Number of rare species was determined using a "species-by-plot matrix". This group included species accounting for less than 1% of the total number or with an occurrence frequency of no more than 20%.

Weed density, plants/m², was determined within a 1 m² Hummert Quadrat frame (Hummert International, USA) during the tillering stage of the cereal crop. This indicator characterised the number of weed plants per standard area at a single stage of crop development. The fresh weight of weeds, g/m², was recorded immediately after cutting the plants using CAS SW-20 field scales (CAS Corporation, Republic of Korea). The dry weight of weeds, g/m², was determined after drying the samples to constant weight in a Memmert UN55 drying oven (Memmert GmbH+Co. KG, Germany) and weighing them on OHAUS Scout STX2202 laboratory balances (OHAUS Corporation, USA). Weed projective cover, %, was assessed using a 20 × 50 cm Daubenmayer frame (Forestry Suppliers Inc., USA). This indicator was defined as the proportion of the soil surface covered by the vertical projection of the above-ground parts of all weeds within the survey area. The Morishita aggregation index, units, was calculated based on weed counts in a series of microplots marked out using a 0.25 m^2 microframe (Seedburo Equipment Company, USA), using the formula:

$$I_M = \frac{\xi \sum \omega_j(\omega_j - 1)}{\Omega(\Omega - 1)}, \tag{6}$$

where I_M – Morishita's aggregation index, pcs; ξ – number of micro-plots; ω_j – number of weeds in the microplot, pcs; Ω – total number of weeds across all microplots, pcs; j – micro-plot serial number. Coefficient of variation in density, %, was used to assess the spatial heterogeneity of weed distribution across the field area (7):

$$V_q = \frac{s_q}{\bar{q}} \times 100, \tag{7}$$

where V_q – coefficient of variation of density, %; s_q – standard deviation of weed density; $\bar{q}$ – average weed density, pcs/m^2. Height of the weed layer, in cm, was measured using a 2 m Nedo mEssfix telescopic ruler (Nedo GmbH & Co. KG, Germany). The average height of the upper edge of the weed cover within the plot was taken as the measurement.

Number of annual species and the number of perennial species were determined following the biological grouping of dominant species by life cycle type, using a Peak 1961 10× hand-held magnifying glass (Peak Optical Co., Japan). Average depth of the root system of the dominant species, in cm, was measured after collecting soil cores using an AMS Regular Soil Probe 1 (AMS Inc., USA) and subsequently washing the roots by hand. This parameter characterised the average penetration depth of the bulk of the active roots of the dominant plants. The calculation was performed using formula (8):

$$R_{deep} = \frac{\sum r_k}{\psi}, \tag{8}$$

where R_{deep} – average depth of the root system of dominant trees, cm; r_k – depth of the root system of the k-th crop, cm; ψ – number of analysed plants. The average leaf area of a single plant, in cm², was determined after selecting typical dominant plants using a CI-202 portable leaf area analyser (CID Bio-Science Inc., USA). The mass of 1,000 seeds of dominant weeds, in g, was determined after preparing a standard sample and weighing it on a Sartorius Secura 225D-1S microbalance (Sartorius AG, Germany). The seed yield per plant, seeds/plant, was determined following the individual dissection of typical generative plants and the counting of seeds using a Pfeuffer Contador electronic counter (Pfeuffer GmbH, Germany). For each treatment, 20 typical generative plants of the dominant species, selected at the stage of full seed maturity, were analysed. The number of herbicide-tolerant species was determined in growth tests following treatment of the plants with standard rates of active ingredients in the Potter Precision Laboratory Spray Tower (Burkard Scientific, UK). Herbicide-tolerant species were defined as those in which the active growing point and viable foliage remained intact after treatment.

The seed bank density, in thousands of seeds per square metre, was determined in the 010 cm layer following the collection of soil cores and the separation of samples using a set of Retsch Test Sieves (Retsch GmbH, Germany). The field germination rate of seeds from the seed bank, %, was determined by vegetative germination of soil samples in a SANYO MLR-351H chamber (SANYO Electric Co., Japan). Nitrogen removal by weeds, kg/ha, was determined following mineralisation of the dry matter using a Kjeltec 8400 analyser (FOSS, Denmark); phosphorus removal, kg/ha, was determined spectrophotometrically using a UV-1900i (Shimadzu Corporation, Japan); and potassium removal, kg/ha, was determined using a Jenway PFP7 flame photometer (Bibby Scientific Ltd, UK). Calculations for each element were conducted using formula (9):

$$U_{el} = \frac{b_{wd} \cdot c_{el}}{100}, \tag{9}$$

where U_{el} – weed removal of the relevant component, kg/ha; b_{wd} – dry weight of weeds, kg/ha; c_{el} – content of the relevant element in the dry weight of weeds, %; el – chemical element for which the calculation was conducted. Reduction in available soil moisture reserves, in mm, was determined in the 0-20 cm layer following sampling with an Eijkelkamp Edelman Auger (Royal Eijkelkamp, Netherlands), followed by drying in a Thermo Scientific Heratherm OMS60 (Thermo Fisher Scientific, Germany), followed by conversion to moisture reserves. Permanent microplots measuring 0.25 m^2 in each replicate were used as reference plots; these were kept weed-free by manual weeding throughout the entire growing season. Crop yield losses, %, were determined based on the results of complete plot-by-plot harvesting using a Wintersteiger Classic mini-combine harvester (Wintersteiger AG, Austria), with the results converted to standard grain moisture content. This indicator characterised the relative reduction in yield due to weed competition compared with the reference weed-free microplots, using formula (8):

$$\mathrm{L_{crop}} = \frac{\mathrm{y_{ref}} - \mathrm{y_{exp}}}{\mathrm{y_{ref}}} \times 100, \tag{10}$$

where L_{crop} – losses in crop yield, %; y_{ref} – yield on the reference weed-free microplot, t/ha; y_{exp} – yield in the relevant experimental treatment, t/ha. For all parameters, the arithmetic mean, minimum and maximum values, range, variance, standard deviation, standard error of the mean, coefficient of variation and 95% confidence interval were calculated. Statistical analysis of the results was performed using Statistica 10.0 (StatSoft Inc., USA).

Results

The floristic structure of the segetal flora varied depending on the herbicide control system and reflected varying degrees of agrocenosis restructuring at the species, taxonomic and local-spatial levels. The most complete floristic spectrum was retained in the control treatment, where the total number of species was 24, whilst with prolonged application of an acetolactate synthase inhibitor, it decreased to 13. With prolonged application of synthetic auxins, the figure remained higher than in the previous scenario but was still noticeably lower than in the control. Under herbicide rotation and the integrated system, the number of species recovered to a level closer to the initial state, indicating a less severe reduction in floristic composition. Consequently, the most pronounced impoverishment of the segetal flora occurred under repeated, single-type chemical stress, whilst combined systems prevented the loss of a significant proportion of species and maintained a broader spectrum of components within the sown area.

A similar pattern was observed at the taxonomic level. The number of families in the control group was 10, whilst with prolonged use of the acetolactate synthase inhibitor it fell to 6. The number of genera followed the same trend: from 20 in the control group to 11 under the same treatment. With synthetic auxins, the reduction was also noticeable, though less pronounced, whilst under rotation and integrated control, the number of families and genera remained significantly higher. This indicated that the herbicidal effect affected not only individual species but also entire taxonomic groups sharing similar biological properties. Consequently, under the same level of pressure, the flora lost not only the number of taxa but also part of its internal taxonomic diversity. In contrast, under herbicide rotation and an integrated system, the taxonomic basis of the weed community remained broader, indicating a shallower selection pressure and the preservation of a greater number of morphologically and ecologically distinct lineages within the agrocenosis.

The average number of species per unit area also varied unevenly. In the control treatment, it was 8.6; with the acetolactate synthase inhibitor, it decreased to 4.2; and with synthetic auxins, to 5.1. Under the herbicide rotation and integrated management systems, this figure remained noticeably higher and was closer to that of the control. This distribution indicated that herbicide regimes of the same type restricted not only the total species list but also the number of forms capable of coexisting simultaneously within a small survey area. Within the micro-space of the crop, this meant a reduction in the number of ecological niches occupied by different components of the flora, and a decrease in the number of interspecific combinations that formed the small-scale mosaic of the weed layer. Crop rotation and integrated pest management, by contrast, supported higher local species richness and, consequently, greater complexity in the spatial organisation of the flora within the crop field.

The response of individual morphological groups also varied. The number of monocotyledonous species changed relatively moderately: from 7 in the control to 46 in the treatments with herbicide application. The dicotyledonous component proved to be significantly more sensitive: 17 species were recorded in the control, whereas only 8 were recorded under the acetolactate synthase inhibitor treatment. Under synthetic auxins, the number of dicotyledonous species was higher than in the previous treatment but lower than under rotation and integrated control. Thus, the reduction in floristic composition occurred primarily at the expense of the dicotyledonous group, which constituted part of the morpho-functional diversity of the segetal community. Consequently, the reduction in the number of dicotyledonous species reflected not isolated losses of sensitive forms, but a general narrowing of the spectrum of life strategies associated with growth rates, plant architecture and methods of space utilisation within the crop.

The floristic saturation coefficient complemented the comparative assessment. In the control treatment, it stood at 2.4; with prolonged application of the acetolactate synthase inhibitor, it fell to 2.17, and with synthetic auxins, to 2.14. Under the herbicide rotation regime, the index remained intermediate, whilst under the integrated system it reached 2.44 and exceeded the control value. This indicated that the integrated approach not only suppressed weed growth but also maintained a relatively more balanced ratio between the number of species and taxonomic groups. Consequently, different control systems altered the floristic structure unevenly: prolonged exposure to a single type of herbicide most severely impoverished the species, genus and family composition; synthetic auxins also reduced the diversity of the flora, but to a lesser extent; whereas herbicide rotation and the integrated system maintained their composition closer to that of the control variant (Table 1).

Table 1. *Floristic structure of the segetal flora within the agrocenosis*

Indicator	**Control (no treatment)**	**Long-term use of an ALS inhibitor (mesosulfuron-methyl + iodosulfuron-methyl-sodium)**	**Long-term use of synthetic auxins (dicamba + MCPA)**	**Herbicide rotation (prosulfocarb → clodinafop-propargyl + carfentrazone-ethyl)**	**Integrated control system (flufenacet + diflufenican + pre-emergence boron application + agronomic measures)**
Total number of species, pcs	24	13	15	20	22
Number of families, pcs	10	6	7	9	9
Number of species, pcs	20	11	12	17	19
Average number of species per 1 m^2, pcs	8.6	4.2	5.1	7	7.8
Number of monocotyledonous species, pcs	7	5	4	6	6

Table 1. *Continued*

Indicator	Control (no treatment)	Long-term use of an ALS inhibitor (mesosulfuron-methyl + + iodosulfuron-methyl-sodium)	Long-term use of synthetic auxins (dicamba + + MCPA)	Herbicide rotation (prosulfocarb → clodinafop-propargyl + + carfentrazone-ethyl)	Integrated control system (flufenacet + + diflufenican + + pre-emergence boron application + + agronomic measures)
Number of dicotyledonous species, pcs	17	8	11	14	16
Floristic richness index, units	2.40	2.17	2.14	2.22	2.44

Source: compiled by the authors

Floristic restructuring of the segetal flora took the form of a sequential change across several interrelated levels of organisation within the weed community. A reduction or preservation of species composition was accompanied by simultaneous shifts in taxonomic composition, local sown area density and the internal ratio of morphologically distinct components. Under prolonged exposure to a single type of herbicide, the flora lost some of the structural elements that had previously supported its branching, mosaic structure and capacity for multi-variant self-regeneration. With the rotation of active ingredients and the combination of chemical and mechanical methods, these processes developed in a different direction, as the community did not transition to a sharply narrowed model but retained a broader spectrum of floristic relationships. Consequently, different control systems determined not only the degree of suppression of the weed component, but also the nature of the subsequent organisation of the segetal flora within the agrocenosis.

The coenotic organisation and species dominance within the weed community varied depending on the herbicide control system and reflected varying degrees of restructuring of the segetal flora at the level of dominant, associated and rare components. The Shannon index was highest in the control treatment – 2.42; it remained close to this level under the integrated system (2.28) and herbicide rotation (2.15) but decreased noticeably with prolonged use of synthetic auxins (1.58) and an acetolactate synthase inhibitor (1.31). This pattern indicated that herbicide rotation and integrated management supported a more complex internal structure of the plant community, whereas the use of a single type of herbicide narrowed the range of species contributing to the weed layer. A similar pattern was evident in the cover of the dominant species. In the control treatment, this was 18.4%; under the integrated system, 19.1%; and under herbicide rotation, 21.3%; that is, the coverage concentration of a single species remained relatively moderate. With synthetic auxins, this figure increased to 30.9%, and with the acetolactate synthase inhibitor, to 36.7%. This meant that, under prolonged exposure to a single type of chemical treatment, a single species is disproportionately more substantial in the spatial organisation of the community. The same trend was observed in the total coverage of the three dominant species: ranging from 44.2% in the control to 45.8% under the integrated system, whilst under synthetic auxins and the acetolactate synthase inhibitor it reached 66.1% and 72.8% respectively. Consequently, under herbicidal pressure of the same type, the bulk of the cover was concentrated in a limited group of more resistant components.

Changes in the core of the community were reflected in the number of co-dominants and the mean abundance on the Braun-Blanquet scale. In the control treatment, there were 5 co-dominant species; under the integrated system, 6; and under the rotation system, 5, whereas under synthetic auxins their number decreased to

4, and under the acetolactate synthase inhibitor, to 3. At the same time, the average abundance in the control was 2.6 points, under the integrated system it was 2.5, under rotation it was 2.7, and under a single-type herbicidal treatment it increased to 3.43.8 points. This indicated that, under crop rotation and integrated management, several species remained substantial in the formation of the vegetation cover, whereas under monocultural herbicide treatment, some of the accompanying components were eliminated, whilst the abundance of a few species increased. The change in the reserve pool of the flora was evidenced by the number of rare species, which decreased from 6 in the control to 5 under the integrated system, 4 under crop rotation, 2 under synthetic auxins and 1 under the acetolactate synthase inhibitor. Thus, the greatest depletion of the community's reserve pool occurred with the prolonged, single-type application of herbicides. Herbicide rotation and the integrated system, by contrast, maintained a coenotic structure closer to that of the control, limiting the cover concentration of dominant species and supporting a broader participation of associated and rare species (Table 2).

Table 2. *Cenotic characteristics and indicators of dominance of the segetal flora*

Indicator	**Control (no treatment)**	**Long-term use of an ALS inhibitor (mesosulfuron-methyl + + iodosulfuron-methyl-sodium)**	**Long-term use of synthetic auxins (dicamba + + MCPA)**	**Herbicide rotation (prosulfocarb → clodinafop-propargyl + + carfentrazone-ethyl)**	**Integrated control system (flufenacet + + diflufenican + + pre-emergence boron application + + agronomic measures)**
Shannon index, units	2.42	1.31	1.58	2.15	2.28
Number of dominant species, pcs	3	2	2	3	3
Number of co-dominants, pcs	5	3	4	5	6
Coverage of the dominant species, %	18.4	36.7	30.9	21.3	19.1
Total coverage of three leading types, %	44.2	72.8	66.1	49.5	45.8
Average abundance on the Braun-Blanquet scale, points	2.6	3.8	3.4	+2.7	2.5
Number of rare species, items	6	1	2	4	5

Source: developed by the authors of this study

Consequently, the coenotic organisation of the weed community responded to herbicide control systems not only by altering the growth rate of individual species, but also by restructuring the entire pattern of internal role distribution amongst dominant, co-dominant and rare components. Under integrated control, the contribution of species to canopy formation remained more balanced, which supported a more complex, multi-component structure of the community and preserved its spatial mosaic pattern. Under prolonged, uniform pressure, by contrast, the concentration of the vegetation cover in a few dominant species increased, the range of co-dominant species narrowed, and the representation of the peripheral part of the flora decreased. As a result, the weed community gradually shifted from a branched, multi-component organisation to a more compact system with a more clearly defined core. At the same time, the community's capacity for internal restructuring was reduced, its structural flexibility was weakened, and its potential for further self-recovery in response to changes in environmental conditions was diminished.

Quantitative development and spatial heterogeneity of the segetal flora varied significantly depending on the herbicide control system. The highest values of the main quantitative indicators were recorded in the control plot, where weed density was 128 plants/m^2, fresh weight was 486 g/m^2, dry weight was 148 g/m^2, projective cover was 62%, and the height of the weed canopy was 42.3 cm. This corresponded to the most fully developed weed cover, under which the segetal flora formed the most robust above-ground canopy and the highest spatial coverage of the crop. Under all herbicide control systems, these indicators decreased, although the extent of this reduction varied. The lowest values of the quantitative parameters were obtained under the integrated control system, where weed density decreased to 36 plants/m^2, fresh weight to 142 g/m^2, dry weight to 47 g/m^2, and projective cover to 18%. Herbicide rotation also significantly curbed the development of the weed component: density was 41 plants/m^2, fresh weight 158 g/m^2, dry weight 52 g/m^2, and projective cover 21%. Consequently, the integrated system and crop rotation were the most effective at reducing the quantitative development of the weed flora. The integrated approach was slightly more effective than crop rotation, indicating a greater suppression of both weed abundance and the development of their above-ground biomass.

Prolonged use of herbicides of the same type also reduced the number and biomass of weeds, but these changes were accompanied by other spatial effects. With the acetolactate synthase inhibitor, weed density was 54 plants/m^2, whilst with synthetic auxins it was 63 plants/m^2; correspondingly, the values for fresh weight, dry weight and cover remained higher. Thus, both schemes of the same type were inferior to the rotation and integrated systems in terms of their ability to limit the quantitative development of the weed community, and the synthetic auxin treatment proved less effective than the acetolactate synthase inhibitor. Spatial indicators revealed a different pattern. In the control treatment, the Morishita aggregation index was 1.28, and the coefficient of variation in density was 24.1%, which corresponded to a relatively more uniform distribution of weeds amidst high overall weed infestation. With prolonged application of the acetolactate synthase inhibitor, these indices increased to 1.74 and 41.3%, and with synthetic auxins – to 1.68 and 37.8%. This indicated that herbicides of the same type not only reduced the total number of weeds but also increased their aggregation and uneven distribution. Under the herbicide rotation and integrated management systems, the aggregation index and coefficient of variation remained lower, indicating a reduced formation of localised clusters of weed density. Thus, the control plot was characterised by the highest values for weed density, mass, cover and height; the integrated system and crop rotation were most effective at reducing these quantitative indicators, whereas the prolonged use of a single type of herbicide, despite lower weed abundance, was accompanied by greater aggregation and greater spatial heterogeneity of the weed community (Table 3).

Table 3. *Quantitative and spatial parameters of weed group*

Indicator	Control (no treatment)	Long-term use of an ALS inhibitor (mesosulfuron-methyl + + iodosulfuron-methyl-sodium)	Long-term use of synthetic auxins (dicamba + + MCPA)	Herbicide rotation (prosulfocarb → clodinafop-propargyl + + carfentrazone-ethyl)	Integrated control system (flufenacet + + diflufenican + pre-emergence boron application + + agronomic measures)
Weed density, plants/m^2	128	54	63	41	36
Fresh weight of weeds, g/m^2	486	214	246	158	142

Table 3. *Continued*

Indicator	Control (no treatment)	Long-term use of an ALS inhibitor (mesosulfuron-methyl + + iodosulfuron-methyl-sodium)	Long-term use of synthetic auxins (dicamba + + MCPA)	Herbicide rotation (prosulfocarb → clodinafop-propargyl + + carfentrazone-ethyl)	Integrated control system (flufenacet + + diflufenican + pre-emergence boron application + + agronomic measures)
Dry weight of weeds, g/m^2	148	73	81	52	47
Projected weed cover, %	62	28	34	21	18
Height of the weed layer, cm	42.3	31.2	34.1	26.4	24.8
Morishita's Aggregation Index, unit	1.28	1.74	1.68	1.39	1.33
Coefficient of variation in density, %	24.1	41.3	37.8	29.4	27.2

Source: compiled by the authors

Comparison of quantitative and spatial parameters showed that the segetal flora responded to the control systems as a multi-level structure, in which a reduction in abundance was not always accompanied by the same pattern of plant distribution. Integrated control limited overall density and prevented the formation of a continuous cover, whereas prolonged, uniform pressure could combine lower abundance with increased aggregation and greater variability between plots. Consequently, quantitative development and spatial heterogeneity emerged as interrelated characteristics, reflecting the transition of the segetal flora from a more continuous coverage of the sown area to a more localised distribution, with plants concentrated in zones suitable for the survival of dominant and tolerant forms.

Biological and ecological characteristics of the dominant species varied depending on the herbicide control system and most clearly reflected the effects of prolonged exposure to a single type of chemical. In the control plot, there were 18 annual species and 6 perennial species, which corresponded to a broader mix of life forms within the dominant community. With prolonged application of an acetolactate synthase inhibitor, the number of annual species decreased to 9 and that of perennial species to 4; with synthetic auxins, these figures were 10 and 5, respectively. Under herbicide rotation, the number of annual species was 14 and that of perennial species 6, whilst under the integrated system these figures were 15 and 7. Thus, herbicide rotation and the integrated control system maintained a ratio of life forms closer to that of the control, whilst the use of a single type of herbicide caused a more pronounced shift in the structure of dominant species. A similar difference was observed in the average root system depth. In the control, it was 16.4 cm; under herbicide rotation, 18.7 cm; under the integrated system, 17.9 cm; whereas under the acetolactate synthase inhibitor it increased to 24.8 cm, and under synthetic auxins to 22.9 cm. A similar pattern was observed for the average leaf area of a single plant: in the control – 29.6 cm^2, with crop rotation – 31.5 cm^2, with the integrated system – 30.4 cm^2, with synthetic auxins – 37.8 cm^2, and with the acetolactate synthase inhibitor – 41.3 cm^2. This indicated that herbicide regimes of the same type selected more strongly for plants with a more developed root system and a larger leaf area, whereas under crop rotation and integrated pest management, these traits showed less variation.

The same trend was observed in terms of reproductive performance. The weight of 1,000 seeds in the control treatment was 1.84 g, in the herbicide rotation treatment 2.03 g, in the integrated system treatment 1.96 g, in the synthetic auxin treatment 2.51 g, and in the acetolactate synthase inhibitor treatment 2.76 g. Seed yield per plant in the control treatment was 5,620 seeds/plant, under the rotation treatment – 4,980 seeds/ plant, under the integrated system – 4,630 seeds/plant, under synthetic auxins – 6,810 seeds/plant, and under the acetolactate synthase inhibitor – 7,340 seeds/plant. The results showed that the acetolactate synthase inhibitor and synthetic auxins formed a dominant group with higher seed weight and greater seed yield, whilst the rotation and integrated system limited the enhancement of these traits. The most pronounced shift was confirmed by the number of herbicide-tolerant species. In the control treatment, there were 3; under herbicide rotation, 4; under the integrated system, 3; under synthetic auxins, 7; and under the acetolactate synthase inhibitor, 8. This indicated that herbicide regimes of the same type caused the most pronounced shift in the biological and ecological characteristics of the dominant species: fewer short-lived species, a deeper root system, greater leaf area, higher seed mass, greater seed productivity and a higher proportion of tolerant forms. Herbicide rotation and the integrated management system kept these indicators closer to the control levels, indicating a weaker enhancement of adaptive traits in the dominant segment of the segetal flora (Table 4).

Table 4. *Biological and ecological characteristics of the dominant species of the segetal flora*

Indicator	Control (no treatment)	Long-term use of an ALS inhibitor (mesosulfuron-methyl + + iodosulfuron-methyl-sodium)	Long-term use of synthetic auxins (dicamba + + MCPA)	Herbicide rotation (prosulfocarb → clodinafop-propargyl + + carfentrazone-ethyl)	Integrated control system (flufenacet + + diflufenican + pre-emergence boron application + + agronomic measures)
Number of juvenile specimens, pcs.	18	9	10	14	15
Number of perennial species, pcs.	6	4	5	6	7
Average depth of the root system of dominant trees, cm	16.4	24.8	22.9	18.7	17.9
Average leaf area of one plant, cm^2	29.6	41.3	37.8	31.5	30.4
Mass of 1,000 dominant seeds, g	1.84	2.76	2.51	2.03	1.96
Seed yield per plant, seeds/plant	5620	7340	6810	4980	4630
Number of herbicide-tolerant species, pcs.	3	8	7	4	3

Source: compiled by the authors based on formula (8)

Consequently, the biological and ecological characteristics of the dominant species shifted towards the formation of a new adaptive core of the segetal flora. The decline in the proportion of short-lived forms was accompanied by an increase in the role of species capable of persisting longer within the agrocenosis and utilising the resources of the soil profile more efficiently. The increased participation of deeper-rooted plants indicated a shift in the dominance structure towards components less dependent on short-term fluctuations in conditions within the surface soil layer. The increase in seed mass reflected a change in reproductive strategy, whereby population recovery increasingly relied on diaspores with higher initial resource endowment. The accumulation of herbicide-tolerant species demonstrated that prolonged selection altered not only the species composition of the weed community but also the very mechanism by which dominant species were maintained in the crop. Under these conditions, herbicide pressure determined not only the current level of suppression of the segetal flora, but also the morphobiological traits of those components that subsequently sustained the dominance, generative renewal and stability of the weed community within the agrocenosis.

Functional indicators of agroecosystem stability revealed clear differences between the herbicide control systems and showed that the segetal flora influenced the crop not only through its aboveground presence, but also through seed reserves, resource extraction and yield losses. The highest level of functional load was observed in the control plot, where the soil seed bank density was 42.8 thousand seeds/m^2, nitrogen leaching was 31.5 kg/ha, phosphorus leaching was 8.7 kg/ha, and potassium leaching was 37.2 kg/ha, a reduction in productive moisture reserves of 18.6 mm, and crop yield losses of 27.4%. This combination of indicators suggested that, in the absence of herbicide control, the weed community retained not only the largest reproductive reserve but also the highest capacity to compete for nutrients and moisture, directly translating this pressure into a reduction in crop productivity. The lowest values for most functional indicators were recorded under the integrated control system. Under this treatment, the density of the soil seed bank decreased to 21.7 thousand seeds/m^2, nitrogen removal to 9.6 kg/ha, phosphorus removal to 2.6 kg/ha, potassium removal to 11.5 kg/ha, a reduction in available moisture reserves to 5.7 mm, and yield losses to 6.9%. Herbicide rotation yielded similar results: 24.3 thousand seeds/m^2 for the seed bank, 11.2 kg/ha for nitrogen, 3 kg/ha for phosphorus, 13.1 kg/ha for potassium, 6.3 mm for moisture loss and 8.1% for yield loss. This demonstrated that an integrated approach and crop rotation were most effective in limiting the functional reserve of the weed flora, reducing its contribution to the depletion of soil resources and mitigating its impact on crop yield.

Prolonged use of herbicides of the same type also reduced weed pressure compared with the control but was less effective than crop rotation and integrated weed management. With the acetolactate synthase inhibitor, the soil seed bank density was 31.6 thousand seeds/m^2, whilst with synthetic auxins it was 34.9 thousand seeds/m^2; in other words, the latent reproductive reserve remained significantly higher than under the other two systems. Resource removal indicators showed a similar pattern: nitrogen removal was 16.4 and 18.8 kg/ha, phosphorus removal was 4.3 and 5.1 kg/ha, and potassium removal was 19.6 and 22.4 kg/ha, respectively. The reduction in productive moisture reserves under these treatments was 9.2 and 10.4 mm, whilst yield losses were 12.8 and 14.3%. Thus, single-type control schemes reduced the functional pressure of weeds compared with the control but did not provide the same level of suppression as crop rotation and the integrated system. Field germination of seeds from the bank was highest under single-type herbicide treatment: 46.8% for the acetolactate synthase inhibitor and 44.1% for synthetic auxins, whereas in the control it was 39.4%, under rotation – 35.2%, and 33.6% under the integrated system. This meant that, despite lower current weed infestation, prolonged application of the same type of herbicide in the soil preserved a functionally more active seed reserve, capable of transitioning more rapidly to a new wave of regrowth. Overall, control treatment was associated with the highest functional load, the integrated system with the lowest, and herbicide rotation was similar to the latter, whilst herbicides of the same type occupied an intermediate position, combining lower weed pressure with higher seed germination rates and a greater latent reserve of seedling flora (Table 5).

Table 5. *Functional indicators of agroecosystem stability under varying herbicide loads*

Indicator	Control (no treatment)	Long-term use of an ALS inhibitor (mesosulfuron-methyl + + iodosulfuron-methyl-sodium)	Long-term use of synthetic auxins (dicamba + + MCPA)	Herbicide rotation (prosulfocarb → clodinafop-propargyl + + carfentrazone-ethyl)	Integrated control system (flufenacet + + diflufenican + pre-emergence boron application + + agronomic measures)
Density of the soil seed bank, thousand seeds/m^2	42.8	31.6	34.9	24.3	21.7
Field germination rate of seeds from a jar, %	39.4	46.8	44.1	35.2	33.6
Nitrogen uptake by weeds, kg/ha	31.5	16.4	18.8	11.2	+9.6
Phosphorus uptake by weeds, kg/ha	8.7	4.3	5.1	3	2.6
Potassium uptake by weeds, kg/ha	37.2	19.6	22.4	13.1	11.5
Decrease in productive moisture reserves, mm	18.6	9.2	10.4	6.3	5.7
Loss of crop yield, %	27.4	12.8	14.3	8.1	6.9

Source: compiled by the authors

A comprehensive analysis of the reproductive reserve, seed dispersal, resource extraction and yield losses revealed that the stability of the agroecosystem was shaped by the interplay of several interrelated processes. The segetal flora influenced this stability through its ability to store a latent seed reserve, rapidly return to an active state, interfere with the crop's trophic regime, and transform this activity into yield losses. Under prolonged, uniform herbicidal pressure, some of these mechanisms did not disappear but took on a new form, related to the selection of more tolerant components and the maintenance of high field germination rates within the soil seed bank. When several control methods were combined, the functional pressure exerted by the weed flora was reduced at various levels simultaneously, which limited not only existing weed infestation but also the possibility of its recurrence. Consequently, the functional indicators proved suitable for assessing the stability of the agroecosystem as a process dependent on the weed complex's ability to interfere with regeneration, resource exchange and crop yield realisation.

Discussion

Results showed that different herbicide control systems altered the segetal flora not only in terms of overall weediness, but also in terms of its floristic, coenotic, spatial and functional organisation. Under prolonged exposure to a single type of chemical treatment, a narrowing of the species and taxonomic composition was observed, along with an increased role of a few dominant components and a reduction in the presence of rare species. This restructuring indicated a transition of the weed community towards a more compact model with less internal mosaicism and more limited capacity for self-regulation. At the same time, the integrated control system maintained a more complex structure of the segetal flora, in which the contribution of species to canopy formation remained more balanced. This was accompanied by a reduction in the compactness of the weed layer, a decrease in localised areas of dense growth, and a reduction in the functional load of the weed component on the agrocenosis. Consequently, it was not only the reduction in weed abundance that was significant, but also the nature of their spatial distribution and their participation in resource processes.

In the context of long-term management of weed communities, the studies by J.G. Guerra *et al.* (2022) and A.S. Westbrook *et al.* (2022) examined changes in the composition of plant communities under the influence of various weed control methods, but without revealing the full structural and functional profile of the segetal flora in the cereal agrocenosis. J.G. Guerra *et al.* demonstrated that weed management practices altered species composition, taxonomic diversity and yield, whilst the proportion of bare soil was associated with both yield and a reduction in species richness. A.S. Westbrook *et al.* linked living mulch systems to varying degrees of weed suppression and changes in community composition. Similar to these studies, in the present research the control system also determined changes in the floristic structure and the nature of dominance. At the same time, this study additionally demonstrated how prolonged, single-type herbicidal pressure narrowed the taxonomic basis of the flora, reduced the proportion of rare and co-dominant species, and restructured the spatial organisation of the community, whereas the integrated approach maintained a more complex mosaic structure. This multi-level interpretation extended the scope outside a general assessment of community composition and correlated changes in weed flora to the stability of cereal crops.

In the context of the dependence of agrosystem stability on the composition of plant communities, the studies by X. Rotllan-Puig *et al.* (2024) and K.A. Stahlheber & K.L. Gross (2025) focused on the role of community composition, dominant species and large-scale observations, but without a field-level analysis of the coenotic mechanisms underlying the restructuring of the semental flora under herbicide pressure. K.A. Stahlheber & K.L. Gross linked the stability of aboveground production primarily to community composition and dominant species, rather than solely to the number of sown species. X. Rotllan-Puig *et al.* used open-access data on weed occurrence in European Union countries as an indicator of agricultural intensification. This study also confirmed that community structure and the role of leading species were decisive for the state of the agrocenosis. At the same time, the results were analysed in much greater depth, as the study tracked not only the overall composition of the flora but also changes in co-dominance, the contribution of rare species, spatial aggregation, the coefficient of variation in density, and the biological and ecological characteristics of the dominant species. This level of detail demonstrated which elements of the weed community were the first to respond to various herbicide control systems and how these changes restructured the entire agroecosystem.

Regarding effects of chemical stress on the soil-plant system, the studies by Q. Li *et al.* (2025) and M. Gaylord *et al.* (2025) analysed the microbial and yield effects of weed control, but without a detailed description of how the sclerotial flora itself changed in the process. Q. Li *et al.* identified changes in arbuscular mycorrhizal fungal communities and increased wheat yields following long-term weed control. M. Gaylord *et al.* concluded that herbicides had minimal and variable effects on the structure and function of bacterial communities in agricultural soils. In the present study, as in these works, the impact of herbicides was considered not only in terms of weed infestation levels but also in terms of their broader functional consequences. The difference consisted in the fact that, in this study, the functional aspect was directly linked to indicators of the segetal flora – the soil seed bank, field germination, nitrogen leaching and yield losses. This made it possible to demonstrate a sequential transition from changes in the floristic, coenotic and spatial structure of the weed community to changes in the resource regime of the crop, seed regeneration and crop productivity.

In relation to the interplay between nutrient supply, soil processes and community structure, the studies by M. Karlsson *et al.* (2025) and Y. Guo *et al.* (2025) examined the effects of resource environment management on vegetation cover and soil biota, but without directly linking these changes to the coenotic organisation of the segetal flora of cereal crops. M. Karlsson *et al.* demonstrated that improved nutrient supply in organic farming was accompanied by a trade-off between yield and weed diversity, and that the response of the community was determined not only by fertilisation but also by the intensity of competition between the crop and weeds. Y. Guo *et al.* found that soil depth and fertilisation regimes altered the composition of fungal communities, with the most pronounced shifts occurring between the upper and lower layers and across different fertilisation treatments. This study also revealed a link between the resource regime of the agrocenosis and the structure of its biotic component. At the same time, the results were presented in a broader context, as changes in floristic composition, dominance, spatial heterogeneity, seed reserve and yield losses were analysed within a single system of indicators, which made it possible to directly link the restructuring of the segetal flora to the functional stability of the crop.

In terms of the interplay between nutrition, soil management and weed phytosociology, the studies by M. Esposito *et al.* (2023) and S. Kumar *et al.* (2022) addressed how agronomic factors altered the composition of weed communities and crop productivity; however, these studies did not provide a detailed analysis of the transition from floristic changes to functional consequences within a single field experiment. M. Esposito *et al.* demonstrated that the nutrient regime in rain-fed winter wheat differentiated weed communities, with excessive fertilisation reducing species richness and promoting the formation of more competitive assemblages, whilst optimal or reduced nutrient supply supported communities that were less harmful to the crop. S. Kumar *et al.* found that prolonged tillage and weed control systems altered the phytocenotic structure, caused a shift towards an increased role of monocotyledonous species, and affected the productivity of the crop rotation system. In the present study, management pressure was accompanied by a restructuring of the flora, a shift in dominance and consequences for productivity. At the same time, these processes were traced across a wider range of levels – from taxonomic narrowing and co-dominance to aggregation, field seed similarity, nitrogen removal and yield losses – which made the causal link between weed community structure and agroecosystem stability more comprehensive.

Beyond the weed layer, the studies by J. Tavella *et al.* (2025) and M. Aguiar *et al.* (2023) analysed the broader ecological consequences of agricultural management for adjacent plant, pollinator and soil systems, but without directly examining the internal restructuring of the segetal flora within the crop field. J. Tavella *et al.* demonstrated that herbicide programmes altered plant and pollinator diversity in non-ploughed areas and indirectly disrupted the structure and potential functioning of "plant-pollinator" networks, with more intensive programmes having a more pronounced effect. M. Aguiar *et al.* found that the edge zones between perennial grasslands and arable land formed a distinct plant community with a high proportion of undesirable annual species and were accompanied by changes in carbon, nitrogen and soil microbial communities. A common feature of this study was that agricultural pressure was considered a factor that altered not only weed abundance but also the broader ecological context. However, in this study, the analysis focused directly on the field weed community; consequently, it was possible to demonstrate how changes in species composition, mosaic pattern, dominance and reproductive reserve translated into changes in resource flows and the level of yield loss – aspects not covered by the approaches of J. Tavella *et al.* and M. Aguiar *et al.*

Concerning species selection under herbicide and soil stress, the studies by Z. Peng *et al.* (2024) and S. Humann-Guilleminot *et al.* (2025) examined the consequences of long-term agricultural impact on plant and soil communities, but without linking these changes to a complete coenotic characterisation of the segetal flora of cereal crops. S. Humann-Guilleminot *et al.* demonstrated that herbicides in cereal crops eliminated non-competitive species whilst simultaneously facilitating their replacement by more competitive weeds. Z. Peng *et al.* found that tillage and fertilisation altered arbuscular mycorrhizae, crop yield and soil functions, linking agricultural management to broader ecosystem consequences. This study found that prolonged, uniform pressure not only reduced overall diversity but also contributed to the establishment of a limited set of more resilient dominant species. At the same time, the results were interpreted more comprehensively, as the sequence of events was traced from taxonomic narrowing and shifts in dominance to changes in spatial heterogeneity, the biological and ecological characteristics of dominant species, seed reserves and yield losses.

Regarding soil resource availability and the restructuring of weed communities, the studies by M.A. Gannett *et al.* (2024) and E. Radicetti *et al.* (2025) addressed how soil conditions, fertilisation and tillage altered weed growth and community composition, but without presenting a comprehensive picture of floristic, spatial and functional shifts within a single experiment. M.A. Gannett *et al.* demonstrated that increasing the C:N ratio reduced weed growth, altered soil microbial parameters and, in soya, influenced the composition of the weed community. E. Radicetti *et al.* examined how fertiliser sources and tillage regimes affected the species composition and functional diversity of weeds in a durum wheat-potato crop rotation. The study also demonstrated that management of the agrocenosis altered not only weed abundance but also their structural organisation and functional load. The distinction lay in the fact that this study simultaneously covered floristic richness, co-dominance, aggregation, the depth of the root system of dominant species, seed mass, the soil seed bank and resource extraction; this made it possible to explain not merely individual responses of weeds, but the holistic mechanism underlying changes in the stability of the agroecosystem.

In the context of the seed bank and climate-driven variability in weed communities, the studies by T. Seipel *et al.* (2022) and Z. Ren *et al.* (2024) analysed either spatial differences in seed bank composition or the responses of weed communities to farming systems under different weather conditions, but without simultaneously combining these factors within a single field model. Z. Ren *et al.* found that region, cropping system and control strategy influenced species richness, functional traits and seed bank composition in herbicide-resistant agrosystems in the United States. T. Seipel *et al.* demonstrated that the farming system remained the primary factor shaping weed communities in winter wheat, whilst warming and reduced moisture levels altered these responses less markedly in the short term. In this study, these lines of research were integrated within a single approach: changes in floristic structure, dominance, spatial distribution, biological and ecological traits, and the seed bank were examined alongside nitrogen removal and yield losses. This demonstrated not only that the segetal flora responded to the control system, but also how this response translated into changes in the reproductive reserve, resource regime and productivity of the cereal crop. Thus, the results showed that this study provided a more accurate insight into the relationship between prolonged herbicide exposure, changes in the segetal flora and the functional manifestations of agroecosystem stability, as it combined floristic, coenotic, spatial, biological-ecological and productivity indicators within a single field analysis.

Conclusions

The study compared five weed control systems and found that the nature of the herbicidal load determined not only the level of weed infestation but also the direction of change in the segetal flora of the cereal agrocenosis. In the control treatment, the total number of species was 24, the number of families was 10, the number of genera was 20, the average number of species per 1 m^2 was 8.6, the number of monocotyledonous species was 7, the number of dicotyledonous species was 17, and the floristic richness index was 2.4. Under prolonged, single-type herbicidal pressure, the floristic structure became narrower, whereas crop rotation and the integrated system better preserved the species and taxonomic framework of the community. Coenotic indicators confirmed that herbicidal pressure altered the internal organisation of the weed layer. In the control plot, the Shannon index was 2.42, the number of dominant species was 3, the number of co-dominant species was 5, the cover of the dominant species was 18.4%, the total cover of the three leading species was 44.2%, the average abundance on the Braun-Blanquet scale was 2.6 points, and the number of rare species was 6. With prolonged, single-type application of herbicides, the dominance of a few species increased, and the proportion of rare species decreased, whilst integrated control maintained a more complex community structure. Quantitative and spatial parameters also reflected a marked differentiation between the control systems. In the control plot, weed density was 128 plants/m^2, fresh weight was 486 g/m^2, dry weight was 148 g/m^2, projective cover was 62%, weed canopy height was 42.3 cm, the Morishita aggregation index was 1.28, and the coefficient of variation in density was 24.1%. Under the integrated system, the quantitative weed pressure decreased, whereas under prolonged, single-type chemical treatment, the spatial concentration of plants and the heterogeneity of their distribution increased. The biological and ecological characteristics of the dominant species showed that herbicidal selection altered the adaptive profile of the leading species. In the control, there were 18 annual species and 6 perennial species; the average root system depth of the dominant species was 16.4 cm, the leaf area of a single plant was 29.6 cm^2, the mass of 1,000 seeds was 1.84 g, the seed production per plant was 5,620 seeds per plant, and the number of herbicide-tolerant species was 3. Under prolonged, uniform stress, the role of forms with deeper root systems, greater seed mass and higher tolerance increased. Functional indicators confirmed that the segetal flora influenced the crop through reproductive reserve and resource competition. In the control, the density of the soil seed bank was 42.8 thousand seeds/m^2, field germination was 39.4%, nitrogen removal was 31.5 kg/ha, phosphorus removal was 8.7 kg/ha, potassium removal was 37.2 kg/ha, a reduction in productive moisture reserves of 18.6 mm, and a loss in crop yield of 27.4%. A limitation of the study was that observations were conducted at a single agroecological site and over the course of a single growing season. Further research should conduct a multi-year analysis under various soil and climatic conditions, with an expanded list of crops and indicators.

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Conflict of Interest

None.

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Фітоценотичний аналіз сегетальної флори як індикатор сталості агроекосистем при тривалому застосуванні гербіцидів

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Анотація. Метою дослідження було встановити закономірності перебудови сегетальної флори та змін функціональної стійкості зернового агроценозу під впливом різних систем гербіцидного контролю. У дослідженні було використано метод квадратних обліків, геоботанічного опису, біометричних і вагових вимірювань, морфолого-біологічного групування, вегетаційного тестування, ґрунтово-хімічного аналізу, поділянкового обліку врожаю та дисперсійного аналізу. Встановлено, що у контролі загальна кількість видів становила 24, кількість родин – 10, середня кількість видів на 1 м^2 – 8,6, а кількість дводольних видів – 17. За інтегрованої системи вони становили 22, 9, 7,8 і 16, тобто залишалися ближчими до контролю. Індекс Шеннона змінювався від 2,42 у контролі до 1,31 за тривалого застосування інгібітора ацетолактатсинтази, тоді як за інтегрованої системи дорівнював 2,28. Покриття виду-домінанта зростало до 36.7 %, а кількість рідкісних видів зменшувалася до 1, що вказувало на посилення домінування і звуження резервного фонду угруповання. Кількісні показники також істотно змінювалися: щільність бур'янів знижувалася зі 128 до 36 шт./м^2, сира маса – з 486 до 142 г/м^2, суха маса – з 148 до 47 г/м^2, проективне покриття – з 62 до 18 %. За тривалого застосування інгібітора ацетолактатсинтази індекс агрегованості Морісіти досягав 1,74, кількість гербіцидотолерантних видів – 8, середня глибина кореневої системи домінантів – 24,8 см, маса 1000 насінин – 2,76 г. Функціональні показники підтвердили цю закономірність: щільність ґрунтового банку насіння зменшувалася з 42,8 до 21,7 тис. шт./м^2, винос азоту бур'янами – з 31,5 до 9,6 кг/га, втрати врожайності культури – з 27,4 до 6,9 %. Практична значимість дослідження полягала в тому, що його результати можуть бути використані агрономами, науковцями та виробниками зерна для вибору систем контролю бур'янів, які не лише знижують забур'яненість, а й сприяють збереженню структурної стійкості агроекосистеми

Ключові слова: сегетальна флора; гербіциди; домінантні види; гербіцидотолерантні види; агроценоз; системи гербіцидного контролю; флористична структура