

## Article

# Impact of Conservation Tillage Technologies on the Biological Relevance of Weeds

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**Abstract:** Limited tillage provides a number of benefits, but a question remains how it affects weed community and biodiversity evolving from the weed community. Our field experiment was established in the cadastral area of Branišovice (South Moravian Region, Czech Republic). Three different tillage technologies were used in this field experiment: conventional tillage, minimum tillage, and no-tillage technology. In 2001–2004, infestation by weeds was evaluated in the stands of spring barley, winter wheat grown after a dicot pre-crop (rape, soybean), in the stands of wheat grown after wheat, and in stands of maize. The recorded weed species were divided according to the criteria of biological relevance. Based on the results of the four-year field experiment, it is possible to state that tillage technologies have only a limited influence on the intensity of weeding but substantially alter the species spectrum of weeds. Weed vegetation in the no-tillage variant exhibits higher values of biological relevance, which allows a higher occurrence of weed-dependent species of organisms. Weed vegetation in the minimum soil tillage variant has the lowest biological relevance values, which limits the occurrence of weed-dependent organisms. Alterations in weeding caused by different tillage technologies are part of the process of vegetation microevolution in the agricultural landscape.

**Keywords:** weed vegetation; soil tillage; conservation tillage; biodiversity



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## 1. Introduction

Land degradation is one of the most pressing challenges for global food security [1]. Causes of degradation lie in intensive agricultural activities, which include excessive use of synthetic fertilizers and pesticides, crop monoculture, and intensive soil tillage [2].

For thousands of years, soil cultivation has been used to prepare the seed bed and to control weeds [3,4]. Currently, reduced tillage, or minimum tillage, is promoted as an alternative to the traditional soil tillage. Reduced tillage improves soil quality and mitigates greenhouse gas emissions, through increased soil carbon sequestration and fuel consumption of conservation tillage [5,6]. The use of conservation tillage is increasing worldwide [7] because of its benefits for soil and water conservation [8,9], as well as for reducing fuel consumption and labor costs [10]. In the United States, 37% of arable land is reported to be no-till, and 35% is conservation tillage [11], while globally, 11% of cropland is no-till [12].

Despite the benefits, many farmers around the world have not adopted conservation agriculture practices yet [13,14]. A commonly cited concern is the difficulty of weed control in no-till technologies, especially in locations where resistant weed populations are predominant [15,16]. Minimum tillage induces a response in the weed community composition and increases weed infestation, leading to greater reliance on herbicides compared to conventional tillage systems [4,17,18], but increased weed infestation is not

always the case [19,20]. According to Nichols et al. [16], field studies of conservation tillage practices often provide inconsistent results, although most studies conclude that no-till practices in monocultures lead to the highest weed density, which does not necessarily result in reduced yields [16,21]. However, there is a considerable variation in the effect of different tillage practices on weed density in different studies [22–25]. According to Cooper et al. [21], benefits of conservation tillage may outweigh any increase in weed pressure, as the increased weed density in conservation tillage systems is not consistently associated with the reduced crop yield.

Cropland weed diversity is key to maintaining biodiversity and providing ecosystem services in agroecosystems [26]. In addition, weed communities can have specific effects on the composition of the soil microbial community. Some studies have shown substantial effects of weed species (e.g., *Centaurea maculosa*) on the abundance of soil microbial functional groups and community composition [27–29]. Soil tillage can change the conditions for both weeds and microorganisms in the soil. Tillage stimulates the germination of weed seeds [30,31] and different tillage systems affect the accumulation and distribution of weed seeds in different soil layers differently [32,33]. Tillage is a significant factor influencing soil microbial communities [34], but it also has a strong negative impact on weeds and, subsequently, also on the communities of specific soil microbial functional groups [35]. However, weeds are also important for other organisms. Some authors suggest that the decline in many species of insects and birds on farmland is related to changes in agricultural practices adversely affecting weeds [36]. The abundance of weeds and the intensity of weed infestation on arable land have drastically decreased in recent decades throughout Europe [37,38].

Minimum tillage is also part of conservation agriculture (CA), which is defined as a combination of three principles: minimal soil disturbance, permanent organic soil cover, and species diversification [39]. In addition to reducing costs, CA prevents some threats such as soil erosion [40–42] and improves several ecosystem services, namely, soil physical and chemical properties, soil organic carbon (SOC), and also biodiversity [43,44].

Conservation tillage brings a number of benefits; the question is, what is the impact on the weed community and weed-related biodiversity? According to our hypothesis, conservation tillage will increase the biodiversity of field weeds. Sub-goals leading to the confirmation of our hypothesis are to (i) determine the effect of different tillage on the species spectrum of weeds (ii); determine the effect of different tillage methods on the intensity of weed infestation (iii); determine the effect of tillage on the biological relevance of weed vegetation. Understanding the relationship between tillage and the biological relevance of weeds will facilitate better prediction of changes in agricultural landscape biodiversity.

## 2. Materials and Methods

The experimental plot is located in the cadastral area of Branišovice municipality of the South Moravian Region, Czech Republic. The terrain is mostly flat to slightly sloping. Average altitude is approximately 205 m above sea level. The area of interest falls into the Dyje River basin. The location belongs to the very warm and dry climatic region of the Czech Republic. Long-term average annual precipitation is 452 mm, the long-term average temperature is 9.4 °C. Soil types are chernozem and clay loam soil on the experimental plot [45–47].

The field semi-operational experiment was established in the autumn of 2000. The balancing crop before establishing the experiment was winter wheat (*Triticum aestivum*). The size of plots was 50 m × 36 m, individual plots were separated from each other by ten-meter strips.

The experimental crops were grown in a five-season crop rotation, in the following sequence: winter rapeseed (later soybean), winter wheat, winter wheat, corn for grain, spring barley. Due to substantial damage of the winter canola stand by voles and consequences of winter at the turn of years 2002 to 2004, the crop was eliminated and replaced with soybeans.

Three different tillage technologies were used for each grown crop in this field experiment. Tillage variants were:

(i) Conventional tillage (CT): composed of the following work operations: under-sowing (carried out with a Kverneland subsoiler to a depth of approximately 0.1 m), ploughing up to 0.22 m (Lemken rotary double-sided plough, ploughing depth varied  $\pm 10\%$ ), pre-sowing soil preparation and sowing with a sowing combination (seeding combination accord);

(ii) Minimum soil tillage (MT): the soil was tilled up to a depth of ca 0.08 m. It consisted of the following work operations: mulching after pre-crop harvesting (carried out with a Kverneland subsoiler), application of total herbicide on emerged weeds, shallow tillage (made with Kverneland chisel subsoiler), and sowing with sowing combinations (carried out seeding combination accord);

(iii) No tillage (NT): tillage was skipped, a total herbicide was applied to the growing weeds after the pre-crop was harvested, and the crops were sown with a special direct seeding machine (carried out seeding combination accord).

In 2001–2004, weed infestation was evaluated in the stands of spring barley, winter wheat after a dicot pre-crop (rape, soybean), in the stands of wheat after wheat, and in the stands of corn. Weeds were evaluated using a numerical method. The number of weed individuals was determined on an area of 1 m<sup>2</sup>, in 25 repetitions for each variant, crop, and year. The evaluation was made before the application of herbicides. The taxonomic nomenclature of plants was according to Kaplan et al. [48]. An overview of the herbicides applied is given in Table 1.

**Table 1.** Summary of herbicides applied in the crops monitored.

| Crop                                     | After Harvesting the Pre-Crops      | Crops Prior to Sowing                                                              | After Sowing and Crop Emergence                                             |
|------------------------------------------|-------------------------------------|------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| Winter wheat (pre-crop: winter rapeseed) | Roundup Forte ( <i>glyphosate</i> ) | -                                                                                  | Aurora ( <i>carfentrazone-ethyl</i> ), Mustang ( <i>florasulam</i> ; 2,4-D) |
| Winter wheat (pre-crop: winter wheat)    | Roundup Forte ( <i>glyphosate</i> ) | -                                                                                  | Aurora ( <i>carfentrazone-ethyl</i> ), Mustang ( <i>florasulam</i> ; 2,4-D) |
| Corn for grain                           | Roundup Forte ( <i>glyphosate</i> ) | Guardian ( <i>acetochlor</i> , <i>furilazole</i> ), Atrazin ( <i>Metolachlor</i> ) | Cobra ( <i>lactofen</i> ), Granstar ( <i>tribenuron methyl</i> )            |
| Spring barley                            | -                                   | -                                                                                  | Aurora ( <i>carfentrazone-ethyl</i> ), Mustang ( <i>florasulam</i> ; 2,4-D) |

The recorded plant species were classified based on the database of Tyler et al. [49] according to criteria for biological relevance (biodiversity relevance). Biological relevance is defined for each species as a number of other organisms that depend on that species or that use it as a food source, substrate, shelter, or reproduction site. The logarithmic scale of biological relevance for the recorded plant species is shown in Table 2.

**Table 2.** Biological relevance of found weed species.

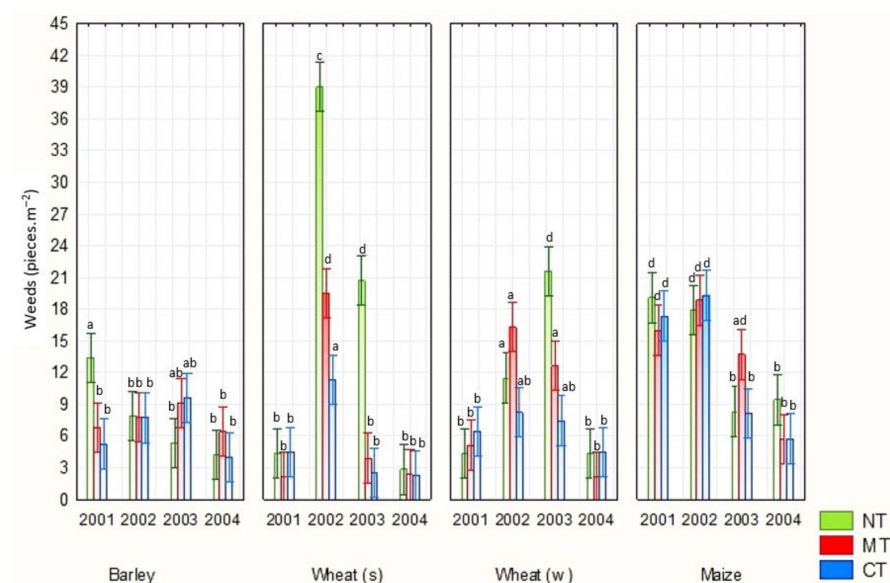
| Labeling | Number of Species Dependent on Plants |
|----------|---------------------------------------|
| BR1      | <6                                    |
| BR2      | 6–12                                  |
| BR3      | 13–24                                 |
| BR4      | 25–50                                 |
| BR5      | 51–100                                |
| BR6      | 101–200                               |

The numbers of weed individuals of all species were statistically evaluated by multifactorial ANOVA and Fischer's LSD test. All data were subjected to homogeneity and normality tests. Data were not transformed prior to the statistical analysis.

The representation of individual weed species in the respective tillage variants was processed by the multivariate analysis of ecological data. The selection of the optimal analysis depended on the length of the gradient, determined by the detrended correspondence analysis (DCA), which was followed by the canonical correspondence analysis (CCA) was used. Statistical significance was determined using the Monte Carlo test where 999 permutations were calculated. The data were processed using the Canoco 5 computer program [50].

### 3. Results

During the four-year monitoring, 51 weed taxa were found. The average number of weed individuals was 9.3 per m<sup>2</sup> in the CT tillage variant, 7.8 per m<sup>2</sup> in the MT variant, and 12.1 per m<sup>2</sup> in the NT variant. Results of the statistical evaluation of weed infestation intensity are shown in Figure 1. Differences in the number of individuals between most variants are not statistically significant. A statistically significant difference was recorded in 2002 in the NT variant for wheat (s) grown after a dicotyledonous pre-crop, where weeding was the highest. Within the cultivated crops and tillage variants, statistically significant differences are rare. A statistically significant difference was detected in the no-tillage variant where higher weeding occurred.



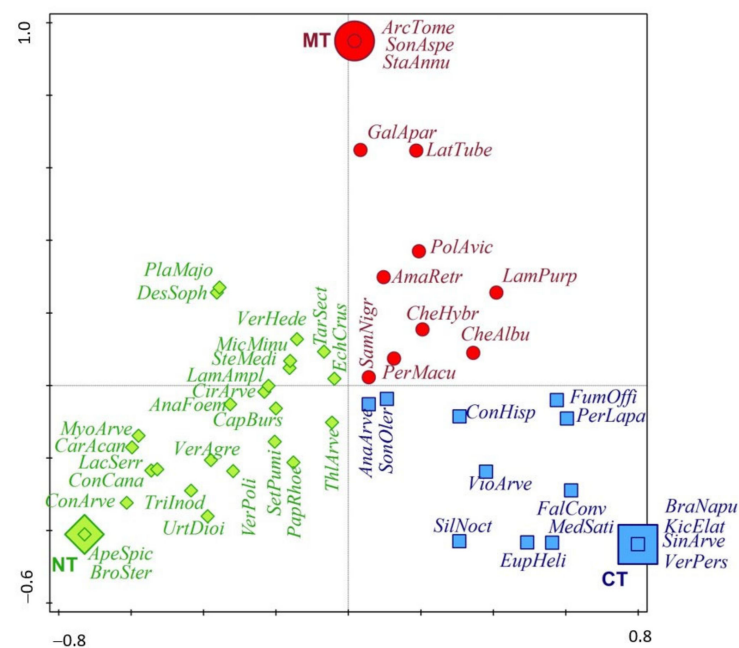
**Figure 1.** Intensity of weeding in the observed tillage variants, in the cultivated crops, and in the observed years. The results represent the mean of 25 biological replicates  $\pm$  SE. Identical letters express statistical non-significance between the variants, different letters express statistical significance at a significance level  $p = 0.05$  (Fisher LSD test). The plot shows the mean, whiskers represent the standard error, values with different letters (a, b, c, d) differ significantly. Variants of tillage technologies: CT—conventional tillage; MT—minimum tillage; NT—no tillage.

Based on the evaluation of biological relevance, it is evident that tillage creates favorable conditions for the growth of weed species from groups BR3 and BR4. The range of weed-dependent species varies between 13–50 species. Results of the evaluation of biological relevance are presented in Table 3. Weeds in the NT variant have the highest values of biological relevance and, thus, create a higher potential for the growth of other types of species on arable land. On the contrary, the weed vegetation in the MT variant has the lowest values of biological relevance.

**Table 3.** Groups of weeds according to the biological relevance of tillage variants.

| Title 1           | Soil Tillage Variant (Pieces.m <sup>-2</sup> ) |     |     |
|-------------------|------------------------------------------------|-----|-----|
|                   | CT                                             | MT  | NT  |
| BR1               | 0.0                                            | 0.0 | 0.0 |
| BR2               | 0.1                                            | 0.1 | 0.3 |
| BR3               | 5.6                                            | 3.3 | 5.4 |
| BR4               | 1.3                                            | 1.1 | 5.0 |
| BR5               | 1.8                                            | 2.0 | 1.0 |
| BR6               | 0.0                                            | 0.0 | 0.0 |
| BR unknown values | 0.5                                            | 1.2 | 0.6 |

The results of the CCA analysis, which evaluates the representation of individual weed taxa in the different tillage variants, are significant at the significance level  $\alpha = 0.001$  for all canonical axes. A graphical representation of the results of the CCA analysis is presented in Figure 2. Based on the CCA analysis, the identified weed taxa can be divided into three groups. The division of taxa into groups according to the CCA analysis is shown in Table 4. The first group of species occurs mainly in the CT variant. The second group of species occurs mainly in the MT variant. The third group of species occurs mainly in the NT variant.

**Figure 2.** Relationship between identified weed taxa and tillage—result of CCA analysis (total explained variability = 11.8%; F-ratio = 15.9;  $p$ -value = 0.001).**Table 4.** Groups of plant species according to CCA analysis.

| Soil Tillage | Weed Groups    | Weed Taxa                                                                                                                                                                       |
|--------------|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| CT           | Spring weeds   | <i>Anagallis arvensis</i> (AnaArve); <i>Fallopia convolvulus</i> (FalConv); <i>Silene noctiflora</i> (SilNoct); <i>Sinapis arvensis</i> (SinArve)                               |
|              | Summer weeds   | <i>Euphorbia helioscopia</i> (EupHeli); <i>Kickxia elatine</i> (KicElat); <i>Persicaria lapathifolia</i> (PerLapa); <i>Sonchus oleraceus</i> (SonOler)                          |
|              | Winter weeds   | <i>Brassica napus</i> (BraNapu); <i>Consolida hispanica</i> (ConHisp); <i>Fumaria officinalis</i> (FumOffi), <i>Veronica persica</i> (VerPers); <i>Viola arvensis</i> (VioArve) |
|              | Perennial weed | <i>Medicago sativa</i> (MedSati)                                                                                                                                                |

Table 4. Cont.

| Soil Tillage | Weed Groups    | Weed Taxa                                                                                                                                                                                                                                                                                                                                  |
|--------------|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| MT           | Spring weeds   | <i>Polygonum aviculare</i> (PolAvic)                                                                                                                                                                                                                                                                                                       |
|              | Summer weeds   | <i>Amaranthus retroflexus</i> (AmaRetr); <i>Chenopodium album</i> (CheAlbu); <i>Chenopodium hybridum</i> (CheHybr); <i>Persicaria maculosa</i> (PerMacu); <i>Stachys annuam</i> (StaAnnu)                                                                                                                                                  |
|              | Winter weeds   | <i>Galium aparine</i> (GalApar); <i>Lamium purpureum</i> (LamPurp)                                                                                                                                                                                                                                                                         |
|              | Perennial weed | <i>Arctium tomentosum</i> (ArcTome); <i>Lathyrus tuberosus</i> (LatTube); <i>Sambucus nigra</i> (SamNigr); <i>Sonchus asper</i> (SonAspe)                                                                                                                                                                                                  |
| NT           | Spring weeds   | <i>Anagallis foemina</i> (AnaFoem)                                                                                                                                                                                                                                                                                                         |
|              | Summer weeds   | <i>Echinochloa crus-galli</i> (EchCrus); <i>Microrrhinum minus</i> (MicMinu); <i>Setaria pumila</i> (SetPumi); <i>Apera spica-venti</i> (ApeSpic); <i>Bromus sterilis</i> (BroSter); <i>Capsella bursa-pastoris</i> (CapBurs); <i>Conyza canadensis</i> (ConCana); <i>Descurainia sophia</i> (DesSoph); <i>Lactuca serriola</i> (LacSerr); |
|              | Winter weeds   | <i>Lamium amplexicaule</i> (LamAmpl); <i>Myosotis arvensis</i> (MyoArve); <i>Papaver rhoeas</i> (PapRhoe); <i>Stellaria media</i> (SteMedi); <i>Thlaspi arvense</i> (ThlArve); <i>Tripleurospermum inodorum</i> (TriInod); <i>Veronica agrestis</i> (VerAgre); <i>Veronica hederifolia</i> (VerHede); <i>Veronica polita</i> (VerPoli)     |
|              | Perennial weed | <i>Carduus acanthoides</i> (CarAcan); <i>Cirsium arvense</i> (CirArve); <i>Convolvulus arvensis</i> (ConArve); <i>Plantago major</i> (PlaMajo); <i>Taraxacum sect. Taraxacum</i> (TarSect); <i>Urtica dioica</i> (UrtDioi)                                                                                                                 |

#### 4. Discussion

Soil tillage has a statistically inconclusive or only a limited effect on the intensity of weed infestation of the monitored crops. These results are consistent with a number of studies that report inconclusive effects of different tillage systems on weed infestation [26,51]. Field studies dealing with minimum tillage practices often provide inconsistent results. Nevertheless, most studies conclude that no-till practices result in the highest intensity of weeds [16,21,22,24].

The results show that NT tillage significantly increases weed infestation in some years, thus, creating a precondition for a higher weed infestation. It shows the largest differences between maximum and minimum weeding values. Findings of some research studies that indicate a higher weed infestation of crops grown under NT system conditions support this claim [52–55]. According to Benech-Arnold et al. [32] and Torreson et al. [56], conventional tillage distributes the weed seeds evenly within the tilled soil layer, while minimum tillage concentrates the seeds in the upper soil layer from where they can germinate readily and at higher rates. The number of weeds is also significantly affected by the crop and weed species [57]. In the case of reduced technologies, the action of inhibitory substances has been proven, which can manifest itself in the limited germination of some species [58].

Based on the results, soil tillage significantly alters the species spectrum of weeds and the biological relevance of weed vegetation. Several studies draw attention to the influence of the species spectrum of weeds by the used tillage system [52,59,60].

The drying out of topsoil, which, according to Singh et al. [61], is faster for reduced systems, or the limited soil degradation, which was monitored for reduced technologies by Vakali et al. [62] and Siegrist et al. [63], may be the cause of the change in the weed species spectrum. Conventional tillage incorporates the weed seeds into greater depths, where their germination is inhibited, which results in a change in the species composition [64]. NT leaves the weed seeds on the surface; some species germinate better from the soil surface [65]. These changes in the soil environment can reflect in the species spectrum of weeds.

The results also demonstrate that NT creates more favorable conditions for grassy weed species, anemochorous species, and for species belonging to the group of winter and perennial weeds. Bilalis et al. [66] point out an increase in the perennial species (mainly *Convolvulus arvensis*).

Weed vegetation with the use of NT has a higher biological relevance, which contributes to the preservation and support of agricultural landscape biodiversity. Weeds provide a range of resources (pollen, nectar, fruits, seeds) that are part of the food for a variety of insects, birds, and mammals [67–70]. Weeds are important as a source of

food and shelter for many natural enemies (parasitoids, predators) on pests of cultivated crops [71,72].

The MT variant creates more suitable conditions, especially for species from the group of summer weeds. A higher representation of summer weeds (*Amaranthus retroflexus*) was also observed by Nakamoto et al. [73], however, their representation varied between the observed years. MT weed vegetation has a lower biological relevance than the other monitored variants. MT tillage contributes only to a limited extent to the stabilization of biodiversity in the agricultural landscape.

An interesting question that would deserve further study is the interaction of tillage, weeds, and soil microorganisms. Studies comparing the effects of deep plowing and reduced tillage point to an increase in soil biological activity if the soil is not turned. There has been an increasing amount of information on the interaction between weeds (e.g., *Chenopodium album*, *Abutilon theophrasti*, *Amaranthus retroflexus*, *Thlaspi arvense*, *Setaria viridis*) and microbial communities in the soil [35]. The unique influence of weeds reflect in the composition of soil microorganisms, as well as in the representation of specific functional groups of microorganisms [27]. However, the effect of weeds on soil microbial communities is not consistent [27,29]. Moreover, changes in the microbial community structure increase the weed species' competitiveness [29].

No-till farming is a core component of CA and is considered preferable to conventional tillage. Reduced production costs, the ease of sowing seeds and fertilizer application, higher and stable production, soil erosion control, and higher efficiency of nutrient use are some of the advantages of minimum tillage [13]. However, there are also agronomic and ecological disadvantages associated with the no-tillage farming [74], which include soil compaction [75], unavailability of nutrients [76], and especially weed control [16]. Cooper et al. [22] claim that agronomic benefits of minimum tillage may outweigh increases in weed pressure, as the increased weed density is not consistently associated with reduced crop yield. On the other hand, Ali et al. [77] point out that the expanding popularity of MT and NT raises problems with the control of resistant weeds. The increased need for herbicide applications due to the increased weed infestation, frequently occurring with minimum tillage [78], causes negative impacts on the whole ecosystem.

## 5. Conclusions

Based on the results of our four-year field experiment, it is possible to state that tillage technologies have a limited influence on the intensity of weed infestation but significantly change the species' spectrum of weeds. The NT variant created more favorable conditions for the grass-type weed species, anemochorous species, and species belonging to the group of winter weeds and perennial species. The MT variant created more suitable conditions, especially for species from the group of summer weeds. It is the change in species composition that leads to changes in weed control, which will be reflected in a higher need for the chemical control of weeds.

MT technologies represent part of CA. One of the advantages of minimum tillage is the support of biodiversity. Weed vegetation in the NT method exhibit higher values of biological relevance; thanks to which, a higher occurrence of dependent species of organisms is possible. On the other hand, with the use of MT tillage, the vegetation features the lowest biological relevance values, limiting the occurrence of weed-dependent organisms. Therefore, there is a significant difference in the support of biodiversity between the minimum tillage methods. Minimum tillage cannot be always considered as a means of supporting biodiversity in the agricultural landscape. The importance of minimizing tillage and other conservation tillage methods will be assessed primarily in terms of environmental impacts. It is the importance for reducing CO<sub>2</sub> emissions, reducing erosion, and the importance for biodiversity that are the parameters that farmers will have to include in their practices.

Changes in weed infestation caused by soil tillage are part of a process we can call microevolution. If a weed species is to succeed under minimum tillage conditions, it must,

as Raup [79] states, “do something better than other weed species”. A more detailed study of the development of weed vegetation will help to understand the processes of genesis and extinction of plant species.

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