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Original article

Changes in weed biodiversity in onion and carrot agrocenoses in the Skierniewice region from 1995 to 2024

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Summary

Observations of weed infestation were carried out in onion and carrot crops from 1995 to 2024 in the Skierniewice region. Weed infestation was assessed on unsprayed fields based on weed numbers determined between 29 and 78 days after sowing. Based on species composition and weed abundance, the weed community structure was determined using the Shannon-Wiener species diversity index (H), Simpson's dominance index (SI), Pearson correlation coefficients (r) and Multiple regression. Weed populations in onion and carrot exhibited substantial year-to-year variability and no long-term trends. The most abundant species in onion and carrot were *Capsella bursa-pastoris, Thlaspi arvense, Chenopodium album*, and *Galinsoga parviflora*. In onion, an increasing tendency in the number of *Galinsoga parviflora Capsella bursa-pastoris, Thlaspi arvense,* and *Echinochloa crus-galli* was observed, while the number of *Chenopodium album* plants showed a tendency to decrease. In carrot, an upward trend in the populations of *Capsella bursa-pastoris* and *Chenopodium album* was observed, although annual fluctuations remained substantial. The climatic effects on weed communities were weak and inconsistent across crops, explaining only a small weed variation and indicating that long-term weed dynamics are shaped primarily by non-climatic factors.

Keywords: weed, onion, carrot, weed population, community structure.

Introduction

Vegetable crops sown in the spring, such as onion, carrot, parsley, leek, and parsnip, are characterized by a long germination and emergence period, slow growth immediately after emergence, and poor coverage of the inter-row area in the initial vegetation period, which makes them susceptible to weed infestation (Dobrzański 1999; Siciński 2000; Mennan *et al.* 2020; Chacko *et al.* 2021). Onion and carrot are commonly cultivated vegetable crops in Poland and are particularly sensitive to weed competition, especially during the early growth stages. Their limited competitive ability against weeds makes them suitable model crops for long-term studies on changes in weed community composition and abundance in vegetable cultivations. Weed communities are determined by site conditions, soil nutrient content, cultivation methods, and interactions with crop plants (Swanton *et al.* 2015; Andreasen *et al.* 2018). Species composition and the degree of weed infestation depend primarily on the size of the soil seed bank, climatic conditions, and interspecific interactions within the community (Kumar *et al.* 2024). Over the years, changes in the species and quantitative composition of weed communities have been observed.

Human activities, including the use of chemicals, simplified cultivation practices, and restrictions on crop rotation, have strongly influenced weed communities (Skrzypczak and Adamczewski 2002; Domaradzki and Bortniak 2023). Long-term use of herbicides can lead to the compensation of some weed species and the development of resistant biotypes among weed species previously considered sensitive to these active substances (Skrzypczak and Adamczewski 2002; Domaradzki and Bortniak 2023). Some studies also suggest that herbicide tolerance may be associated with microorganisms and endophytes (Tétard-Jones and Edwards 2016; Bai *et al.* 2025). Human impact on agrophytocenoses leads to changes in habitat conditions, while the use of chemicals, changes in agricultural practices and harvesting methods influence weed species composition. Organic cropping systems contain a greater number of weed species than conventional fields, but they are generally not dominated by one or more weed species and are more likely to contain rare species (Berbeć *et al.* 2020).

The quantitative and qualitative relationships in weed communities within crop fields depend on the interaction of habitat and agronomic factors, as well as the crop's developmental rhythm (Westbrook *et al.* 2024). Current trends indicate the need to preserve biodiversity. Biodiversity protection is related, among other factors, to the problem of endangered weed species, including some segetal weeds (Muñoz *et al.* 2020).

Some weed species that appear sporadically in vegetable crops can enter these crops from adjacent areas (wastelands and ruderal habitats). The penetration of ruderal species from orchard and park habitats into vegetable crop weed communities was reported by Dobrzański (1999). The persistence of these species often hinges on their ability to adapt to the biological rhythms of the crops. Piórek and Krechowski (2010) reported that species such as *Achillea millefolium*, *Lolium perenne*, *Cerastium holosteoides, Artemisia campestris, Cardaminopsis arenosa*, and *Conyza canadensis* can enter segetal communities from adjacent zones of these crops.

Recent years have seen climate-related changes that may influence weed communities by altering species composition and favoring thermophilic species (Feeley *et al.* 2020; Kiebacher *et al.* 2023). Climatic factors, particularly temperature and precipitation, are considered to be environmental factors affecting weed occurrence and abundance in agricultural systems (Karkanis *et al*. 2019; Storkey *et al*. 2021). A full assessment of changes in weed communities on cultivated fields is only possible when it is based on long-term observations. Short-term assessments can only indicate emerging trends, and their verification requires a much longer period of observation (Gonzalez-Andujar and Gonzalez-Garcia 2025). Although, weed communities are shaped by numerous agronomic and environmental factors, long-term datasets combining weed assessments with climatic data remain limited, particularly in vegetable crop production.

This study aimed to evaluate long-term changes in weed infestation in onion and carrot cultivations from 1995 to 2024, taking into account the climatic factors in the Skierniewice region, such as mean daily temperature and precipitation.

Materials and methods

Observations of weed infestation were conducted in carrot and onion crops grown from seeds from 1995 to 2024 in the Skierniewice region, located within the Masovian Lowland (Nizina Mazowiecka) in Central Poland. The Masovian Lowland is characterized by a flat landscape, with poor tree cover. Agricultural crop production predominates with numerous individual farms. The majority of observations were performed on the same fields. However, due to crop rotation practices, it was not always possible to conduct observations on the same fields, therefore , some observations were conducted on different farmers` fields, within the same region. All observation sites were characterized by comparable soil and climatic conditions representative of the Skierniewice area. Although the exact field locations varied between years due to crop rotation requirements, some sites were included repeatedly in successive observation periods. The study area was characterized by predominantly medium-quality soil types, specifically brown and podsolic soils, which are categorized as classes III and IV. There was also a small proportion of class II soils, as noted in the Public Information Bulletin (Gmina Skierniewice 2023). Podsolic soils are typical for Skierniewice and many regions of Poland, primarily lowland areas. These soils usually contain 1.5 to 3% organic matter. The soils in the study area were moderately fertile, but the cultivation of vegetables, including onions and carrots, was feasible with adequate fertilization. The climatic conditions in the observation area reflected those of the broader lowland region of Poland, featuring a moderate and variable climate influenced by both continental air masses from the east and oceanic air masses from the west. The prevailing wind directions in Skierniewice were westerly and southwesterly. Additionally, this region falls within a low rainfall zone, with the highest precipitation occurring during the growing season.

Vegetable crops on experimental fields were cultivated primarily after winter or spring cereals, and in some fields, as a part of crop rotations that included spring wheat, a cereal-legume mixture, and vegetables. On individual agricultural farms, the forecrops for carrots and onions included winter cereals, a legume-cereal mixture, potatoes, peas, and occasionally rapeseed. On the fields where weed infestation observations were conducted, no herbicides were applied before assessments were made. This made it possible to evaluate naturally occurring weed communities under comparable agronomic conditions. Herbicide treatments applied in preceding crops reflected standard agricultural practices and varied depending on the year, field, and crop rotation. Weed infestation was assessed once per growing season, at the beginning of the vegetation period, after weed emergence, when they were in intensive growth. The observations were carried out both on farms and in experimental plots.

At each site, the number of weeds was determined in randomly selected locations. In total, weed infestation was assessed each year in 16 sampling areas in each crop. The mean number of weeds per square meter was calculated from all observations. The observation method did not change during the entire study period, and the number of assessments carried out each year remained the same. The assessment was based on the number of weeds occurring in unsprayed areas of the field where no weed control was implemented. Weed numbers were determined using the frame method (frame size 20 x 50 cm), depending on the species and year of observation, between 29 and 78 days after sowing. Each year, weed infestation was assessed on one sampling date, during the period of the highest weed occurrence and the greatest crop sensitivity to weed competition. The growth stages of weed during observations were from 4 to 9 or more leaves (sometimes at the beginning of flowering), depending on the species. From all observations, the mean number of weeds per square meter (m^2), standard deviation (±SD), and coefficient of variation (CV) were calculated. Based on the species composition and abundance of weeds, the structure of weed communities was determined using ecological indices:

– the Shannon-Wiener species diversity index (H')

$H = -\sum_{i=1}^{s} p_i \log p_i$

$p_i = \frac{n_i}{N_i}$

H – Shannon-Wiener diversity index

ni – number of individuals of a specific species

Ni – total number of all species

pi – share of individuals of a given species in the total of all species

– Simpson's Dominance Index (SI), using the following formulas: (H):

SI = ∑ Pi 2

SI – Simpson's dominance index

Pi – the share of individuals of the i-th species in relation to the sum of all species.

Pearson correlation coefficients (r) were calculated to assess the relationship between climatic variables and weed species diversity in onion and carrot crops. Multiple regression analyses were also conducted for each species to determine the effect of weather conditions on the abundance of total weeds.

Weather conditions were monitored for onion and carrot, including air temperature and rainfall. Measurements were obtained from the Climate Station, located at the Experimental Field of the Institute. Because the distances between the study areas were relatively small and the soil and crop management conditions were similar, all locations were treated as representative of one production region. Therefore, location was not included as a separate factor in the statistical analyses. The tables provide the air temperatures and the total precipitation in 5-year intervals, with averages calculated for individual months of the growing season.

To assess the relationships between climate and weed communities in onion and carrot crops, weather data (mean daily temperature and total precipitation during the growing season) and weed observation records were analyzed. Pearson correlation coefficients (r) were calculated to evaluate the associations between climatic variables and weed species diversity in both crops for the period 1995–2024. Additionally, the effects of weather conditions on the abundance of overall weed species were assessed using multiple regression analyses performed separately for onion and carrot. Statistical analyses were conducted in Statistica, and significance was evaluated at $\alpha = 0.05$.

Results

The data presented in Figure 1 indicate that between 1995 and 2024, there was a notable upward trend in the average daily air temperature during the growing season of the studied crop species, which runs from April to September. Among the analyzed months, May exhibited the most consistent temperatures, with average daily temperatures ranging from 13.8°C to 14.9°C across the examined 5-year periods. In the summer months - June, July, and August - a significant increase in average daily air temperature was observed. Additionally, an upward trend in temperature was also seen in September, which may have contributed to an extended growing season for both crops and weeds.

During the analyzed period, significant variability in precipitation was observed both between years and within individual months. The highest rainfall was recorded from 2010 to 2014, while the lowest from 2015 to 2019. In the period, from 2020 to 2024, total rainfall increased compared to the previous five-year period, although it remained below the average for earlier years. Analysis of the rainfall during the growing season revealed a decreasing trend in total rainfall beginning from April 2004, particularly between 2005 and 2009, as well as from 2015 to 2019. May and June were characterized by stable precipitation with only minor fluctuations. The highest rainfall during the analyzed period was recorded in July. An upward trend in precipitation was observed in August, followed by a decrease in September, marking the end of the growing season. Furthermore, extreme weather events, characterized by longer periods of seasonal drought interrupted by short bursts of intense rainfall, have become increasingly frequent in recent years.

Figure 1. Average daily air temperatures and total precipitation during the growing season (from April to September) in the Skierniewice region, 1995-2024.

Onion and carrot crops were characterized by a high weed infestation and diversity of species. The number of weeds in these crops varied between years, reflecting variability in weather conditions during the growing seasons. In onion, which is considered to be one of the species most susceptible to weed infestation, a total of 20 weed species were observed, with an average number of 244.2 weeds.m^{-2} (Tab. 1). Carrot is also susceptible to weed infestation, with 21 weed species observed. The total number of weeds in this crop was 254.0 weeds.m^{-2} (Tab. 2).

In both vegetable species, the weed infestation structure was dominated by the following weed species: *Capsella bursa-pastoris* (onion – 59.3 pcs.m^{-2}, carrot – 75.7 pcs.m^{-2}), *Thlaspi arvense* (onion – 38.8 pcs.m^{-2}, carrot – 24.4 pcs.m^{-2}), *Chenopodium album* (onion – 25.3 pcs.m^{-2}, carrot – 51.6 pcs.m^{-2}), *Galinsoga parviflora* (onion – 31.3 pcs.m^{-2}, carrot – 32.8 pcs.m^{-2}), *Lamium amplexicaule* (onion – 21.5 pcs.m^{-2}, carrot – 23.4 pcs.m^{-2}*), Urtica urens* (onion – 15.1 pcs.m^{-2}, carrot – 11.1 pcs.m^{-2}). *Echinochloa crus-galli* also played a significant role in the overall weed infestation. In onion, the total number was 36.9 weeds.m^{-2}, representing 14.7% of the total number of weeds, and in carrot, 14.5 weeds.m^{-2}, representing 5.7% of the total number of weeds. In both crops analyzed, smaller numbers (between 1 and 4 weeds.m^{-2}) were also found: *Erodium cicutarium, Tripleurospermum inodorum, Senecio vulgaris, Amaranthus retroflexus* and *Sinapis arvensis*. Additionally, *Fallopia convolvulus* and *Stellaria media* appeared in onions, and *Persicaria maculosa* and *Solanum nigrum* in carrots. Sporadic occurrences of species such as *Polygonum aviculare, Raphanus raphanistrum*, and *Viola arvensis* were also observed in crops, at less than 1 plant.m^{-2}. The presence of *Euphorbia helioscopia* was also noted in onions, while *Erigeron canadensis* and *Portulaca oleracea* were found in carrots.

Table 1. Dynamics of changes in weed numbers in onion cultivation.

Table 2. Dynamics of changes in weed numbers in carrot cultivation.

Biodiversity indices are commonly used to assess the structure of weed communities and allow for monitoring the dynamics of weed infestation over time and space. The Shannon-Wiener species diversity index (H) takes into account both the number of species and their relative share in the weed community (Westbrook *et al.* 2024), while the Simpson dominance index (SI) indicates the degree of dominance of one or more species over others. Between 1995 and 2024, changes in weed infestation were observed in onion and carrot crops in the Skierniewice area (Figs. 2 and 3). The highest weed biodiversity index (H: 0.967 in onion and 0.917 in carrot) and low dominance index (SI: 0.129 in onion and 0.151 in carrot) in both crops were recorded between 1995 and 1999, indicating a diverse composition of weed communities and an even distribution of individual species within their structure during this period. The lowest species diversity, combined with the dominance of one or a few species in the weed infestation structure of onion, was observed in the years 2000-2004 and 2020-2024 (Fig. 1). This trend indicates a gradual reduction in the number of species occurring in onion crops and an increase in the share of several dominant, highly competitive weed species.

* Trend lines were added to visualize long-term changes; equations for linear regression are shown on the graphs.

Figure 2. Shannon-Wiener species diversity (H) and Simpson dominance (SI) indices in onion cultivation over the years.

In carrot cultivation (Fig. 3), the variation in ecological indices of weed infestation over the years was smaller than in onion, but the greatest diversity was observed in the years 1995-1999 (H: 0.917, SI: 0.151). In both vegetable crops, a tendency of decreasing diversity index and increasing Simpson's dominance index was observed. This indicates a reduction in the number of species and an increasing dominance of one or a few dominant species.

In summary, an analysis of Shannon’s diversity index and Simpson’s dominance index showed that weed communities in the fields of both vegetable species were characterized by moderate species diversity and low species dominance. However, the weed communities in carrot fields exhibited greater stability and a more balanced community structure than those in onion fields, as evidenced by higher values of the Shannon index and lower values of the Simpson dominance index.

* Trend lines were added to visualize long-term changes; equations for linear regression are shown on the graphs.

Figure 3. Shannon-Wiener (H) and Simpson (SI) species diversity indices in carrot cultivation over the years.

Table 3. Pearson correlations (r) between climate and weed diversity in onion and carrot crops (1995–2024).

The Pearson correlation analysis (Tab. 3) indicated trends where the temperature showed stronger associations with weed diversity than precipitation in both onion and carrot crops. In onion, mean temperature during the growing season was moderately negatively correlated with the Shannon-Wiener index (H; r = -0.53) and moderately positively correlated with the Simpson index (SI; r = 0.39), suggesting a tendency toward reduced species richness but increased dominance of certain species under warmer conditions. Precipitation showed weaker associations, with a slight positive correlation with H (r = 0.31) and a negligible negative correlation with SI (r = -0.18). In carrot, temperature exhibited stronger trends, with H strongly negatively correlated (r = -0.67) and SI strongly positively correlated (r = 0.59), while precipitation showed a moderate positive correlation with H (r = 0.46) and a weak negative correlation with SI (r = -0.30). In summary, in both onion and carrot crops, the trends in Pearson correlations suggested that higher temperatures tended to coincide with lower weed species diversity and increased dominance of certain species, whereas precipitation showed more variable associations with weed community structure.

* Trend line numbers correspond to species: 1 – *C. bursa-pastoris*; 2 – *G. parviflora*; 3 – *E. crus-galli*; 4 – *C. album*; 5 – *L. amplexicaule*, 6 – *T. arvense*; 7 – *U. urens*.

Figure 4. Number of main weed species in onion cultivation over the years 1995–2024

* Trend line numbers correspond to species: 1 – *C. bursa-pastoris*; 2 – *C. album*; 3 – *G. parviflora*; 4 – *L. amplexicaule*; 5 – *T. arvense*; 6 – *E. crus-galli*; 7 – *U. urens*.

Figure 5. Number of main weed species in carrot cultivation over the years 1995–2024

The dynamics of changes in weed populations in onion (Fig. 4) and carrot (Fig. 5) demonstrate trends over the years. These trends were not statistically significant. During the analyzed period, the weed population structure in onion showed an upward trend in the numbers of *Capsella bursa-pastoris, Thlaspi arvense*, and *Echinochloa crus-galli*, while the number of *Chenopodium album* plants decreased. Species such as *Galinsoga parviflora* and *Lamium amplexicaule* remained stable. In carrot, a clear upward trend in the weed populations of *Capsella bursa-pastori*s and *Chenopodium album* was observed, while the remaining species remained stable.

Table 4. The effects of weather conditions (temperature and precipitation during the growing season) on the abundance of individual weed species assessed using multiple regression analyses.

Temperature and precipitation showed no statistically significant effects on weed abundance in onion and carrot crops (Tab. 4). For both onion (R^2 - 0.02) and carrot (R^2 - 0.09) weed infestation, the multiple regression model explained only a small portion of the variability in weed abundance. Although the regression coefficients (Beta) were negative, indicating a tendency for weed abundance to decrease with increasing temperature and precipitation, these relationships were not statistically significant.

Discussion

A warming tendency during the growing season was observed in the Skierniewice region, indicating an increase in thermal conditions relevant to plant development. Changes in temperature and precipitation patterns observed in the study region are consistent with broader trends reported in the literature (Marosz *et al.* 2023; Szyga-Pluta 2022; Kejna and Pospieszyńska 2023). Extreme weather events, characterized by prolonged seasonal droughts interrupted by brief episodes of intense rainfall, have become increasingly frequent in recent years and represent a clear consequence of ongoing climate warming. The reduced rainfall during the vegetation period, especially at the beginning of the growing season, may hinder and delay plant germination and emergence, lead to lower plant density, increase susceptibility to diseases and pests, and heighten competition from weeds (Körner 2013). Additionally, under water-deprived conditions, the root systems of young plants may not develop properly. This could result in limited water and nutrient uptake (Passioura 2007) and, consequently, reduced crop yields (Farooq *et al.* 2009). The varying rainfall totals during the growing season do not change the species composition of primary weed infestations in vegetables but may influence their numbers (Storkey and Neve 2018; Westbrook *et al.* 2024). Olesen and Bindi (2002) indicate that although annual rainfall totals may remain close to average, their extreme variability can hinder plant growth, as plants require consistent moisture for proper development. Data relating to local conditions demonstrate the effects of a global trend.

Observations of weed infestation in the Skierniewice region indicate that all weed species found in onion and carrot, particularly those present in larger quantities, are commonly seen in vegetable crops (Kosterna and Zaniewicz-Bajkowska 2014). Based on studies conducted in the Łęczyca region on onion and carrot crops, Siciński (2000) concluded that the floristic composition of these crops, regardless of the species grown, is similar to that found in root crops such as potatoes and beets. This similarity results from their similar cultivation methods, growing dates, maintenance practices, and the nature of the crops. These weeds primarily belong to the group of annual species. Dobrzański and Adamczewski (2009) reported that the composition of weed communities, along with their relative proportions and abundance, is influenced by habitat conditions, including soil type, soil moisture, pH, nutrient content, thermal conditions, tillage methods, and the specific crops being cultivated. In addition, the biodiversity, community structure, and quantitative proportions of weed species are strongly determined by the presence and biology of dominant species, as well as by interspecific interactions within the population (Storkey and Neve 2018; Westbrook *et al.* 2024). In a single crop, one can typically find up to a dozen weed species, with only some clearly dominating others (Sawicka *et al.* 2020). According to Zingsheim and Döring (2024), a high dominance index resulting from low diversity of the community and the dominance of one or only a few weed species may indicate a greater harmfulness of weed infestation to the crop than a situation where the community is composed of many species occurring in low abundance. The phenomenon of decreasing biodiversity in agrocenoses due to the intensification of agricultural production is widely described in the literature. Ługowska *et al.* (2016) reported that the structure of agrophytocenose biodiversity is also influenced by site conditions. Communities occurring on heavier and more compact soils exhibit higher H values and lower SI values. Other authors report that frequent use of broad-spectrum herbicides and nitrogen fertilization causes a decrease in the H index and an increase in SI (Travlos *et al.* 2018; de Mol *et al.* 2025). Furthermore, simplified crop rotations lead to the elimination of less competitive species, which translates into an increased dominance of ruderal and expansive weeds (Mayerová *et al.* 2023). A similar effect was observed by Woźniak (2025), who reported that winter wheat grown in monoculture had almost three times the number of weeds compared to crop rotation, and the Shannon–Wiener biodiversity index was also higher. This confirms the premise that simplified cultivation systems contribute to reduced agroecosystem stability. Many weed species adapt their developmental cycle to that of the crop. Many researchers have discussed the variety of weed flora in different crops, both in various regions of Poland and in other countries, and have examined the reasons for these differences (Siciński 2000; Fried *et al.* 2009; Gołębiowska 2012; Meyer *et al.* 2013; Wesołowski *et al.* 2015; Andreasen *et al.* 2018; Karkanis *et al.* 2019; Wanic *et al.* 2019; Domaradzki and Bortniak 2023). Many sources indicate that more intensive agricultural production results in lower biodiversity within a given habitat (Firbank *et al.* 2008; Dobrzański and Adamczewski 2009, Wesołowksi *et al.* 2015; Emmerson *et al.* 2016; Beckmann *et al.* 2019). Bourgeois *et al.* (2020) report that the structure of weeds varies even within a single field, from the edge to the interior, depending on the microenvironment and weather conditions.

Weed communities in vegetable crops are determined by habitat conditions, abundance of nutrients in the soil, and cultivation practices (Swanton *et al*. 2015; Andreasen *et al.* 2018).

In the present study, temperature and precipitation did not show statistically significant effects on weed abundance in onion and carrot crops. However, some weak correlations between climatic variables and weed community characteristics were observed. Therefore, the results do not provide evidence of a direct causal effect of climate variables on changes to the weed community over the study period. Other factors, such as soil properties, crop rotation and cultivation systems, seed bank composition, and interspecific competition, may contribute to variation in weed populations. These factors are likely to have played a more important role in shaping weed populations, as suggested by previous studies (Ruisi *et al.* 2015; Restuccia *et al.* 2019; Schwartz-Lazaro and Copes 2019; Feledyn-Szewczyk *et al.* 2020).

Recent studies have shown that anthropogenic activities and agricultural practices strongly influence the structure and dynamics of weed communities in cultivated fields (Blank *et al.* 2023). This impacts habitat conditions, while chemical interventions, and changes in agricultural practices and harvesting methods influence species composition (Domaradzki and Bortniak 2023). Results regarding changes in weed abundance in various crops over time are presented by various authors. Wanic *et al.* (2019) demonstrated that over the past years, the abundance of weed species, such as *Solanum nigrum* and *Polygonum persicaria* in potato crops has increased, while the share of *Apera spica-venti* has decreased.

Rola *et al.* (2005) indicate that simplified tillage systems, the dominance of certain crops, and the increasing use of selective herbicides contribute to the depletion of weed flora and the dominance of broad-spectrum species, such as *Chenopodium album, Capsella bursa-pastoris*, and *Echinochloa crus-galli*. The development of herbicide resistance can also play an important role in shaping weed populations. Recent studies have reported high levels of herbicide resistance in species such as *Capsella bursa-pastoris* (Li *et al.* 2019), *Chenopodium album* (Li *et al.* 2025), and *Galinsoga parviflora* (Rojas-Sandoval and Acevedo-Rodríguez 2014). Moreover, herbicide tolerance may also be associated with microorganisms and endophytes (Tétard-Jones and Edwards 2016; Bai *et al.* 2025). Gołębiowska (2012) reported that simplified tillage techniques (including direct sowing and reduced tillage) are among the main factors influencing changes in weed communities, favoring an increase in the population of perennial and deep-rooting species, such as *Elymus repens* and *Cirsium arvense*. These trends are consistent with observations conducted in other European countries. Marshall *et al.* (2003) report that in the UK, there is evidence of changes in the weed flora over the last century, with some species declining and others increasing. There is also some evidence of a decline in the size of weed seed banks. Some of these changes reflect improved agricultural productivity, changes in winter crop rotations, and the use of broader-spectrum herbicides. Similar changes have also been observed in Germany. According to Meyer *et al.* (2013), as a result of agricultural intensification and herbicide pressure, the abundance of many rare and crop-adapted species has declined, while the proportion of ruderal and intensively tolerant species has increased. Similarly, in France, Fried *et al.* (2009) demonstrated that with higher agricultural intensification, the number of nitrophilous species decreased, while the dominance of several resistant taxa has increased. These authors also emphasize the important role of conservation measures and the use of ecologically friendly practices in maintaining weed diversity. Mwangi *et al.* (2024) report that the organic cultivation system contributes to an increase in weed diversity, which may be important from the point of view of biodiversity protection.

Climate change has been suggested as one of the factors influencing weed flora in agricultural systems (Peters *et al*. 2014). These effects may impact germination timing and species composition; however, the strength of these effects varies between studies (Domaradzki *et al.* 2008; Pautasso *et al.* 2010; Peters *et al.* 2014; Gołębiowska *et al.* 2015; Ramesh *et al*. 2017; Storkey *et al*. 2021; Hazarika *et al*. 2024). Nevertheless, the present study found only limited evidence of associations between climatic variables and weed community characteristics in onion and carrot crops.

Although climate-related shifts in weed flora have been reported in Europe (Rojas-Sandoval and Acevedo-Rodríguez 2014; Li *et al*. 2025), similar patterns were not clearly confirmed in the present study.

Conclusions

Observations showed that weed infestation patterns in onion and carrot in the Skierniewice region changed over the 30-year study period. Although some weak tendencies were observed for selected weed species, the relationships were inconsistent and did not indicate strong or uniform climatic effects.

Onion and carrot crops showed similar general tendencies in associations between weather conditions and weed communities. However, the strength of these associations differed between the two crops, and no statistically significant effects of temperature or precipitation on overall weed abundance were detected.

The observed climatic associations only accounted for a small proportion of the variation in weed abundance. This suggests that climatic factors are just one component influencing long-term weed community dynamics, alongside non-climatic factors such as management practices and the soil seed bank

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Table 1. Dynamics of changes in weeds number in onion cultivation.

Weed species	Onion from seeds							
	Number of weeds in pcs.m-2 (average for the years)						Average over the entire period (1995-2024)	Standard deviation (±SD)*
	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019	2020-2024		
Capsella bursa-pastoris (L.) Medik.	34.0	66.3	47.2	77.3	64.0	68.3	59.3	44.8
Thlaspi arvense L.	17.3	134.2	18.1	28.7	27.6	4.1	38.8	105.3
Lamium amplexicaule L.	30.5	13.0	41.7	13.5	10.1	19.3	21.5	25.1
Chenopodium album L.	34.0	22.0	20.7	10.4	13.4	59.0	25.3	21.6
Galinsoga parviflora Cav.	25.6	8.0	11.2	31.6	44.5	71.1	31.3	29.8
Urtica urens L.	26.0	14.5	14.9	22.6	7.4	2.1	15.1	20.7
Erodium cicutarium (L.) L`Her.	4.8	1.3	1.1	4.2	1.7	1.0	2.3	5.8
Tripleurospermum inodorum (L.) Sch. Bip.	2.4	0	0.9	6.8	1.0	0.5	2.0	3.2
Senecio vulgaris L.	2.0	1.9	0.5	3.7	1.3	1.3	1.8	1.8
Amaranthus retroflexus L.	0	0	2.5	1.0	0.3	4.8	1.3	2.0
Polygonum persicaria L.	0.7	0.4	2.8	0.1	0.7	0.7	0.9	1.7
Fallopia convolvulus (L.) Á. Löve	7.5	1.6	0.4	0.1	0.9	0	1.8	4.6
Sinapis arvensis L.	1.7	2.0	1.1	1.0	0	0	1.0	2.2
Stellaria media (L.) Vill.	0	0	4.3	1.1	0	1.5	1.2	3.8
Polygonum aviculare L.	0.5	0	0	0	0	0	0.1	0.3
Raphanus raphanistrum L.	1.1	0	0	0	0	0	0.2	1.0
Euphorbia helioscopia L.	1.3	0	0.3	0	0	0	0.2	1.2
Viola arvensis Murr.	0.2	0	0	0.3	0	0	0.1	0.3
Erigeron canadensis L.	-	-	-	-	-	-	-	-
Solanum nigrum L.	0	0	0	0	0	0.6	0.1	0.3
Portulaca oleracea L.	-	-	-	-	-	-	-	-
Echinochloa cruss-galli (L.) Beauv.	7.8	41.2	10.0	132.5	17.0	6.9	36.9	108.5
Total weeds number	197.4	306.4	177.7	334.7	186.2	241.2	241.3	-
Number of weed species	17	12	16	16	13	14	20	-

* Data based on analysis of the source results of the weed count from each year, from 1995 to 2024

Table 2. Dynamics of changes in weeds number in carrot cultivation.

Weed species	Carrot							
	Number of weeds in pcs.m⁻2 (average for the years)						**Average over the entire period** (1995-2024)	**Standard deviation** (±SD)*
	1995-1999	2000-2004	2005-2009	2010-2014	2015-2019	2020-2024		
Capsella bursa-pastoris (L.) Medik.	19.4	63.4	99.6	95.5	52.4	124.1	75.7	62.4
Thlaspi arvense L.	5.7	15.7	42.4	29.0	30.4	23.5	24.4	33.7
Lamium amplexicaule L.	11.2	17.3	23.8	20.4	17.3	50.5	23.4	29.1
Chenopodium album L.	22.8	26.3	41.6	22.3	60.3	136.3	51.6	84.2
Galinsoga parviflora Cav.	37.6	9.7	27.1	28.3	25.6	68.3	32.8	29.3
Urtica urens L.	7.6	13.2	17.3	18.9	4.0	5.4	11.1	14.5
Erodium cicutarium (L.) L`Her.	0	2.5	7.3	2.1	4.7	1.1	3.0	6.6
Tripleurospermum inodorum (L.) Sch. Bip.	7.6	2.4	0.6	3.4	3.6	2.8	3.4	6.0
Senecio vulgaris L.	1.8	2.3	0.1	3.9	3.4	6.6	3.0	4.2
Amaranthus retroflexus L.	0.7	0	3.1	0.3	3.8	12.1	3.3	6.9
Polygonum persicaria L.	0.7	0.5	0.1	0.5	2.0	4.5	1.4	3.1
Fallopia convolvulus (L.) Á. Löve	1.0	0.5	0	0	0	0.2	0.3	0.8
Sinapis arvensis L.	17.5	0	2.3	0	1.5	0	3.6	16.0
Stellaria media (L.) Vill.	0	0	0	1.8	0	1.5	0.5	1.8
Polygonum aviculare L.	0	0	0.3	0	0	0	0.1	0.2
Raphanus raphanistrum L.	0.1	0	0	0	0	0	0	0.1
Euphorbia helioscopia L.	-	-	-	-	-	-	-	-
Viola arvensis Murr.	0	0.1	0	0	0	0	0	0.1
Erigeron canadensis L.	0	6.0	0	0	0	0	1.0	5.5
Solanum nigrum L.	0	0	0	5.8	0	0.6	1.0	5.2
Portulaca oleracea L.	0	0	0	0	0	0.2	0	0.1
Echinochloa cruss-galli (L.) Beauv.	5.3	18.4	23.5	28.9	6.1	5.0	14.5	23.1
Total weeds number	139.0	178.3	289.1	261.1	215.0	441.6	254.0	-
Number of weed species	14	14	14	14	13	16	21	-

* Data based on analysis of the source results of the weed count from each year, from 1995 to 2024

Table 3. Pearson correlations (r) between climate and weed diversity in onion and carrot crops (1995–2024).

Crop species	**Climatic factor**	**Pearson correlations (r)**	
		Shannon-Wiener H	**Simpson SI**
Onion	Temperature (°C)	-0.53	0.39
	Precipitation (mm)	0.31	-0.18
Carrot	Temperature (°C)	-0.67	0.59
	Precipitation (mm)	0.46	0.30

Table 4. The effects of weather conditions (temperature and precipitation during the growing season) on the abundance of individual weed species assessed using multiple regression analyses.

Weed species	R²	Temperature (°C)		Precipitation (mm)	
		Beta	p	Beta	p
	Onion *				
Total weeds number	0.02	-31.54	0.46	-0.26	0.57
	Carrot *				
Total weeds number	0.09	-47.74	0.23	-0.63	0.15

* For each model, Beta coefficients and statistical significance were reported at α = 0.05. All remaining species showed $R^2 < 0.2$.

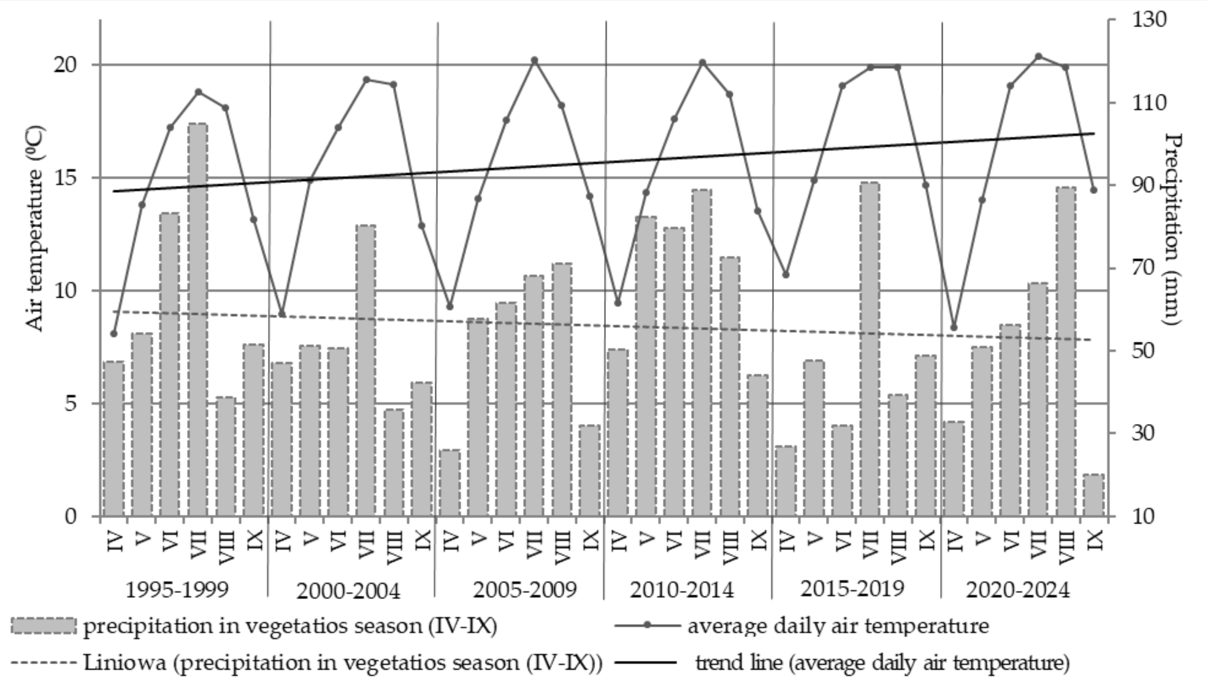
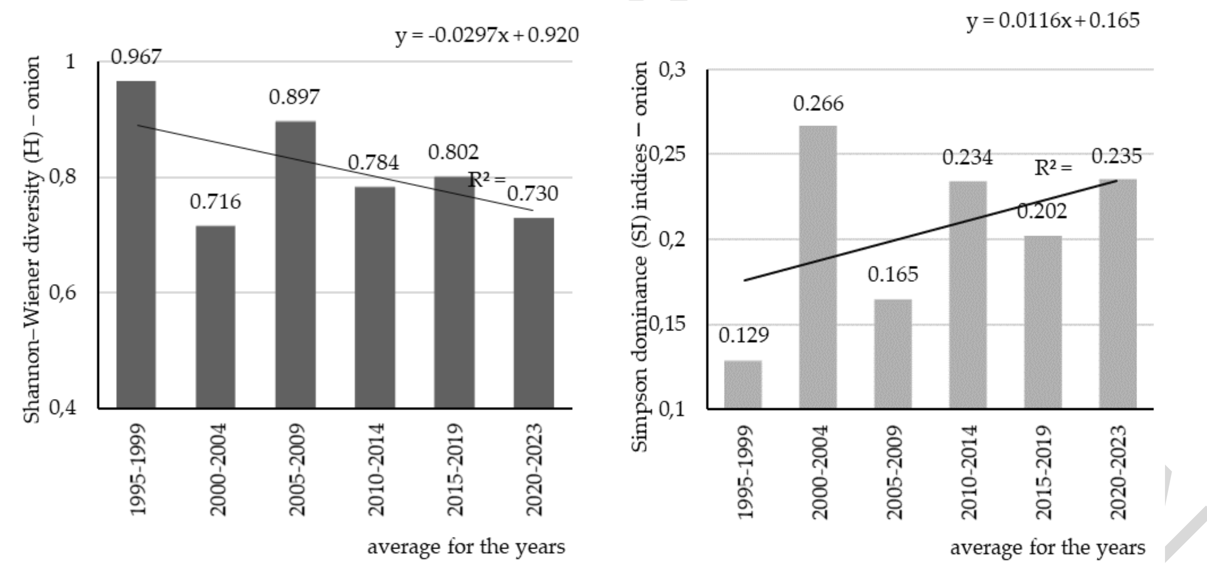
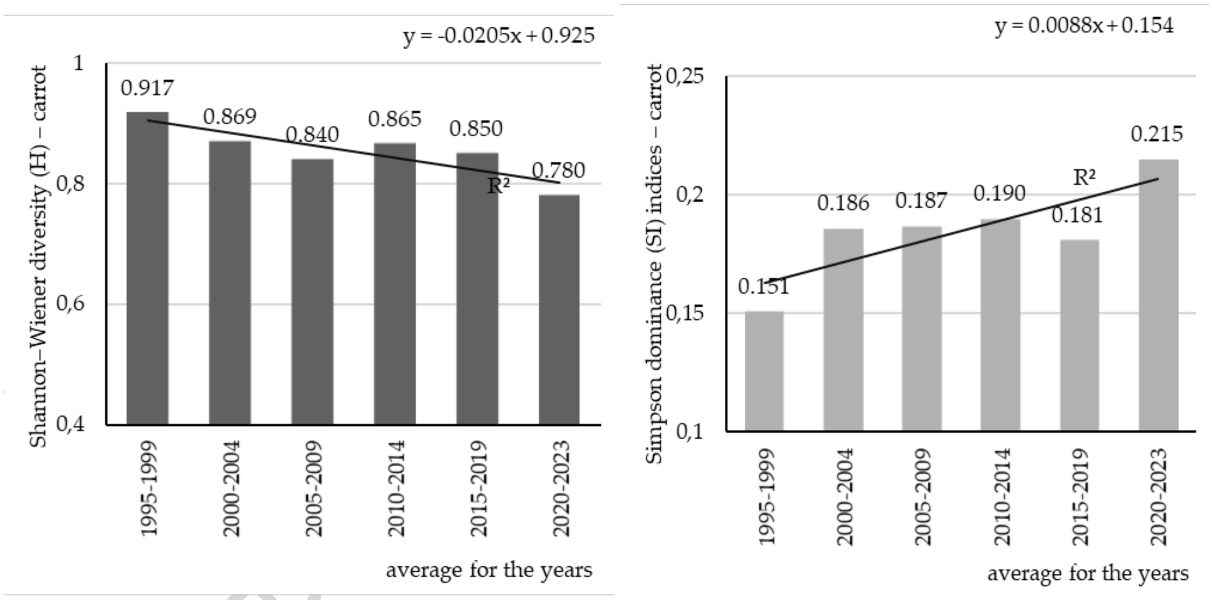


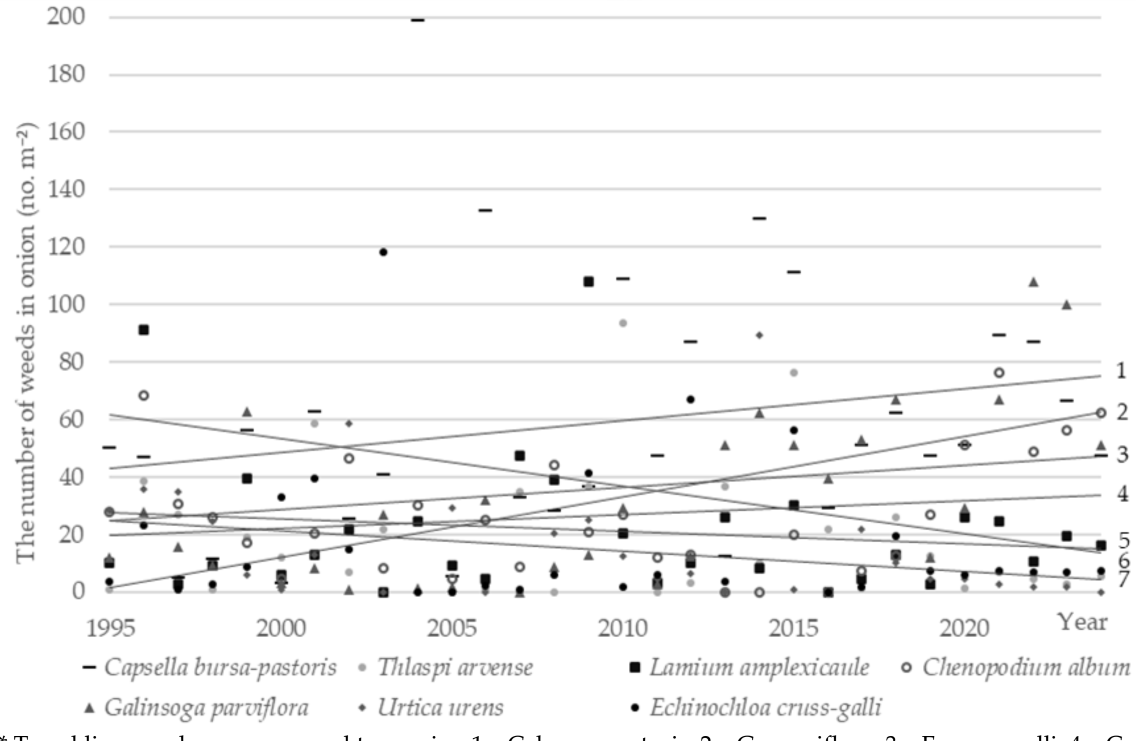
Figure 1. Average daily air temperatures and total precipitation during the growing season (from April to September) in Skierniewice region, 1995-2024.



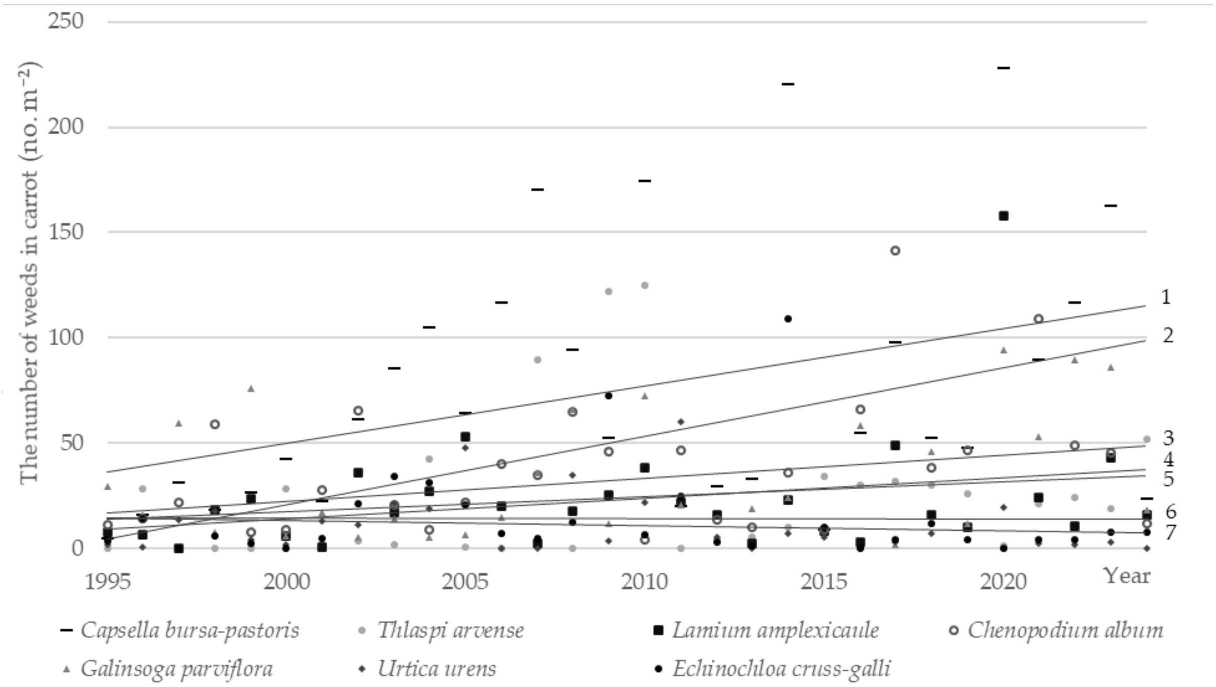
* Trend lines were added to visualize long-term changes; equations for linear regression are shown on the graphs.
Figure 2. Shannon-Wiener species diversity (H) and Simpson dominance (SI) indices in onion cultivation over the years.



* Trend lines were added to visualize long-term changes; equations for linear regression are shown on the graphs.
Figure 3. Shannon-Wiener (H) and Simpson (SI) species diversity indices in carrot cultivation over the years.



* Trend line numbers correspond to species: 1 – C. bursa-pastoris; 2 – G. parviflora; 3 – E. cruss-galli; 4 – C. album; 5 – L. amplexicaule, 6 – T. arvense; 7 – U. urens.
Figure 4. Number of main weed species in onion cultivation over the years 1995–2024



* Trend line numbers correspond to species: 1 – *C. bursa-pastoris*; 2 – *C. album*; 3 – *G. parviflora*; 4 – *L. amplexicaule*; 5 – *T. arvense*; 6 – *E. cruss-galli*; 7 – *U. urens*.

Figure 5. Number of main weed species in carrot cultivation over the years 1995–2024