WEED SPECIES SHIFTS DUE TO CLIMATE CHANGE: A CASE STUDY OF ROW CROPS IN THE NORTHEASTERN CROATIA

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Abstract. *The structure and diversity of world crops' weed flora are greatly influenced by the pronouncing global climate change, which are reshaping the face of the modern agricultural production. The phytocoenological surveys conducted during the summer period in the years 2004 and 2023 in the northeastern Croatia determined qualitative and quantitative changes in the row crops' weed communities. Maize, soybean, sunflower, and sugar beet fields were visited each time in June when the weed vegetation was fully developed, and all occurring weed species within the randomly selected 10 m × 10 m quadrats per 30 and 29 fields in the 2004 and 2023, respectively, were evaluated using a seven-degree Braun-Blanquet scale. The weed community from past research was more heterogeneous, compared to a recent survey. In the past period (2004), weeds with the C_3 photosynthetic pathway dominated in the community, while the C_4 plants were significantly underrepresented. However, the dominance-diversity curve in the recent survey (2023) depicts a similar slope of the curve indicating the growing abundance and species richness of the C_4 weeds. This shift in ranges of weed species with the C_3 and C_4 photosynthetic pathways confirms that climate conditions exert a significant influence on the spread, population dynamics, and infestation pressure.*

Keywords*: weeds, row crops, climate change, C_3 photosynthetic pathway, C_4 photosynthetic pathway*

INTRODUCTION

Over the past decades, many changes have been recorded in the weed flora of arable ecosystems worldwide (SUTCLIFFE and KAY, 2000; KOLAROVA et al., 2013). Current research highlighted that, not only rapid changes in agricultural practices, the increase in inputs of industrial fertilizers, pesticides, and other chemicals; effective seed cleaning and shifting the timing of sowing from spring to autumn, but also global climate change, dramatically altered the arable flora (PETERS et al., 2014).

Climate change refers to a change in the climate variables that persist for extended periods, particularly for decades or longer. There is already a visible trend of average annual temperature growth, severe precipitation extremes, and greenhouse gas emissions which inevitably affect the composition of the weed flora, leading not only to significant changes in the ecological niches within the weed communities, but to changes in the bio-ecological traits of certain weed species at the population level as well (VILÀ et al., 2019). The constant rise in atmospheric CO_2 concentration has a potential effect on other climate variables such as temperature, precipitation, relative humidity, and radiation. All of these may have significant consequences for sustainable weed control and crop production (ALBERTO et al., 1996).

Carbon dioxide (CO_2) as one of the main greenhouse gases is the primary source of carbon required for the normal ongoing process of photosynthesis. Terrestrial plants have developed different mechanisms of CO_2 fixation, and regarding which type of CO_2 fixation plants use, three types of photosynthetic pathways can be distinguished: C_3, C_4, and CAM (PEVALEK-KOZLINA, 2003). Bearing in mind the fact that both weeds and crops include species with the C_3 and C_4 photosynthetic pathways, it is anticipated that the crops' yield will be severely affected by the interaction between impending new environmental conditions and their photosynthetic pathway (AINSWORTH and ROGERS, 2007). For example, the C_4 plants have an advantage over the C_3 plants in terms of water absorption in hot, dry, and highly illuminated habitats. It has been pointed out, that under prolonged drought periods, water deficit stress will significantly increase the leaf area and total dry mass of the C_4 weed species such as *Echinochloa crus-galli*, *Digitaria sanguinalis*, and *Eleusine indica* (PATTERSON, 1985). Also, many studies in the field of weed biochemistry indicate that the C_3 and C_4 weeds will intensify their growth while reducing the yield of the competing C_3 and C_4 crops, respectively (ZISKA, 2001; 2003).

The objective of this study was to analyze the floristic composition and diversity of weeds in recent and past period in row crops, i.e., sunflower, soybean, maize, and sugar beet. More specifically, the goal of this research was to examine the effect of climate change on weed species shifts regarding the plant photosynthetic pathways.

MATERIAL AND METHODS

The study area

The investigation was conducted in the northeastern part of the state territory, an important agricultural region in Croatia where farming is characterized by capital-intensive and market-oriented production (Figure 1). This area experiences a warm and moderate to dry lowland climate with an average annual temperature of around 11°C and average annual rainfall of about 700 mm having the highest spring rainfall regime in June.

Figure 1. The survey area (in circle) displayed on the map of the Republic of Croatia
Source: https://upload.wikimedia.org/wikipedia/commons/7/76/Croatia_location_map.svg

Sampling procedure and statistical analysis

The phytocoenological surveys were conducted in row crops during the summer period in 2004 (ŠTEFANIĆ E, unpublish data) and in 2023. The sites were visited in June after the weed vegetation was fully developed. A total of 30 (in 2004) and 29 (in 2023) phytocoenological relevés have been chosen for a survey where maize, soybean, sunflower, and sugar beet were cultivated. All occurring plant species within the randomly selected 10 m

× 10 m quadrats per field were evaluated using a seven-degree Braun-Blanquet scale (BRAUN-BLANQUET, 1964). The obtained values of each weed species were transformed to an ordinal scale (VAN DER MAAREL, 1979) for further analysis. Plant nomenclature was unified in accordance with the Flora Croatica Database (NIKOLIĆ, 2019).

Firstly, the data were subjected to multivariate canonical discriminant analysis (CDA) to determine the associations between species composition with selected row crops using the CANOCO 5.0 package (TER BRAAK and SMILAUER, 2012). The statistical significance was tested using the Monte Carlo permutation test with 1000 iterations.

Afterward, the rank-abundance plots were used to provide a description of the community photosynthetic pathways between the past and recent surveys (WHITTAKER, 1975). This is a very sensitive measure since it simultaneously shows both components: species number and evenness of species abundance (MAGURRAN, 1988).

Finally, the weed flora was analyzed according to their photosynthetic pathway and, for each crop, the changes in the ratio of weeds with the C_3 and C_4 photosynthetic pathway were presented.

RESULTS AND DISCUSSIONS

A weed community that occurred in row crops consisted of typical flora of this region (ŠTEFANIĆ et al., 2020), but with different species composition, density, and relative abundance. A total of 45 weed species belonging to 18 families were found in 2004, whereas in the recent survey weed community in row crops composed of 32 weed species from 17 plant families. Surveys of weed flora have been the subject of many researches and they also report a huge decline in weed biodiversity (CHAMORRO et al., 2016; BURDA, 2018).

Dominant weeds from both study periods are shown in Table 1. Total cover values of dominant weeds with the C_3 photosynthetic pathway changed over time. In 2004 cumulative cover values of the C_3 plants were significantly higher (623) compared to cumulative cover values of the C_4 plants (293). However, in 2023, cumulative cover values of dominant weed species did not differ significantly (569 and 596 for the C_3 and C_4 plants, respectively). This shift in ranges of weeds with the C_3 and C_4 photosynthetic pathways confirms that climate conditions exert a significant influence on the spread, population dynamics, and infestation pressure (AMARE, 2016).

Table 1.

Changes in dominant weed species of row crop's weed communities from 2004 to 2023

The year 2004			The year 2023		
Weed species	Photosynthetic pathway	Total cover	Weed species	Photosynthetic pathway	Total cover
Stellaria media	C_3	262	*Ambrosia artemisiifolia*	C_3	350
Ambrosia artemisiifolia	C_3	260	*Digitaria sanguinalis*	C_4	260
Setaria pumila	C_4	161	*Convolvulus arvensis*	C_3	219
Sorghum halepense	C_4	132	*Sorghum halepense*	C_4	199
Convolvulus arvensis	C_3	101	*Setaria verticillata*	C_4	137

Based on the ordination diagram in 2004 (Figure 2), the first axis explained the 12,83% of the total variation of species data and divides the weed communities that were developed in sunflower, soybean, and maize from those in sugar beet. A further 12,43% distinguished the weed community in maize from those in soybean and sunflower (Table 2).

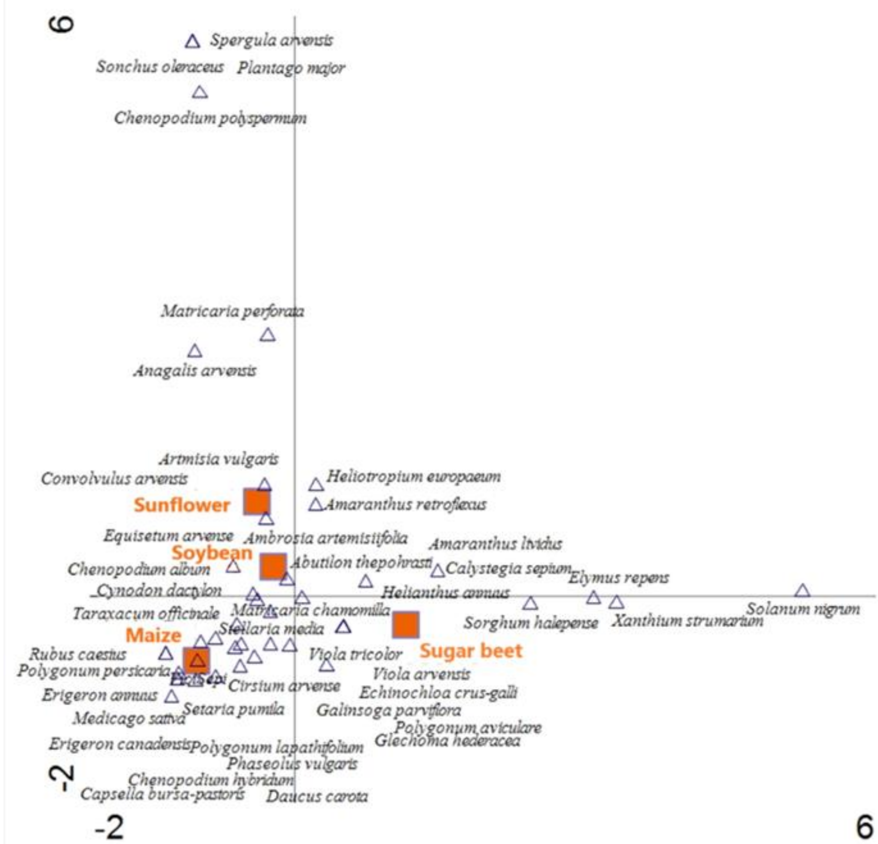

Figure 2. Two-dimensional CCA ordination diagram of weed species in 2004 with explanatory variables (row crops)

Table 2.

A summary of CCA analysis of the row crop’s weed flora recorded in the year 2004

	Axes				Total variation
	1	2	3	4	
Eigenvalues	0,5763	0,5583	0,4587	0,3737	4,4924
Explained variation	12,83	25,26	35,47	43,78	
Pseudo-canonical correlation	0,3645	0,3790	0,3493	0,6396	

The weed community that occurred in 2023 was less diverse and did not show significant variations in species composition (Figure 3, Table 3). Canonical axis 1 explains 6,3% and axis 2 only 4,58% of variations in the weed community, grouping all weeds around the crops in the same quadrant. Nowadays, the crop structure does not reveal significant differences in the floristic composition of weed communities in maize, soybean, sunflower, and sugar beet fields.

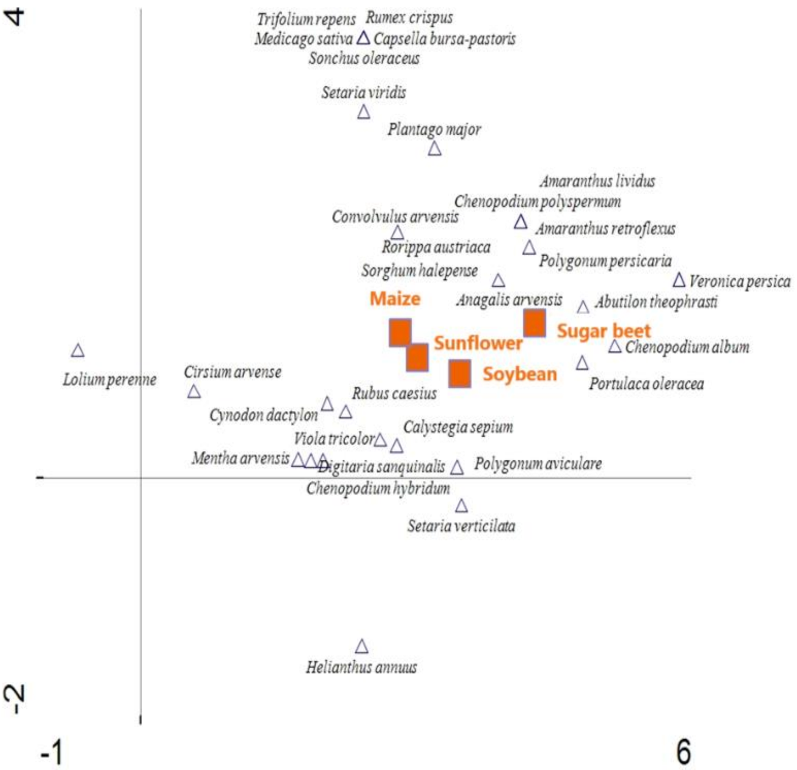

Figure 3. Two-dimensional CCA ordination diagram of weed species in 2023 with explanatory variables (row crops)

Table 3.

A summary of CCA analysis of the row crop's weed flora recorded in the year 2023

	Axes				Total variation
	1	2	3	4	
Eigenvalues	0,2449	0,1781	0,0780	0,5854	3,8874
Explained variation	6,30	10,88	12,89	27,95	
Pseudo-canonical correlation	0,7524	0,6386	0,4504	0,0000	

In accordance with the empirical data, it has been determined that heterogenous weed communities, such as those found in the past research (2004) are much more resilient to altered environmental conditions than more homogenous weed communities from the recent survey in 2023 (TILMAN et al., 2014). This also confirms results from the recent survey (2023) with a visible shift in the floral composition (Table 1), where some new species have become dominant (*Digitaria sanguinalis*) or achieved significantly higher abundance (*Ambrosia artemisiifolia*).

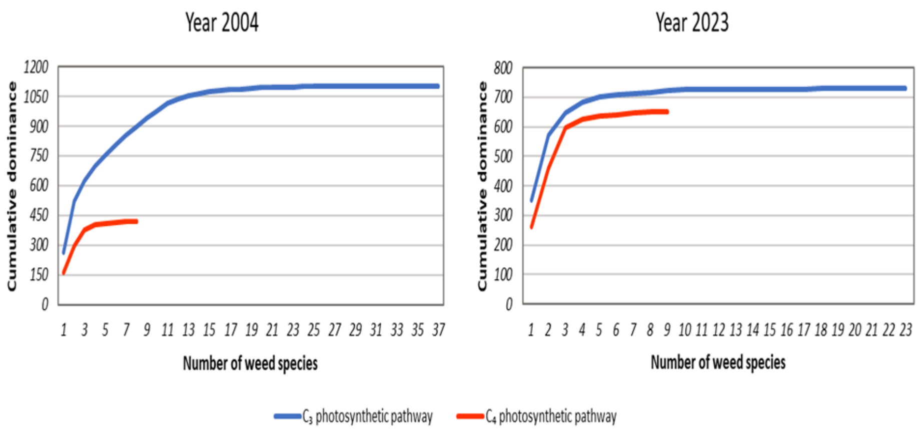

Figure 4. Dominance-diversity curves for row crops in the northeastern Croatia in 2004 and 2023 as a measure of cumulative dominance of the C_3 and C_4 weeds

The structure and diversity of row crop's weed communities in 2004 and 2023 presented by the dominance-diversity curves reflect their species structure regarding the abundance of the C_3 and C_4 plants (Figure 4). It is visible that in the past period (2004), weeds with the C_3 photosynthetic pathway dominated in the community, whilst the C_4 plants were significantly underrepresented. However, the dominance-diversity curve in the recent survey (2023) depicts a similar slope of the curve indicating the growing abundance and species richness of the C_4 weeds.

Although weed communities of row crops from both surveys (Figure 5) are predominant with the C_3 photosynthetic pathway weed species, there is a high probability that under the auspices of climate change and owing to their broad phenotypic plasticity, weeds will benefit compared to crops. This is the case of sugar beet where the significant shift from the dominance of the C_4 over C_3 weeds appeared in 2023.

Only the corn as a C_4 plant will compete with the weeds to a certain extent at elevated CO_2 concentrations, but only in the scenario where all other climate conditions are favorable. Although the very nature of these interactions is very complex and uncertain (TYLIANAKIS et al., 2008) it is necessary to develop models of precise assessments of the potential weed damages under the auspices of climate change, with an emphasis on the development of effective control measures while achieving an economically acceptable yield.

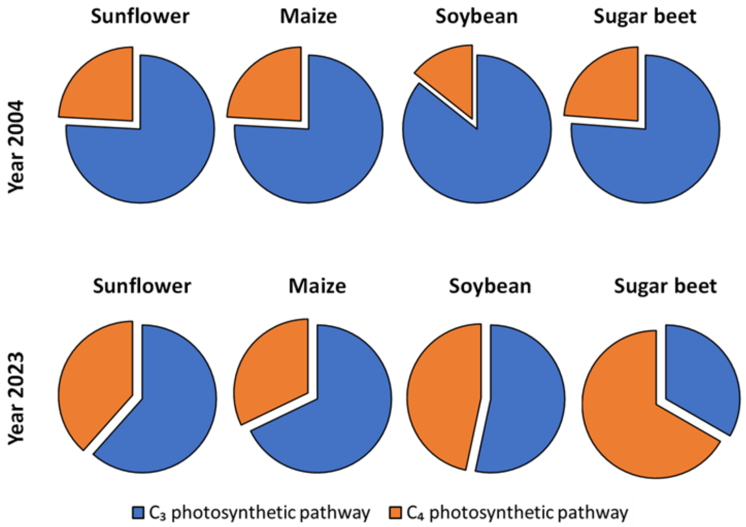

Figure 5. Photosynthetic pathways' share of the recorded row crop's weed species in the northeastern Croatia

CONCLUSIONS

The floristic composition of the weed communities in the northeastern Croatian row crops showed significant qualitative and quantitative changes during the study period (2004 and 2023). A more heterogeneous and floristically rich weed community surveyed in 2004, was replaced with a less diverse one with few very abundant and dominant weeds like *Ambrosia artemisiifolia* and *Digitaria sanguinalis*. In the past period (2004), weeds with the C_3 photosynthetic pathway dominated in the community, while the C_4 plants were significantly underrepresented. However, the recent survey (2023) depicts the growing abundance and species richness of the C_4 weeds. This shift in ranges of weeds with the C_3 and C_4 photosynthetic pathway confirms that climate conditions exert a significant influence on the spread, population dynamics, and infestation pressure.

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