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ORIGINAL RESEARCH PAPER

The effects of soil conditions and crop types on diversity of weed communities

Maria Ługowska[1]*, Zbigniew Pawlonka[2], Janina Skrzyczyńska[1]

[1] Department of Agricultural Ecology, University of Natural Sciences and Humanities, Prusa 14, 08-110 Siedlce, Poland
[2] Department of Agriculture, State Higher School of Vocational Education in Ciechanów, Narutowicza 9, 06-400 Ciechanów, Poland

* Corresponding author. Email: maria.lugowska@uph.edu.pl

Abstract

The paper presents the diversity of weed communities growing in different crops (winter cereals, spring cereals, and tuber plants) and in diverse soil conditions. To determine weed diversity, phytosociological relevés were made. Simpson's index of dominance and the Shannon index of biodiversity for weed communities in different crops growing in different soil conditions were calculated and compared. The highest values of the Shannon index and the lowest values of Simspon's index of dominance were obtained for weed communities noted on compacted and semi-compacted soil with the following granulometric composition: silty loam with underlying sand at a depth of 100 cm, heavy silty sandy loam, silt with underlying sand at a depth of 50 cm, and silt with underlying sand at a depth of 100 cm. The highest index of dominance and low species diversity were determined for weed communities in light soils. The Shannon index of biodiversity was moderately positively correlated with soil pH and granulometric composition. Simpson's index of dominance was moderately negatively correlated with granulometric composition and was weakly correlated with soil pH.

Keywords

soil granulometric composition; ecological indices; weeds; arable crops

Introduction

Human activity has contributed to the development of weed communities in agricultural crops. The growing demand for agricultural products induces permanent and continuous changes and increases anthropogenic pressure [1]. The knowledge of transformation in weed communities makes it possible to select appropriate methods of weed control. Appropriate weed control can reduce production costs and improve yield quantity and quality. The harmful effect of weeds on the crop plant is usually due to one or two species, which form dense populations. Weed species with lower density are less dangerous [2–4]. In particular, intensive farming leads to habitat destruction and impacts negatively weed biodiversity in crops [5,6].

Currently, dynamic changes in weed communities are noted in agricultural crops. The changes are due to the modification and advancement in agricultural technologies, i.e., simplified crop rotation management, intensive mineral fertilization, increased herbicide application, or advanced development in plant breeding. Moreover, land abandonment or field consolidation is a common trend. These changes impact the spread of certain weed species, which extend the range of occurrence and move to new habitats as well as increase in population size and density. The rapid increase in weed biotypes resistant to several classes of herbicides is also noted [7–11].

All forms of crop production intensification have a negative impact on ecosystems [12]. Growing human pressure on nature results in a dramatic decrease in biodiversity, in particular in agricultural ecosystems, which belong to the least stable. In particular, species with a narrow ecological amplitude and archeophytes are in danger [13–16].

Agricultural biodiversity involves the richness and abundance of weed species associated with crops, the existence of other organisms as well as proportions noted between different species. Diversity indices are widely used to study biodiversity in agricultural crops. The indices are also used to determine changes in segetal communities [17–19].

The objective of our study was to compare values of Simpson's index of dominance (*D*) and the Shannon index of biodiversity (*H'*) for weed species associated with different crops and different soil types in the Middle Vistula River Valley, Poland.

Material and methods

Field studies in the area of the Middle Vistula River Valley were conducted from 2003 to 2008. Phytosociological observations were carried out in winter and spring cereal crops as well as in tuber crops cultivated on the following soil types: Bw – leached brown soils (pl – sand; ps.pl – slightly loamy sands with underlying sand at a depth of 50 cm; pgl:gl – loamy sands with underlying very sandy loam at a depth of 100 cm); Dz – degraded black earths (silts with underlying sand at a depth of 50 cm); F – river alluvial soils (ps:pl – slightly loamy sands with underlying sand at a depth of 100 cm; pglp – light silty loamy sands; płz:pl – silt with underlying sand at a depth of 100 cm; pgmp – heavy silty loamy sands; płz – silt; płi:pl – silty loams with underlying sand at a depth of 100 cm).

Agricultural soil maps of 1:5000 scale were used to determine the soil types. Additionally, the soil pH was measured by means of the colorimetric method using a Hellige pH meter. The Braun-Blanquet method was applied to make relevés. In total, 900 relevés were analyzed in the study.

The biodiversity in plant communities was assessed using the following formulas:

- Shannon index of biodiversity – H' [20]: $H' = -\Sigma(p_i \ln p_i)$
- Simpson's index of dominance – D [21]: $D = \Sigma p_i^2$

where: p_i is the proportion (n/N) of individuals of one particular species (n) divided by the total number of individuals (N), ln is the natural log, Σ is the sum of the calculations. The indices of biodiversity and dominance were determined using a modified 6-point Braun-Blanquet cover scale [22]: "+" – 0.5%; 1 – 5%; 2 – 17.5%; 3 – 37.7%; 4 – 62.5%; 5 – 87.5%.

In order to test differences between means, one-way analysis of variance (ANOVA) was used. Post hoc comparison of means was determined using Tukey's test, with 0.05 level of significance. Additionally, correlation coefficients were calculated to measure the correlation between the calculated indices and the granulometric soil composition and the soil pH. The Statistica 10 software (Statsoft, Krakow, Poland) was used to do all calculations.

Results

A higher value of the biodiversity index (H') was calculated for compacted soil than for light soil as well as for crops cereal than for tuber crops (Fig. 1). Moreover, the value of H' index was higher for winter cereals than for spring cereal crops, with the exception of the most compact soils where it was higher for spring cereal crops than for winter cereals.

The highest average value of the biodiversity index was noted for weed communities in spring and winter cereals ($H' = 1.926$ and $H' = 1.823$, respectively) grown on the

F płi:pl soil and for tuber crops ($H' = 1.665$) cultivated on the F pgmp soil (Fig. 1). By contrast, the least biodiversity was noted in weed communities growing on the following light soils: Bw pl with tuber crops ($H' = 1.084$), F ps:pl with winter cereals ($H' = 1.113$), and Bw pl with spring cereals ($H' = 1.132$) (Fig. 1). Statistical analysis revealed significant differences in weed biodiversity between crops ($F = 7.61$, $p < 0.0001$ for H' index). By contrast, no significant differences were found if the same crops were compared ($F = 1.48$, $p = 0.226$ for H' index).

Simpson's index of dominance (D) was significantly higher for weed communities observed on light soils compared to weed communities found on heavy soils. In several cases, higher values of the dominance index were found in weed communities established in spring cereal crops than in winter cereal crops. The highest dominance index was found for weed communities growing in spring and winter cereals on leached brown soils developed from sands (Bw pl) ($D = 0.538$ and 0.692, respectively; Fig. 2).

Dominance index values for the studied crops on most soils were affected by a mass occurrence of *Apera spica-venti*, *Matricaria maritima* subsp. *inodora*, *Centaurea cyanus*, *Vicia tetrasperma*, *Vicia hirsuta*, and *Galium aparine* (on more fertile soils) in

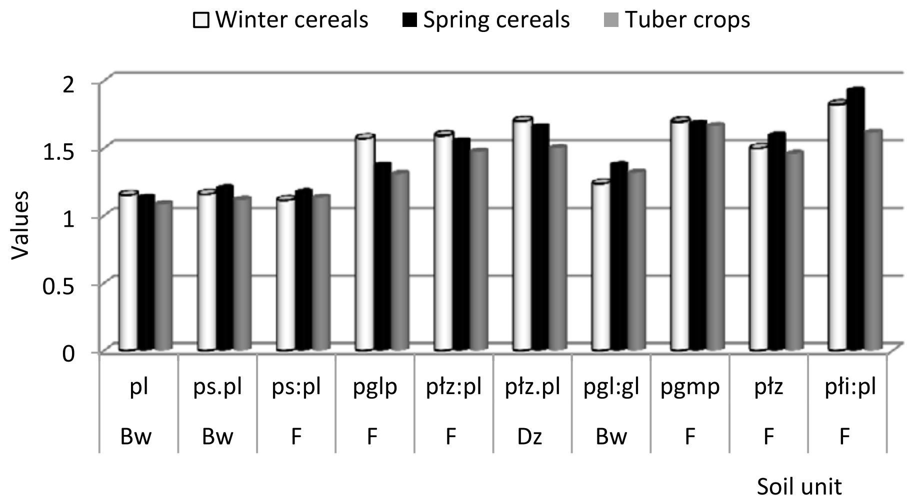

Fig. 1 Average values of the biodiversity index (H') calculated for crops grown in different soil conditions.

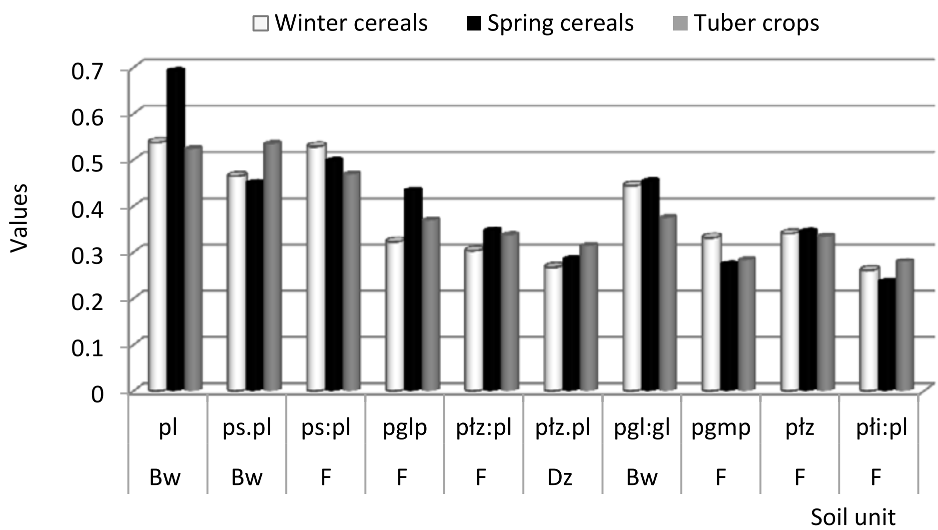

Fig. 2 Average values of the index of dominance (D) for crop groups and different soil conditions.

winter crops, and *Chenopodium album*, *Apera spica-venti*, and *Avena fatua* in spring cereals. Unlike the index of biodiversity, the index of dominance was higher for many weed communities observed in tuber crops (on the ps.pl, płz.pl, and płi:pl soils) than for those growing in cereals. The highest dominance index values were obtained for weed communities developing on brown soils formed on medium sands with underlying loose sand (Bw ps.pl) ($D = 0.534$; Fig. 2). The values of the index of dominance calculated for weed communities were affected by a mass occurrence of *Echinochloa crus-galli*, *Chenopodium album*, *Setaria pumila*, *Galinsoga parviflora*, or *Digitaria ischaemum* on light soils. Much lower values of the dominance index were obtained for weed communities observed on compacted soils. The lowest dominance index was found for weed communities growing on alluvial soils formed from silty loam with underlying sand (F płi:pl). The Simpson's index values determined for weed communities were as follows: $D = 0.261$ – in winter cereals, $D = 0.236$ – in spring cereals, and $D = 0.279$ – in tuber crops (Fig. 2).

The values of both the index of biodiversity (H': $F = 114.89$, $p < 0.001$) and of the index of dominance (D: $F = 110.92$, $p < 0.001$) significantly differed for weed communities found in different types of soil. Similarly, the values of both H' and D indices were significantly different for weed communities found on soils with a different granulometric composition (H': $F = 76.21$, $p < 0.001$ and D: $F = 58.36$, $p < 0.001$; Fig. 3). The highest average values of the Shannon index (H') were noted for alluvial soils with the granulometric composition płi:pl or pgmp, while for leached brown soils with the granulometric composition płz.pl. By contrast, the lowest values of the Shannon index were obtained for light soils (Bw pl, Bw pl.pl, F ps:pl; Fig. 3a).

A similar dependence was observed for Simpson's index of dominance (Fig. 3b). Moreover, the index of biodiversity was moderately positively correlated with soil pH and soil granulometric composition (Fig. 4). Simpson's index of dominance was moderately negatively correlated with granulometric composition, and the correlation with soil pH was weak (Fig. 5).

Discussion

The composition and structure of agricultural phytocenoses are affected by both anthropogenic and natural factors. Soil and its fertility, water status, climate, and land topography are natural factors which exert the greatest impact on the diversity of segetal weed communities that accompany cultivated crop plants [23]. Alluvial soils with sediments left by flowing water are typical for river banks. These soils are typically made up by a variety of sediments (fine particles of clay and larger particles of sand and gravel).

Many publications on changes in segetal communities frequently focus on the effects of agriculture intensification on the impoverishment of the diversity of segetal weeds [5,6,24]. Application of herbicides and mineral fertilizers impacts weed resistance and leads to a steady increase in the density of weed populations [25–29]. The dominance of weed species with high nutrient uptake is frequently noted [30]. Apart from the impact of chemicals, the weed composition in crops is affected by the type of crop grown and tillage methods [31–33]. Both indices (H', D) calculated for weed communities were higher in cereal crops than in tuber crops. Significant differences in H' and D values noted between crops are in agreement with Rzymowska et al. [17] who noted the highest biodiversity in winter cereals. In our study, significant differences in weed biodiversity were established only between spring and winter cereal crops. No differences were found between spring cereals and tuber crops. This finding is opposite to Lososowa et al. [16]; studying weeds in Slovakia and the Czech Republic, they found that weed biodiversity was higher in cereals than in tuber crops. Fried et al. [34] noticed that crop type exerts more influence on weed composition than on species richness.

According to Lososova et al. [16], the species richness and biodiversity of weeds is low in tuber crops and thus the composition of weed species is similar. Dominance of nitrophilous and thermophilous species (*Echinochloa crus-galli*, *Chenopodium album*, *Galinsoga parviflora*, *Setaria* sp.) is often observed in tuber crops [16,35,36]. A similar

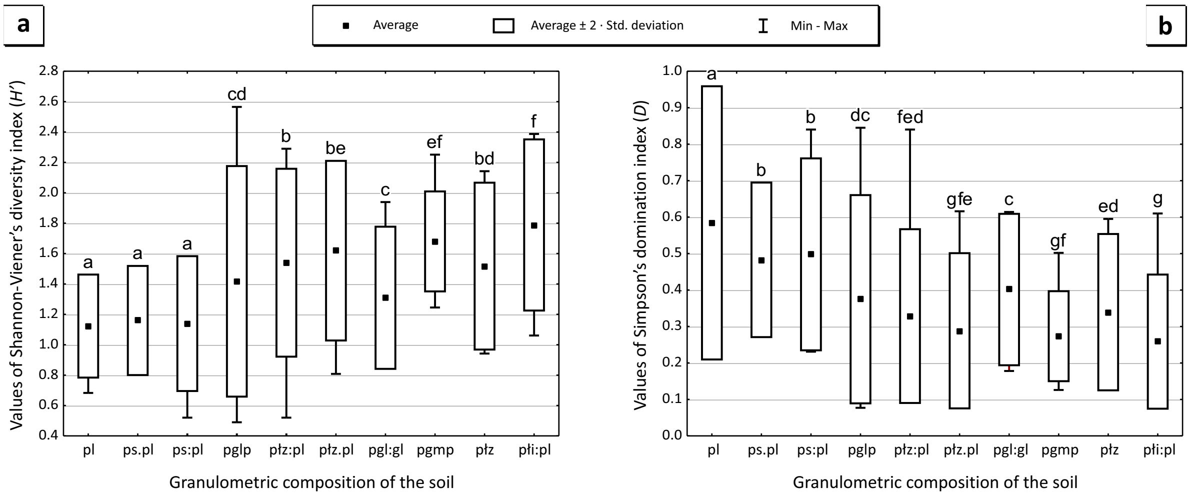

Fig. 3 Values of the Shannon index of biodiversity (H') and Simpson's index of dominance (D) in relation to the granulometric composition of the soil. Average values accompanied by different letters differ significantly at $p < 0.05$.

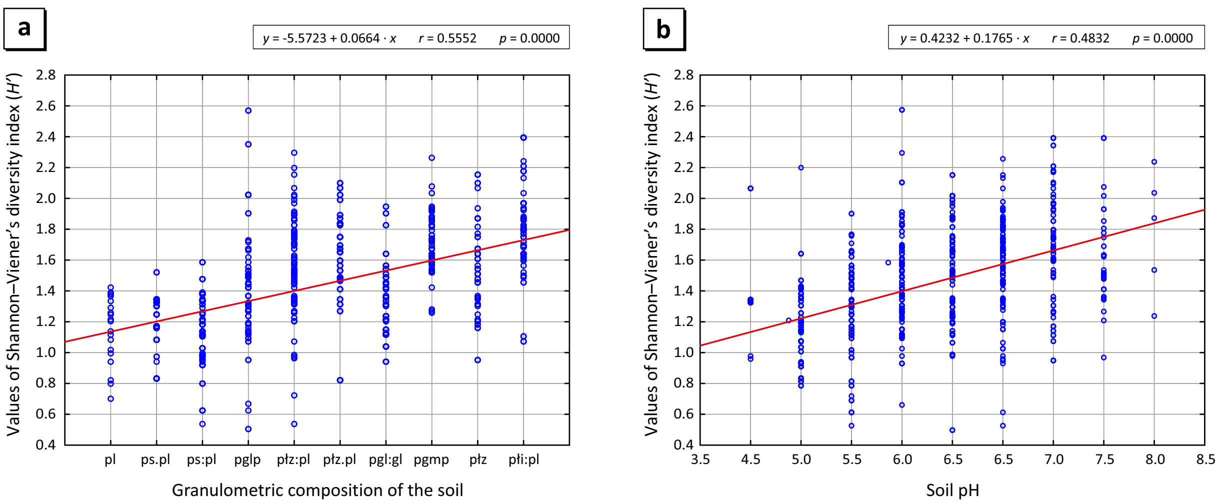

Fig. 4 The correlation of the Shannon index of biodiversity (H') with soil granulometric composition and pH.

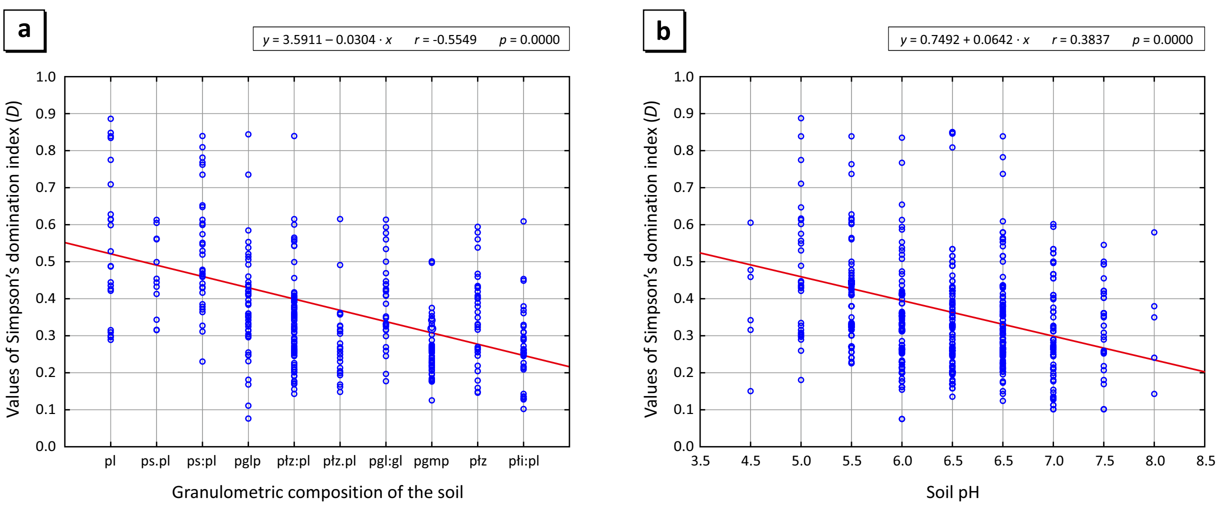

Fig. 5 The correlation of Simpson's index of dominance (D) with soil granulometric composition and pH.

relationship was found in the present study. Among the species, the following were very common in winter cereals and associated with most soil types: *Apera spica-venti*, *Matricaria maritima* subsp. *inodora*, *Centaurea cyanus*, or *Galium aparine*. The latter one requires rich soils and has affected the values of the index of dominance. It is often pointed out that weed species are capable to adapt to reduced tillage methods and are more competitive than crops [7,37]. Furthermore, weeds become resistant to herbicides from different groups [28,38]. In our study, *Chenopodium album*, *Avena fatua*, and acidophilous species growing on light soils were common in spring cereals. *Avena fatua* is resistant to herbicides and therefore this species is ubiquitous in cultivated crops [39]. In south and central Finland, *Chenopodium album* has been identified to have a strongly negative effect on spring cereals [40].

The high values of the biodiversity index for weed communities developed on semi-compacted and compacted soils were due to the location of the study area in the neighborhood of the Vistula River. Grassland communities and small-area fields with fairly traditional farming management are present nearby. The effect of neighboring habitats on plant species biodiversity in arable crops was stressed by José-Maria et al. [41] and Fried et al. [34]. Additionally, the species richness in phytocenosis depends on soil conditions and is usually greater on fertile soil [4,42,43]. Our study has confirmed this relationship. The highest values of the Shannon index were obtained for communities growing on good soil formed on silty loam (płi), while the lowest H' index was found for weed communities observed on infertile soils developed from sands (pl) and slightly loamy sands (ps). In many studies (e.g., [34,44]), soil compaction, pH, and nutrient content were indicated as important soil properties which affect the species richness, composition, and diversity of weed phytocenoses. According to Cimalová and Lososová [45], soil type and soil pH have less effect on the composition of segetal species than crop type or climatic conditions. Contrary to this opinion, in the present study the values of the biodiversity index increased as soil pH increased in the area of the Middle Vistula River Valley. A similar relationship was reported by Fried et al. [34], but in their study the biodiversity of communities declined when the soil pH exceeded 7.7.

Conclusions

- The most diverse weed communities were found in winter and spring cereal crops, while the lowest values of the biodiversity index were noted in tuber crops. There were significant differences in the index H' values calculated for the studied crops.
- Irrespective of the crop type, the index of dominance (D) had the highest values for weed communities on light soils compared to heavy soils. No significant differences between the values of this index were found for plant communities developed in the crop types.
- Simpson's index of dominance significantly differed for weed communities depending on the soil type and the soil structure. The highest average values of the index of biodiversity were obtained for weed communities on compacted heavy soils, whereas the highest values of the index of dominance for weed communities on soil developed from light sands or slightly loamy sands.
- The Shannon index was moderately positively correlated with soil pH and granulometric composition. Simpson's index was moderately negatively associated with soil granulometric composition and weakly correlated with soil pH.

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Wpływ rośliny uprawnej i warunków glebowych na bioróżnorodność agrofitocenoz

Streszczenie

W pracy przedstawiono wyniki badań dotyczące bioróżnorodności zbiorowisk chwastów wykształcających się w uprawach rolniczych na tle zróżnicowania siedliskowego. Określano wpływ typu uprawy i warunków glebowych na wartość wybranych wskaźników ekologicznych wyliczonych na podstawie pokrycia chwastów. Najwyższe wartości indeks bioróżnorodności osiągał na glebach zwięzłych i średniozwięzłych o składzie granulometrycznym płi:pl, pgmp, płz.pl, płz:pl, analogicznie na tych glebach indeks dominacji Simpsona przyjmował najniższe wartości. Gleby lekkie charakteryzowały się najwyższą dominacją i jednocześnie wykształcały się na nich najuboższe zbiorowiska. Indeks bioróżnorodności był dodatnio umiarkowanie skorelowany z pH gleby i składem granulometrycznym. Indeks dominacji Simpsona był ujemnie umiarkowanie skorelowany ze składem granulometrycznym, natomiast w przypadku pH gleby korelacja była słaba.