THE RESPONSE OF WEED COMMUNITIES TO CHANGING MANAGEMENT PRACTICES

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Abstract

The response of weed communities to changing management practices was assessed as part of the Crop Management Study at the Indian Head Experimental Farm from 1988 to 1990. A split plot design with four reps (144 plots), zero, minimum, and conventional tillage as the main plots, two continuous crop rotations and one crop-fallow rotation as the sub-plots, and spring wheat, winter wheat, flax, and field pea as the crops. Each crop in a rotation was present each year. Weeds were sampled during July each year, after the application of post-emergent herbicides, in order to assess the density and composition of the residual weed flora. In each plot (except the 12 fallow plots) the weeds were counted in 20 quadrats, each 0.25 m^2. Multivariate statistical methods were used to determine if weed communities differed among years, tillages, rotations, and crops. Weed densities were generally low for all years (< 10 plants m^{-2}). From 1988 to 1990, the proportional abundance of different weed types changed. Annual broad-leaved weeds accounted for 40% of the total weed abundance during 1988 and 70% during 1990. Redroot pigweed, kochia, Russian thistle, and thyme-leaved spurge were the major weeds in this group and all increased in frequency of occurrence. Winter annuals decreased from 35% of the total abundance to 19% during the same period. Stinkweed and flixweed were the major weeds in this group. The annual grasses, wild oats and green foxtail, accounted for 5% or less of the abundance in all three years. The perennial group, Canada thistle, perennial sow-thistle, and foxtail barley and the volunteer crop group, spring wheat, winter wheat, and flax were less than 11% of the total abundance in each of the three years. The year to year variation in weed abundance was greater than any variation due to tillage system. The highest weed densities were associated with the rotation that included field pea.

Introduction

The Crop Management Study on the Indian Head Experimental Farm was begun in 1987 to address problems of soil erosion and soil degradation by investigating extended or continuous crop rotations with less emphasis on fallowing and by evaluating the feasibility of reducing tillage operations. A multidisciplinary systems approach was employed to study the impact of crop sequence and tillage system interactions on soil quality, soil nutrient budget, economic returns, plant disease incidence, and weed community structure. The research reported here will deal with the weed community component in this integrated study.

This research project differs from other published studies on reduced tillage in a number of important ways (Wiese 1985). The majority of these other studies used monoculture cropping with cereals. Options for weed control were limited because of the lack of crop diversity. Even if crop rotations were employed, the crops were all of one type. Rarely were cereal, pulse, or oilseed crops used in a rotation and forage crops were almost never used. Often the effect of reduced tillage systems in these other studies were difficult to ascertain because different seedling implements or different types and methods of fertilizer application were used for each tillage system. Herbicides were frequently applied according to a fixed schedule which did not take into account the variation in weed populations and therefore did not optimize weed control on the various rotation and tillage systems. These limitations in other studies pose problems that prevent the clear identification of the impact of reduced tillage systems on crop production. Also most of this information comes from areas where the growing season is long, annual precipitation is high, row crops are commonly grown, continuous cropping is normal, or the weed flora is different than in Saskatchewan. This project was designed to avoid these limitations.

A review of published research in the U.S.A. and Europe have indicated that several generalizations about weed populations in reduced tillage systems can be made (Froud-Williams 1988). Annual broad-leaved weed populations decrease in size and perennial weed populations increase in reduced tillage systems. Certain species tend to be associated with a specific tillage system. There is also a belief that a reduction in tillage will start a successional shift in weed populations that cannot be reversed unless a management system with increased tillage is used again for a period of time. Each of these generalizations will be discussed using the results from the Indian Head Crop Management Study.

Materials and Methods

The Crop Management Study was initiated at Indian Head in 1986 and the first year for observations was 1987. Weeds populations were assessed in 1987 but a different method was used. During the second (1988), third (1989) and fourth (1990) year of the study, the weed survey methodology of Thomas (1985) was adapted for use on this management study. Weed data from only the last three years of the experiment are summarized in this paper. Since the crop sequence is four years long, it is appropriate to summarize the results at the end of the first cycle.

The study used a split plot design with four replicates (144 plots). The three tillage systems were the main plots. In the zero tillage system, no tillage was used in either the fall or spring. The only soil disturbance occurred during the seeding operation. Minimum tillage involved only tillage prior to seeding in the spring. Conventional tillage included tillage in the fall and prior to seeding in the spring. The sub-plots were three cropping sequences of four years in length: spring wheat, spring wheat, winter wheat, fallow; spring wheat, spring wheat, flax, winter wheat; spring wheat, flax, winter wheat, field pea. Each crop in a rotation was present each year. Seeding operations and fertilizer placement were standardized on all tillage systems by using the same seeding implement as well as the same method of fertilizer placement.

Weed management practices in the experimental plots were based on recommended cultural and chemical practices. These varied according to tillage system and crop sequence. In general, weed control in the conventional tillage system involved tillage between crops, with herbicides used in the crop as required. Fall weed control in zero and minimum tillage systems involved the use of herbicides. In the spring, tillage was used in the minimum tillage system while a chemical burnoff was used as required in the zero tillage system. Weed control in the fallow plots of the conventional tillage system was based only on tillage. In the minimum tillage system, both tillage and herbicides were used for control on the fallow plots. Only herbicides were used for control of weeds in fallow plots of the zero tillage system. Chemical weed control in fallow plots involved a combination of 2,4-D and glyphosate.

Herbicide applications were based on specific problems. Winter annual weeds were controlled annually with a fall application of 2,4-D. Annual broad-leaved weeds were treated each year with 2,4-D in winter wheat, 2,4-D + dicamba or bromoxynil + MCPA in spring wheat, bromoxynil + MCPA in flax and MCPB + MCPA in field pea. Graminicides were applied each year in flax, every year but 1989 in field pea, and only in 1988 and 1990 in spring wheat. Graminicides were never applied to winter wheat.

In 1989, dry spring conditions resulted in a delay in weed germination, and as a result the flax was too advanced for application of bromoxynil + MCPA and annual broad-leaved weeds were abundant. Difficulty in controlling Russian thistle and kochia in field pea resulted in high densities of these weeds in that crop sequence. Currently, thorough soil incorporation is recommended with the ethalfluralin and trifluralin based herbicides registered to control these weeds in field pea. Hence, these herbicides are not suitable for minimum and zero tillage systems.

Weeds were counted in July in 1988, 1989, and 1990, after all tillage and herbicide applications, in order to measure the impact of the tillage system and crop sequence treatments on the residual weed community. In each plot (except for the 12 fallow plots), the weeds were counted in 20 quadrats, each 0.25 m^2. The number of annual weeds were recorded by species in each quadrat. Shoot numbers were recorded for perennial herbaceous species. A tillered annual grass was considered a single plant.

The data were summarized using three quantitative measures calculated from the weed count data in the plots. The frequency, uniformity, and density were computed for each species using the method of Thomas (1985). Frequency indicated the percentage of plots infested with a species. The frequency measure only considers the presence or absence of the weed in a plot. Uniformity indicated the percentage of quadrats infested with a species. Density was a measure of the number of plants or shoots per square metre and was used to indicate the magnitude of the infestation. The three quantitative measures for each species were combined into a single synthetic value called relative abundance (Thomas 1985). The total relative abundance of all species is 300. The advantage of using relative abundance was that the single value for a species was a more comprehensive estimate than any one measure alone. This synthetic value provided a convenient way of ranking species and of comparing the percentage contribution of individual species or groups of species to the total abundance on the experimental plots.

The species found on the plots were classified according to weed type. Annual broad-leaved weeds included summer annuals, winter annuals, and biennials since no attempt was made to distinguish these three groups during the July weed assessments. Most of the species considered winter annuals or biennials may in fact have a summer annual life cycle during some years. Stinkweed and flixweed are examples of species that may be either summer or winter annuals. Volunteer crop weeds included any annual species that are normally seeded as crops in Saskatchewan. Perennial weeds included both vegetatively reproducing species (eg. Canada thistle) and species that reproduce only by seed (eg. dandelion). The annual grass weed type included any monocotyledonous species with the exception of the volunteer cereal species.

Multivariate statistical methods and ordination techniques were used to determine if the residual weed community differed among years, tillage systems, and crop sequences. Ordination is a technique that is used to summarize multivariate data. Ordination arranges the plots along axes on the basis of data for species composition (Jongman et al. 1982). Results from the ordination are shown on a two dimensional (axes) diagram in which points that are close together correspond to plots that are similar in species composition and points that are far apart correspond to plots that are different in species composition. The method used to express this pattern of variation in species composition is principal component analysis (PCA). In this paper a canonical form of PCA called redundancy analysis is used. The goal of the method is to detect the pattern of variation in the species data that can be explained best by the treatment variables. This analysis results in an ordination diagram that shows not only the species variation but also the relationships between the species and each of the treatment variables.

Redundancy analysis is based on a iterative approach using PCA and multiple regression (ter Braak and Prentice 1988). The treatment variables are coded as nominal (0 or 1) response variables for regression. Log transformed density data were used as the measure of species abundance in the analysis. In each iteration cycle, the plot scores for the PCA are regressed on the treatment variables and the fitted values of the regression are taken as new plot scores and the cycle begins again. The iteration continues until a set limit is reached. Thus the axes in the ordination optimize both the fit of the species data and treatment variables. When the effect of covariables is removed from the ordination, then the technique is termed partial redundancy analysis.

In terms of these experimental data, the analysis was performed twice using a program called CANOCO (ter Braak 1988). In the first stage of the analysis, the four replicates were removed as covariables and the treatment variables were tillage systems and crop sequences. In the second analysis, the four replicates and the three crop sequences were removed as covariables to see if the variation that remained was related to tillage system. Each year was treated separately. The CANOCO program also provides a method of testing the significance of the ordination results by a Monte Carlo permutation test on the first eignvalue from the analysis. The test randomly links the treatment variables to the species data, giving rise to new random data sets. Ninety-nine permutations (random data sets) were used for a significance test. Because covariables were included in the analysis, a restricted permutation was used in which a permutation class had identical values for covariates.

The ordination diagrams show species as points. Species near the edge of the diagram are the most important for indicating the plot differences. Species near the centre of the diagram are of minor importance. Plots can also be shown on the ordination diagram but have been omitted to reduce the complexity of the presentation. Treatment variables are shown as arrows. The arrow points in the direction of maximum variation in value of the treatment variable. The length of the arrow indicates the importance of the variable. Species located close to an arrow indicate a high positive correlation between the treatment variable and species. If the species is located on the opposite side of the diagram from the treatment arrow, then the correlation is negative.

Results and Discussion

The residual weed community on the experimental plot area consisted of 26 species that were recorded during the three year period from 1988 to 1990 (Table 1). All species were commonly found in fields of the area. Stinkweed, redroot pigweed, kochia, and Russian thistle were the most abundant weeds. This is in contrast to the most recent weed survey for the area where green foxtail, wild buckwheat, wild oats, and stinkweed were found to be the most abundant species (Thomas and Wise 1987). Stinkweed was the most frequently encountered species but it was recorded on only 31.6% of the plots. Most species occurred in a small proportion of the quadrats sampled (uniformity value in Table 1), which was a function of the large number of quadrats without weeds. During the 1988, 1989, and 1990 July assessments 59%, 40%, and 17% of the quadrats respectively were found to be free of weeds. The highest average density for plots in which the weed occurred was only 4.5 plants m^{-2} for Russian thistle. Many of the weeds had occurrence densities of <1.0 plant m^{-2}. Weed frequencies and the average occurrence densities were low in comparison with many local fields. These low values were expected since the site had been in breeder seed production for approximately 30 years.

A comparison of weed types based on the sum of the relative abundance values (Table 1) indicated that annual broad-leaved weeds were the largest component of the residual weed flora with a value of 248.8 (82.9% of the total abundance). The list of broad-leaved weeds contains both summer annuals such as redroot pigweed, kochia, Russian thistle, and thyme-leaved spurge and winter annuals such as stinkweed and flixweed. The volunteer crops with a value of 23.5 (7.8% of the total) and perennials with 19.8 (6.6% of the total) made small but nearly equal contributions to the residual weed flora. During the last three years of the study, annual grass weeds with a value of 7.9 (2.6% of the total) were an insignificant component of the weed flora.

The contribution of the four weed types to the community is used as an indicator of the impact of changes in tillage system. Differences do exist among the systems (Table 2). For example, perennial weeds had a total relative abundance value of 45.0, 33.2 and 9.6 for zero, minimum, and conventional tillage systems. This pattern was consistent over the past three years. However, the relative abundance of the perennial weeds has been declining. A declining total relative abundance value was also observed for volunteer crop weeds. This decline in perennial and volunteer crop weeds is paralleled by an increase in the relative abundance of annual broad-leaved weeds. The high relative abundance of perennial weeds in zero tillage systems was noted during the first year of the experiment (1987) and may only indicate differences due to background levels in the population.

An examination of the average density for all weeds combined in each tillage system indicated that more weeds were found in the conventional tillage system during 1988 and 1989 than in the zero tillage system but the reverse was true in 1990 (Table 2). Although perennial weed densities were highest in the zero tillage system, the densities were low and the differences between zero and conventional tillage were small. There was a decreasing trend in perennial weed density during the past three years whereas the frequency of occurrence (data not presented) has remained more or less constant. The result of these trends has been a decrease in the relative abundance of the perennial weeds.

Average densities for all weeds were significantly higher in the crop sequence with spring wheat, flax, winter wheat, and field pea during each of the three years and for each tillage system (Table 3). These high densities were associated with high weed species diversity. The spring wheat, spring wheat, winter wheat, and fallow sequence had a weed flora of 145 species for the three years. The spring wheat, spring wheat, flax, and winter wheat crop sequence had 19 species and the spring wheat, flax, winter wheat, and field pea crop sequence had 26 species. The high densities in the field pea crop sequence cannot be attributed to one specific crop (Table 4). The field pea crop in the sequence had the highest density during 1988, the flax crop during 1989, and the spring wheat crop during 1990.

The ordination diagram based on partial redundancy analysis of the 1988 residual weed community data with tillage system and crop sequence as treatment variables is given in Figure 1. The first axis (X-axis) accounted for 92% of the variance and is related on weed density. Redroot pigweed and lamb's-quarters are located at the extreme right end of the axis. These two species had the highest densities during 1988. No species are located at the opposite end of the first axis. Plots in this area of the ordination were free of weeds. The crop sequence of spring wheat, flax, winter wheat and field pea was most closely associated with species occurring at high density. The other two crop sequences were associated with plots having no weeds. The second axis (Y-axis) separated the tillage systems and accounted for an additional 6% of the variance. To investigate whether the observed differences could be accounted for by pure chance, the data were subjected to the Monte Carlo permutation test. The 99 random data sets all produced a lower eigenvalue indicating there were significant differences in the residual weed community among the treatments (P = 0.01).

The arrows for the three crop sequences are all longer than the arrow for the three tillage systems, indicating that crop sequences are more important for indicating differences in the weed community. The impact of tillage system was tested after removal of the three crop sequences as covariables. The variation in the weed community that remained after fitting crop sequence was not significantly related to tillage system (P = 0.27).

Redroot pigweed, stinkweed, lamb's-quarters, and flixweed were the species most closely correlated with the spring wheat, flax, winter wheat, and field pea crop sequence. The results indicate that Canada thistle is an important species for separating plots and is most closely associated with zero tillage plots.

During 1989, as in the previous year, most of the variation was accounted for by the first axis (91%) with only 6% accounted for the second axis. The Monte Carlo test indicated significant differences in the residual weed community among the treatments (P = 0.01). The relative length of the arrows for tillage treatments have increased when compared to 1988 (Figure 2). Zero tillage was a more important factor than the spring wheat, spring wheat, flax, and winter wheat crop sequence and the conventional tillage treatment was nearly as important as the field pea rotation in explaining the variation in the weed community. The Monte Carlo test with crop sequence treatments removed as covariables indicated that a significant amount of the variation in the residual weed community was related to tillage system (P = 0.01). Redroot pigweed and stinkweed were the two most important weeds associated with conventional tillage and the field pea crop sequence. Kochia has increased in importance but is not closely associated with any treatment. Canada thistle is still an important species and like kochia it is not associated with any treatment. Lamb's-quarters is of less importance than in 1988 for indicating differences.

A similar ordination diagram was produced for 1990 (Figure 3). The first and second axis accounted for 76% and 21% of variance respectively. The relationship between species variation and treatment variables indicated a similar pattern to 1989. The Monte Carlo permutation test indicated significant differences in the residual weed community among the treatments (P = 0.01). As indicated by the relative lengths of the arrows, tillage system treatments were again more important than in 1988. The Monte Carlo test with crop sequence treatments as covariables indicated that some of the variation in the residual weed community was related to tillage system (P = 0.01). Redroot pigweed and stinkweed were important species that were associated, but not closely with conventional tillage and the field pea sequence respectively. In 1990, lamb's-quarters was one of the minor species located at the centre of the ordination. Russian thistle and kochia were important species during 1990 that were correlated with the minimum tillage system but the correlation was relatively unimportant because of the short arrow for minimum tillage. Canada thistle decreased in importance.

These results based on the partial redundancy analysis have indicated that crop sequences were more important than tillage system treatments in explaining the variation found in the residual weed community during the first four year cycle of the experiment. This observation is given further support if the structure of the weed community is examined using dominance-diversity curves. The relative abundance of individual species is plotted cumulatively against the species number ranked in order of their individual relative abundance (Figure 4). The curves for each of the tillage systems are nearly identical even though the species sequence is quite different. For zero tillage, the first to fourth species in ranked order are Russian thistle, kochia, Canada thistle, and stinkweed compared to stinkweed, Russian thistle, redroot pigweed, and kochia for minimum tillage and redroot pigweed, stinkweed, kochia, and prostrate/tumble pigweed for conventional tillage. In contrast, the curves for each of the crop sequences are dissimilar. The first to fourth species in ranked order for the s1/s2/ww/fa crop sequence are thyme-leaved spurge, redroot pigweed, Russian thistle, and kochia, for the s1/s2/fx/ww crop sequence are stinkweed, thyme-leaved spurge, redroot pigweed, and volunteer winter wheat, and for the s1/fx/ww/fp crop sequence are stinkweed, redroot pigweed, kochia, and Russian thistle.

Based on the first cycle of four years in this management study, the four generalizations concerning weeds in reduced tillage systems were found to not apply. The density and relative abundance of the annual broad-leaved weeds did not decrease in zero and minimum tillage systems during the four year study period. The abundance of these weeds increased in all three tillage systems. The relative abundance and density of perennial weeds did not increase in reduced tillage systems. Abundance either decreased or remained the same in all three tillage systems. Specific species were not closely associated with specific tillage systems but rather species were more closely associated with crop sequences and related herbicide control. The relatively high weed density in the spring wheat, flax, winter wheat, and field pea crop sequence in comparison to other treatments in the experiment were the result of inadequate management in flax and field pea and was not closely associated with tillage systems. Irreversible shifts in the weed community due to reduced tillage were not evident from the analysis of the data. The residual weed community in zero and minimum tillage systems was not uniquely different from the weed communities in other treatments of the experiment.

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Table 1. Residual weed flora found on the plots of the crop management study at the Indian Head Experimental Farm during 1988, 1989, and 1990.

Weed type and common name	Code[1]	Frequency (%)	Uniformity (%)	Occurrence density (no. m^{-2})	Relative abundance
Annual broad-leaved					
Stinkweed	St	31.6	7.0	2.5	50.5
Redroot pigweed	Rp	28.5	5.3	3.5	48.5
Kochia	Ko	24.0	4.5	2.7	37.0
Russian thistle	Rt	18.7	3.0	4.5	34.5
Thyme-leaved spurge	Ts	21.7	2.7	0.9	21.7
Flixweed	Fl	16.4	2.2	1.1	17.4
Prostrate/tumble pigweed	Pp	11.1	1.8	2.7	16.3
Wild buckwheat	Wb	10.6	0.9	0.5	8.5
Lamb's-quarters	Lq	5.3	0.8	1.7	6.7
Wild mustard	Wm	4.3	0.4	0.8	3.7
Sweet clover species	Sc	3.3	0.3	0.4	2.5
Prickly lettuce		1.0	0.1	0.4	0.7
Black medick		0.5	<0.1	0.2	0.3
Vetch species		0.5	<0.1	0.2	0.3
Shepherd's-purse		0.3	<0.1	0.8	0.2
TOTAL					248.8
Volunteer crop					
Winter wheat	Ww	9.1	2.1	2.1	13.9
Spring wheat	Sw	4.3	1.1	2.5	7.1
Flax	Fx	2.5	0.1	0.4	1.8
Canola		0.5	<0.1	0.3	0.4
Field pea		0.5	<0.1	0.2	0.3
TOTAL					23.5
Perennial					
Canada thistle	Ct	13.9	2.2	0.2	16.9
Perennial sow-thistle	Ps	2.5	0.2	0.4	1.8
Foxtail barley	Fb	1.0	0.1	0.3	0.7
Dandelion		0.5	0.1	0.7	0.4
TOTAL					19.8
Annual grass					
Wild oats	Wo	4.0	0.6	2.3	5.5
Green foxtail	Gf	3.0	0.2	0.9	2.4
TOTAL					7.9

[1] Only the 19 species with codes were used in the partial redundancy analysis

Table 2. Relative abundance and total weed density for weed types present in each tillage system during 1988, 1989, and 1990. The values are averaged over crop sequence.

		Weed type			
Tillage system	Year	Annual	Volunteer	Perennial	Grass
(a) Relative abundance					
Zero	1988	173.5	43.3	79.8	3.5
	1989	219.5	24.4	41.4	14.8
	1990	244.8	23.2	30.2	1.8
	Combined	221.3	28.2	45.0	5.5
Minimum	1988	220.1	35.8	39.0	5.1
	1989	248.2	3.1	45.5	3.1
	1990	247.7	22.6	24.3	5.4
	Combined	241.3	20.8	33.2	4.7
Conventional	1988	211.0	54.1	22.4	12.5
	1989	222.7	45.0	5.5	26.8
	1990	273.6	12.8	8.3	5.4
	Combined	236.2	37.1	9.6	17.0
(b) Density (no. m^{-2})					
Zero	1988	1.7	0.3	0.5	<0.1
	1989	2.2	0.1	0.3	0.2
	1990	6.0	0.1	0.3	<0.1
	Combined	3.3	0.2	0.3	0.1
Minimum	1988	2.4	0.2	0.3	<0.1
	1989	1.7	<0.1	0.2	<0.1
	1990	5.5	0.2	0.3	<0.1
	Combined	3.2	0.1	0.3	<0.1
Conventional	1988	3.9	0.5	0.2	0.2
	1989	9.0	1.3	0.1	0.6
	1990	5.2	0.1	0.1	<0.1
	Combined	6.1	0.6	0.1	0.3

Table 3. The average density for all weeds in each tillage system and crop sequence during 1988, 1989, and 1990.

Year	Tillage	Sequence[1]	Number of plots	Density (no. m^{-2})	S.E.[2]
1988	zero	s1/s2/ww/fa	12	0.1	0.1
		s1/s2/fx/ww	16	0.7	0.3
		s1/fx/ww/fp	16	6.0	2.7
	minimum	s1/s2/ww/fa	12	0	-
		s1/s2/fx/ww	16	0.5	0.3
		s1/fx/ww/fp	16	7.8	3.2
	conventional	s1/s2/ww/fa	12	0.1	0.1
		s1/s2/fx/ww	16	0.8	0.6
		s1/fx/ww/fp	16	12.2	4.8
1989	zero	s1/s2/ww/fa	12	0.2	0.1
		s1/s2/fx/ww	16	1.4	0.8
		s1/fx/ww/fp	16	5.8	2.2
	minimum	s1/s2/ww/fa	12	0.2	0.1
		s1/s2/fx/ww	16	0.8	0.3
		s1/fx/ww/fp	16	4.1	0.8
	conventional	s1/s2/ww/fa	12	0.5	0.4
		s1/s2/fx/ww	16	5.8	1.6
		s1/fx/ww/fp	16	24.0	6.3
1990	zero	s1/s2/ww/fa	12	0.7	0.2
		s1/s2/fx/ww	16	1.5	0.3
		s1/fx/ww/fp	16	15.7	8.9
	minimum	s1/s2/ww/fa	12	0.7	0.2
		s1/s2/fx/ww	16	1.3	0.3
		s1/fx/ww/fp	16	14.6	4.1
	conventional	s1/s2/ww/fa	12	1.5	0.6
		s1/s2/fx/ww	16	3.0	0.8
		s1/fx/ww/fp	16	10.6	3.8

[1] Crop s1 = first spring wheat, s2 = second spring wheat, ww = winter wheat fa = fallow, fx = flax, and fp = field pea.
[2] Standard error of the mean.

Table 4. The average density (no. m^{-2}) for all weeds in each crop of the four sequences during 1988, 1989, and 1990. The values are averaged over tillage system.

Crop	1988	1989	1990
Spring wheat	0.1	0	1.7
Spring wheat	0.1	0.4	1.1
Winter wheat	0	0.5	0.2
Fallow	---	---	---
Spring wheat	1.0	0.5	3.0
Spring wheat	0	0.2	1.9
Flax	1.4	4.6	2.3
Winter wheat	0.2	5.5	0.5
Spring wheat	1.4	4.5	24.7
Flax	2.8	23.3	11.1
Winter wheat	0.3	7.4	6.5
Field pea	30.3	10.1	12.1

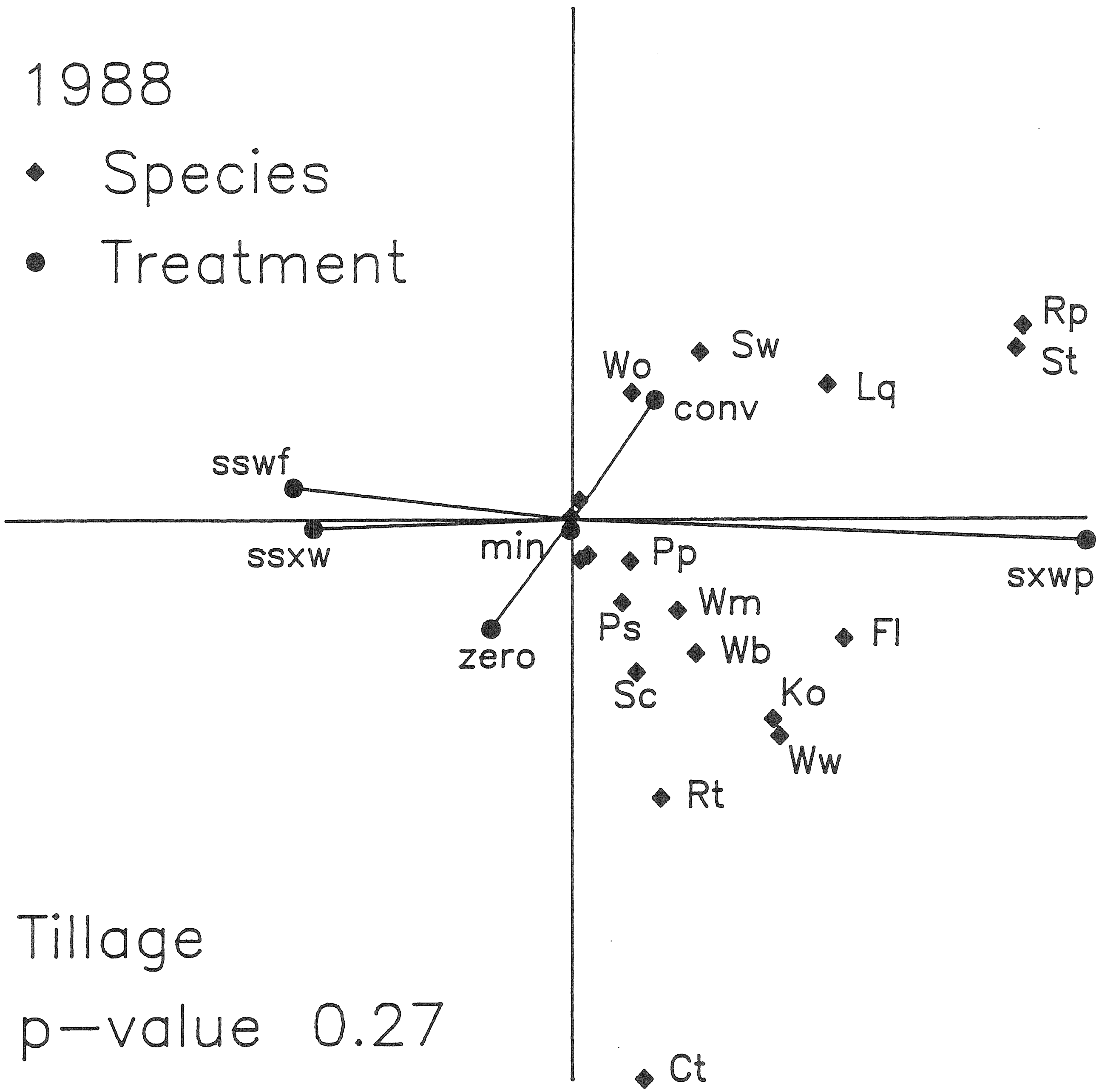

Figure 1. Ordination diagram based on partial redundancy analysis of the 1988 residual weed community with tillage systems and crop sequences as treatment variables and replicates as covariables. Abbreviations of species names are given in Table 1 and crop sequences in Table 3. The significance for tillage system treatments based on the Monte Carlo permutation test is given for a subsequent analysis with replicates and crop sequences removed as covariables.

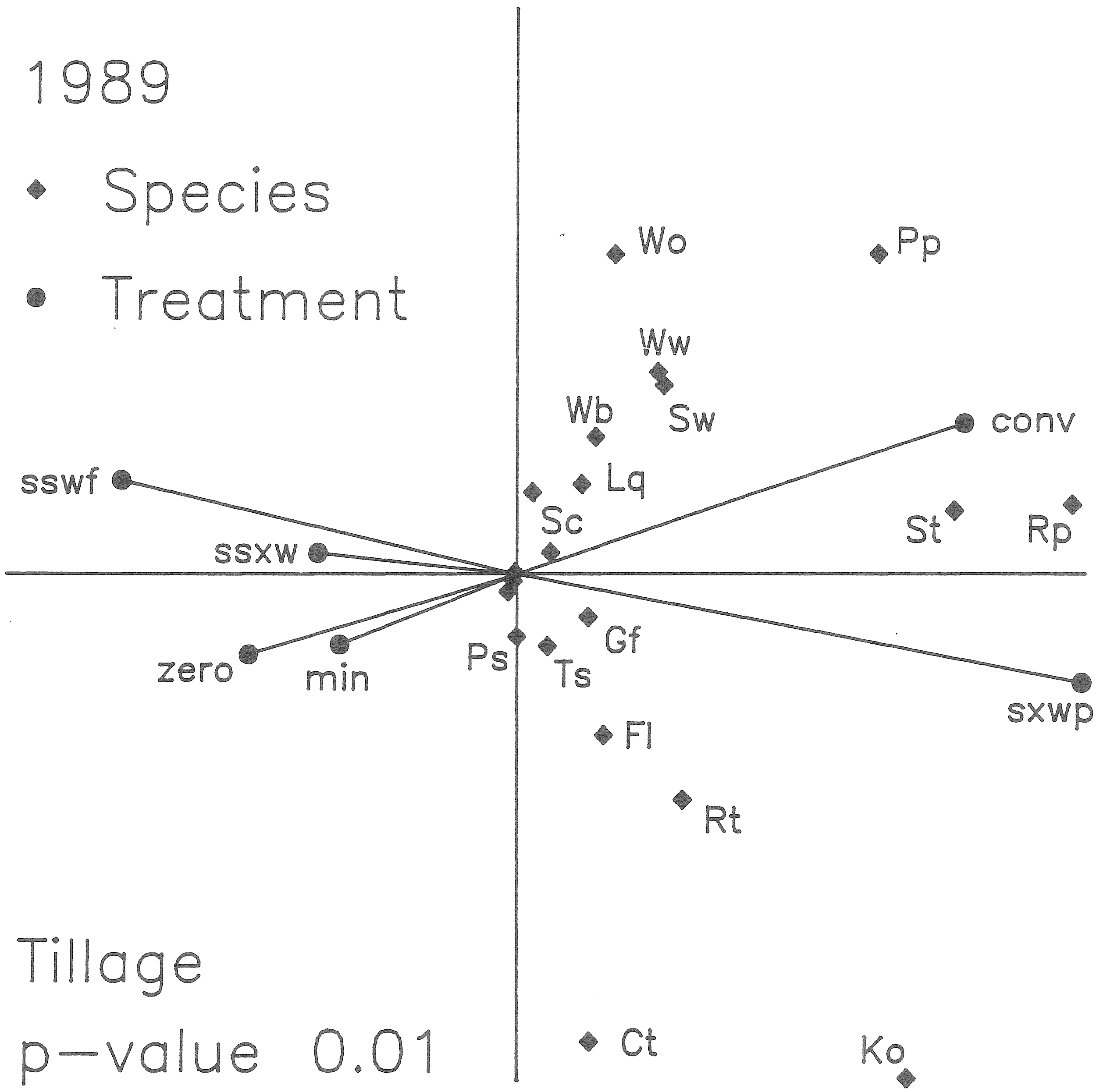

Figure 2. Ordination diagram based on partial redundancy analysis of the 1989 residual weed community with tillage systems and crop sequences as treatment variables and replicates as covariables. Abbreviations of species names are given in Table 1 and crop sequences in Table 3. The significance for tillage system treatments based on the Monte Carlo permutation test is given for a subsequent analysis with replicates and crop sequences removed as covariables.

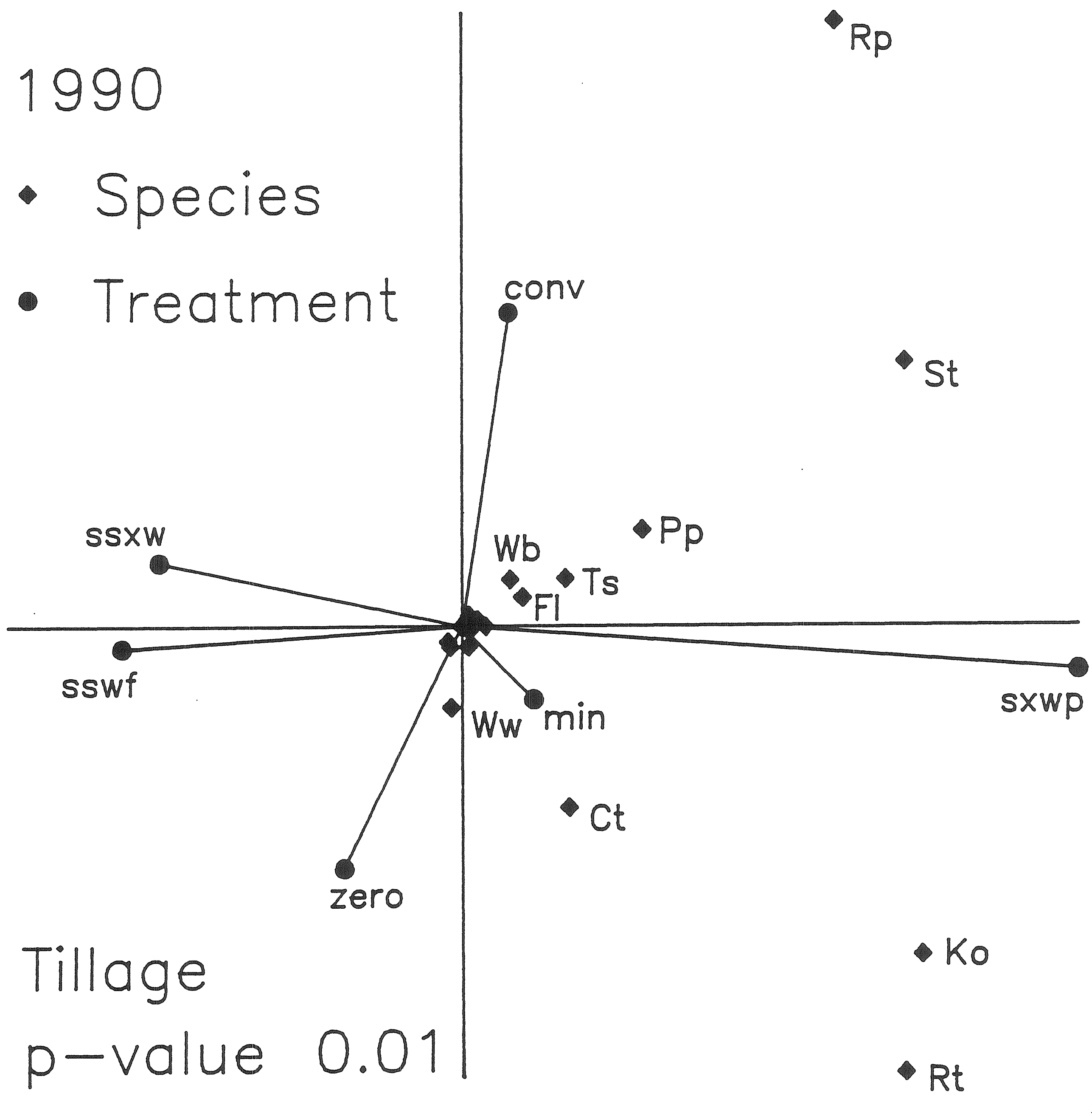

Figure 3. Ordination diagram based on partial redundancy analysis of the 1989 residual weed community with tillage systems and crop sequences as treatment variables and replicates as covariables. Abbreviations of species names are given in Table 1 and crop sequences in Table 3. The significance for tillage system treatments based on the Monte Carlo permutation test is given for a subsequent analysis with replicates and crop sequences removed as covariables.

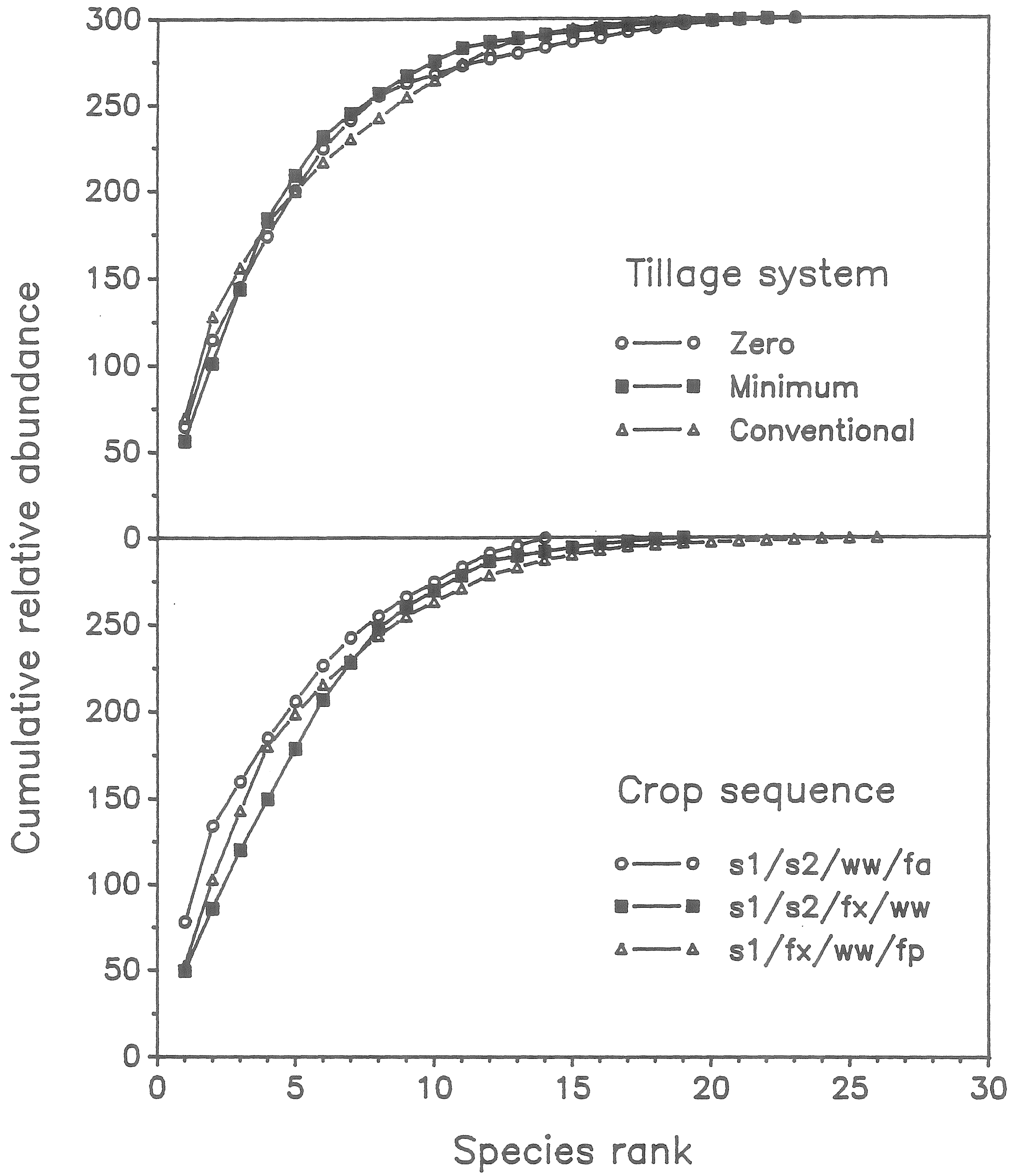

Figure 4. Dominance-diversity curves for the residual weed community in each tillage system and crop sequence using the combined data from 1988, 1989, and 1990.